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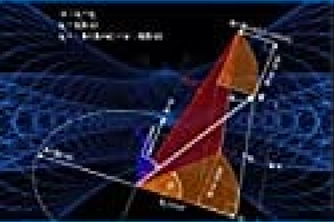
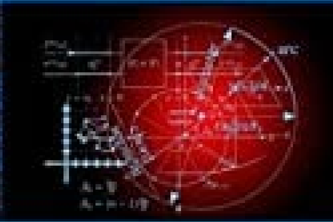
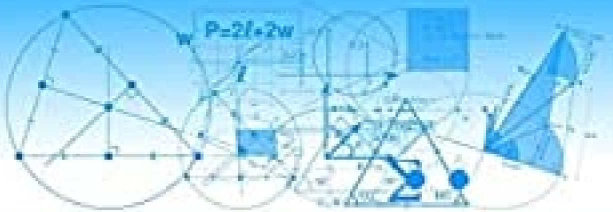
MECHANICS







Biomentors Classes Online

R. K. MALIK'S
NEWTON CLASSES

Effective Revision Guide

CONCEPTS AND DEFINITIONS OF BIOLOGY

For NEET / AIIMS / CMC JIPMER

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Nature & Scope of BIOLOGY

WHAT IS BIOLOGY

Biology, the word comes from Greek *bios* meaning life and *logos* meaning thought or science of, can be defined as the study of various aspects of living beings (plants and animals). Biology is the study of life from the simplest forms of plants and animals (including one-celled animals and algae) to highly complex structures of the human being. It includes the study of how organisms are structured as well as how they function and relate to each other. Biology is also called **life science** as it makes to understand how living things perform their life activities and interacts with the other living and non-living things. Main branches of biology are **botany, zoology** and **microbiology. Pure biology** is concerned with gaining fundamental knowledge of the subject and studied only for better understanding of natural phenomenon. It has no direct practical application in human welfare, eg. taxonomy, physiology etc. **Applied biology** is related to well being of mankind and is directly beneficial economically. Some of the main branches of applied biology are agriculture, animal husbandary, sericulture, poultry, genetic engineering, breeding, biotechnology, bioinformatics etc.

Table : Branches of biology

Branch of Biology	Definitions
Agriculture	The study of how best to grow and improve crops.
Horticulture	Development and management of orchards and gardens.
Apiculture	The rearing of bees especially for commercial purpose.
Sericulture	The breeding and treatment of silkworms for raw silk.
Anthropology	The study of physical and mental constitution of man with social conditions exhibited both in the present and the past.
Entomology	The study of insects.
Medicine	The study of structure and functioning of the human body and mind in sickness and health.
Agronomy	Branch of agricultural science which deals with the study of crops and soils.
Soil Science	Study of structure, types and dynamics of the soil.
Breeding	To produce or procreate improved varieties by selective mating.
Veterinary Medicine	Deals with the diseases of domesticated animals and their health care.
Fishery	Occupation or industry of catching fish or other products of the sea, lakes or rivers.
Poultry Science	Deals with study of domestic fowls such as chickens, ducks and geese.
Forestry	Science of developing, cultivation and conserving forests.
Dairy Technology	Application of science for the manufacture of milk products.
Microbiology	Science that deals with the structure, function, uses etc. of microscopic organisms.
Pharmacy	Science that deals with preparing and compounding medicines and dispensing them according to the medical prescriptions.
Pharmacology	Science that deals with the knowledge of drugs and preparation of medicines.

Forensic Science	Application of scientific knowledge to questions of civil and criminal law (includes use of finger-prints, blood typing, identification of narcotics etc).
Surgery	Surgery involves physical operations to cure diseases or injuries to the body.
Human Reproductive Biology	Science of understanding and regulating reproduction.
Nutrition	Study of the nourishment of human beings or other organisms.
Physiotherapy	Science of treatment of diseases, bodily weaknesses or defects by physical remedies such as massage and exercise.
Occupational Therapy	A method of treatment of convalescents and the physically handicapped utilising light work for diversion, physical exercise or vocational training.
Genetic Engineering	Science that involves manipulations at gene level so as to produce an organism with a new combination of inherited properties.
Biomedical Engineering	Science for production of spare parts for man, implants, artificial limbs, heart lung machines etc.
Food Technology	Application of science for processing and preservation of foods.
Silviculture	Management of useful forest.
Olericulture	Cultivation of vegetables.
Anatomy	Internal structures of living organisms.
Biochemistry	Science connected with chemistry (composition, chemical nature, mode of formation, functioning) of living matter.
Biogeography	Distribution of organisms on various parts of earth.
Cytology	Structure and functions of cells and their organelles.
Ecology	Relationship between organisms and environment.
Embryology	Development stages of organisms up to hatching or birth.
Endocrinology	Endocrine glands and hormones.
Evolution	Origin of life and the gradual differentiation or descent of species.
Eugenics	Factors related to improvement of human race.
Exobiology	Life on other planets.
Genetics	Heredity and variations.
Histology	Tissues by microscopy.
Immunology	Resistance of organisms to infection.
Limnobiology	Fresh water lakes, ponds and streams.
Morphology	External shape of living organisms in contrast to function.
Molecular biology	Physio-chemical organization of biomolecules.
Palaeontology	Fossils and their distribution in time.
Palaeozoology/Palaeobotany	Fossil animals/fossil plants.
Physiology	Functions of various organs within the organisms.
Psychology	Behaviour and working of mind.
Parasitology	Parasitic organisms.
Pathology	Diseases and their control.
Radiobiology	Effects of radioactivity on life.
Taxonomy	Classification of organisms and their evolutionary relationship with other organisms.
Teratology	Malformation or birth defects.
Zoogeography	Distribution of animals over the earth.
Zoopathology	Diseases of animals.

RELATIONSHIP OF BIOLOGY TO OTHER SCIENCE

In order of study biology one has to understand and know other sciences like physics and chemistry as well. Because our present knowledge of biology has reached to such an extent that it has become a multidisciplinary branch of science involving participation of the fundamental knowledge of all the basic sciences.

Structure/ Mechanism Studied	Example	Related Science	Knowledge of other sciences is required because
Cell membrane	Structure of lipids, and proteins	Chemistry	Living organisms are made up of inorganic and organic compounds.
Transportation of O_2 in body	Formation of oxyhaemoglobin	Chemistry	All metabolic pathways involve chemical changes.
Excretory system	Absorption and elimination of salts	Chemistry	Homeostasis involves acid-base equilibrium to maintain pH of living organism.
Absorption of food/water	Absorption of sugars amino acids, fatty acids, water or salts	Chemistry	During diffusion and osmosis molecules move in and out of cells.
Transportation of water in plants	Conduction of water from root to leaves	Physics	Liquids have certain properties like cohesion and adhesion that result in surface tension and capillary action which help in certain processes.
Release of energy during respiration	Electron transport chain	Chemistry	Energy transfer and transformation are important in all the living cells.
Effect of light on flowering	Absorption of different wave lengths of light	Physics	Light induces definite pattern of responses in plants and animals.

Similarly other branches also have relationship with Biology in their particular characters like –

- Geography – Required for studying the distribution of organisms.
- Climatology – There is an intimate relationship between distribution and adaptations of organisms with the climate of the area.
- Geology – Study of palaeobiology and soil types cannot be carried out without the knowledge of geology etc.

UTILITY OF STUDY OF BIOLOGY

The scope and application of biology is quite vast. Its study provides a necessary knowledge and perfect understanding about almost all the spheres of life, its requirements and the various ways by which they can be fulfilled.
Study of biology is connected with the following objectives.

- To help us to understand ourselves better. It explains the basic concepts like structure and functions of cells, organs and organ systems. It explains about heredity *i.e.*, why do we resemble our parents and why are we different. It helps us to answer the basic questions about ourselves like what happens during sleep, when we eat food, when we get hurt, and how do we remember things etc.
- To help us to meet our needs by utilising the sources available. The knowledge of medicine, surgery, crops rotation, animal husbandry help us to cure diseases and improve the quality of plants and animals. Meeting our basic requirements of food, clothing and shelter.
- To acquaint us with the fundamentals of nutrition, health and population control. To have a scientific approach while solving problems.
- To enlighten us about our place in the universe. It helps us to understand that man is only a small part of the living system and we have a responsibility to protect and respect other living things on earth.

- To increase the awareness of the inter-relationships of organism with the environment. It makes us aware about the threat that lies before us if the natural resources are not taken care of. It helps us to identify measures to overcome them.
- To warn us about health hazards due to indiscriminate use of pesticides, fertilizers, cutting of forests, depletion of the ozone layer, dumping of radioactive wastes in water, discharge of pollutants in air and water and wastage of our natural resources.
- To help us overcome the superstitions and to remove the biases of sex, race and colour.
- To enable us to enjoy nature and appreciate the rich, varied life of living things on earth.

BIOLOGY : SCIENCE OF EXCEPTIONS

Physical sciences are governed by a set of laws, such as the laws of gravity, magnetism, thermodynamics and so on. Biology, however, is a science which have many exceptions. This is due to the fact that it deals with living organisms which show enormous variations and are capable of change. **Some of the common exceptions** are given below.

- DNA is the hereditary material in all living organisms except in some plant viruses such as Tobacco mosaic virus where RNA is the hereditary material.
- RNA is usually single stranded but in Rheovirus it is double stranded.
- DNA is normally double stranded except in some viruses in which it is single stranded.
- Most roots grow towards the centre of gravity but in mangrove plants (*Rhizophora*) the roots are negatively geotropic.
- *Cuscuta* (Amerbel) is classified as dicotyledonous plant but lacks cotyledons.
- Normally the roots lack chlorophyll and are non-green but the assimilatory roots of Tinospora (Gilo) contain chlorophyll, are green and perform the function of photosynthesis.
- The venation in monocot leaf is as a rule parallel but in *Smilax* (a monocot plant) the leaf show reticulate venation.
- Stem is the part of plant above the ground but potato, corn and ginger are underground stems.
- Most plants follow Calvin cycle during dark phase of photosynthesis but sugarcane follows Hatch Slack cycle.
- All living cells have a nucleus except red blood cells (RBC) of mammals.
- RBCs of mammals are without nucleus excepts those of camel.
- Blood of all vertebrates is red due to the presence of a pigment-haemoglobin but in a shark (*Carcharhinus*) it is colourless.
- The heart of all reptiles is three chambered but in crocodile it is four chambered.
- Birds fly, but some birds like Kiwi and Ostrich are unable to do so.
- Lungs, as a rule are absent in fishes, but some fishes the *Protopterus* possess lungs as well as gills.
- Larval stage in the life history of an animal is not capable of sexual reproduction sexually before they change into adults.
- All mammals give birth to young ones (viviparous) but some primitive mammals like Duck billed platypus and spiny ant earter (*Echidna*) lay eggs (oviparous).
- All land inhabiting animals drink water but Kangaroo rat never drinks water.
- *Lacerta saxicola*, a kind of lizard found in Caucasian region of Soviet Union has only females but no males.

A student of biology must be prepared to accept exceptions. Some exceptions has been explained. In other cases the reasons for the exceptions are still no known. It is worth noting that the quantum of unexplained phenomena in biology is much larger than in any other natural science.

SERENDIPITY

Discoveries of important facts by chance unexpectedely, intuition and thoughts without making well planned conscious effect are called serendipity.

Some of the examples of serendipity are –

- **Discovery of antibiotic – Penicillin : Alexander Fleming** (1881-1955) was culturing the bacterium – *Staphylococcus* (the causal organism infection) in Petri dishes on agar medium. He found that one of his culture plate was contaminated by blue-green mould – *Penicillium notatum*. Such a contamination in laboratories was not new. Normally such contaminated cultures are discarded but Fleming retained it and observed minutely. To his surprise, he noticed that fungal growth inhibited in those areas where fungus was growing. By flash idea Fleming poured the extract of fungus over fresh bacterial cultures and found that even the extract inhibited the bacterial growth. This curious observation **led the discovery of the most important antibiotic – Penicillin**.
- **Law of Gravitation : Newton** was simply sitting in the garden when an apple fell on the ground. He started thinking about the cause of its fall and came to a conclusion that some force is present in the earth which attracts everything towards it. This observation led the formation of **Newton's law of gravitation**.
- **Structure of Benzene ring :** Chance observation of snake licking its tail led the discovery of ring – structure of benzene by **Kekule**.
- **Archimede's Principle :** While taking bath he came to the conclusion that a body which is immersed partially or completely in a liquid, experiences an up thrust equal to the weight of the liquid displaced by it. This led to the discovery of principle of floatation by Archimedes.

Table : Fathers of Biology

Antibiotics	Alexander Fleming (1881-1955)	Histology	Xavier Bichat (1771-1802)
Ayurveda	Charaka	Homeopathy	Hahnemann (1755-1843)
Bacteriology	Antony Van Leeuwenhoek (1632-1723)	Immunology	Edward Jenner
Biochemical genetics	Archibald Garrod	Indian palaeobotany	Birbal Sahni (1891-1949)
Biochemistry	Justus vol Liebig (1803-73)	Medicine	Hippocrates (460-377 BC)
Biology	Aristotle (384-322 BC)	Microbiology	Antony Van Leeuwenhoek
Blood circulation	William Harvey (1578-1657)	Microbiology	Louis Pasteur (1822-1895)
Blood groups	Karl Landsteiner	Microscopic Anatomy	Marcello Malpighi (1628-1694)
Botany	Theophrastus (372-287 BC)	Microscopy	Antony Van Leeuwenhoek
Chromatography	Micheal Tswett	Modern embryology	Von Baer (1792-1876)
Comparative anatomy	Georges Cuvier (1769-1832)	Modern genetics	William Bateson (1861-1926)
Cytology	Robert Hooke (1635-1703)	Modern palaeontology	Georges Cuvier (1769-1832)
ECG	Einthoven	Palaeontology	Leonardo da Vinci
Ecology	Theophrastus (370-285 BC)	Parasitology	Platter
Embryology	Aristotle	Protozoology	Antony Van Leeuwenhoek
Endocrinology	Thomas Addison (1793-1860)	Science	Aristotle
Eugenics	Francis Galton	Surgery	Susruta
Experimental genetics	Thomas Hunt Morgan (1866-1945)	Taxonomy	Carolus Linnaeus (1707-1778)
Gene Therapy	Anderson	Tissue culture	Harrison
Genetic engineering	Paul Berg	Virology	Wendell M. Stanley
Genetics	Gregor Johann Mendel (1822-1884)	Zoology	Aristotle

■■

Chapter 1

Systematics

- **Systematics** is the study of the historical relationships of groups of biological organisms – the recognition and understanding of biodiversity.
- The term systematics was coined by **Linnaeus (1735)**.
- The terms systematics, taxonomy and classification are often held as **synonyms but technically they carry different meanings.**
- **G. Simpson** (1961) has distinguished the three terms.
- **Taxonomy** is the branch of study which deals with **identification, nomenclature** and **classification of organisms**.
- Term taxonomy was first given by French botanist **A.P. de Candolle** (1778-1841) for the theory of plant classification.
- Taxonomy is also called **systematic botany**.
- **Carolus Linnaeus** is called **father of taxonomy**.
- **H. Santapau** is called the **father of Indian taxonomy**.
- Taxonomy is of **three types** – **alpha (α) taxonomy, beta (β) taxonomy** and **omega (ω) taxonomy**.
- When only morphological characters are used for identification and classification of plants then it is called **alpha taxonomy**.
- β-taxonomy involves **genetical, anatomical cytological, palynological, physiological and other characters**.
- β-taxonomy is also called **biosystematics**.
- α and β taxonomy terms were given by **Turill**.
- Analysis and synthesis of all information and types of data to develop classification system based on phylogenetic relationships is called **omega taxonomy**.
- **Classification** is the placing of an organism or a group of organisms in category according to a particular system and in conformity with a nomenclature system.
- **Aristotle (father of zoology)** made the first recorded attempt to classify the animals in his book *Historia Animalium*.
- Aristotle made two main groups - **anaima** (animals with no RBC, invertebrates) and **enaima** (animals with RBC, vertebrates).
- **Theophrastus** (372 - 287 BC), referred to as **father of botany**, classified plants on the basis of form and texture and described 480 plants in his book *Historia Planatarum*.
- **Identification** is to determine the exact place or position of an organism in the set plan of classification. Identification is **carried out with the help of taxonomic keys**.
- A **key** provides a convenient way for easy identification of an organism by applying **diagnostic or distinguishing characters**.
- Taxonomy **discovers and describes new species**, while systematics **uses evolutionary relationships** to understand biogeography, coevolution, adaptation and options for biological conservation.
- **Systematists or taxonomists** are thus the scientists whose expertise provides the data about the identification, description, distribution and relationship of life on Earth.
- **New systematics or biosystematics** is concept of systematics which brings about taxonomic affinity on the basis of evolutionary genetic and morphological traits.
- **Julian Huxley (1940)** proposed the term **new systematics**.

Table : Types of taxonomy

Cytotaxonomy	based on cytological study
Karyotaxonomy	based on nucleus and chromosomes
Morphotaxonomy	based on morphological characters
Biochemical taxonomy	based on biochemical studies
Chemotaxonomy	based on specific chemicals like secondary metabolites
Numerical taxonomy (also called adansonian taxonomy)	based on statistical methods
Experimental taxonomy	based on experimental determination of genetical inter-relationships and role of environment in their formation

Nomenclature

- **Nomenclature** is giving distinct scientific names to various structures including living organisms, for their identification.
- Biological nomenclature is of **two types** - **vernacular** and **scientific**.
- Common names by which plants and animals are known in their regional places are called **vernacular names**.
- The vernacular name or common names are **based on some peculiarity of the organisms**, eg. Kandiali (a plant having spines).
- **Scientific name** are names given to organisms based on agreed principles and criteria for their acceptability all over the world.
- Scientific names are distinct and specific, they **have particular spellings which are not changed**.
- **Three types of nomenclature** are – **polynomial, trinomial** and **binomial nomenclature**.
- **Polynomial nomenclature** was the **first scientific attempt at nomenclature**, in which an organism is given a name consisting number of words that incorporate all its important characteristics. Eg. *Caryophyllum saxatilis folis gramneus umbellatis corymbis* which means caryophyllum growing on rocks, having grass like leaves and umbellate corymb flowers.
- **Trinomial nomenclature** is a taxonomic naming system that extends the standard system of binomial nomenclature by adding a third taxon. It is used in biology when the organisms within a species fall into separate groupings that need to be distinguished.
- Trinomial nomenclature is **different for animals** and **plants**.
- In animals **trinomen** or **trinominal** name **refers to the name of a subspecies**.
- **Trinomen** is a name **consisting of three names** – **generic name**, **specific name** and **subspecies name**. All three names are typeset in italics and **only the generic name is capitalised**. Eg. *Buteo jamaicensis borealis* is one of the subspecies of the red tailed hawk (*Buteo jamaicensis*).
- For plants trinomial nomenclature provides three part name (**ternary name**) for any taxon below the rank of species.
- **Binomial nomenclature** is a system of providing distinct proper scientific names to organisms with each name consisting of two words, **generic** and **specific**.
- Binomial nomenclature was **developed by Linnaeus** (a swedish biologist) who gave certain principles (called **Linnaean principles**) for this in his book *Philosophica Botanica* (1751). The standard references recognised for this are *Species Planatarum* (1733) and *Systema Naturae* (1758).
- According to binomial system, each organism is given a name made of **two Latin words**.
- For nomenclature the Latin language is used because **it is the dead language and no changes are supposed to occur in it**.
- Binomial system of nomenclature was introduced by **Gaspard Caspar Bauhin (1956)**. But he did not follow it scrupulously.
- Binomial names are of **universal application** for all the countries and languages.
- The **names indicate relationship of a species with others present in the same genus**.
- In binomial nomenclature following **rules are applicable**.
  - Name consist of two words – first word represents **the genus** and is **called generic name (generic epithet)**, whereas the second word represents the **species** called the **specific name (specific epithet)**.
  - The **generic epithet** always starts with **capital**

letters & **specific epithet** starts with **small letter**.

- Both these name must be **underlined separately (if handwritten) or italised (if printed)**.
- **No comma, hyphen etc**. between specific and generic name is used.
- To the two word, name is appended the name of taxonomist who discovered the organism and provided with a scientific name, *e.g., Ficus bengalensis L, Homo sapiens L.*
- The different names given to same species by different workers are called **synonyms**, but the name given first is considered to be valid.

- The foundations of **International Code of Botanical Nomenclature (ICBN)** was found in **Philosophia Botanica**, a book written by **C. Linnaeus**. Current code of botanical nomenclature appeared in **1978**.
- Botanical nomenclature is **independent of zoological and bacteriological nomenclature which are governed by their own code**.

Some important abbreviation

ICBN	–	International code of botanical nomenclature
ICZN	–	International code of zoological nomenclature
ICBacN	–	International code of bacteriological nomenclature
ICVN	–	International code of viral nomenclature
ICNCP	–	International code of nomenclature for cultivation plants

Types of specification

- The particular illustration designed by author of the species to represent the type of species is called **holotype**.
- A specimen which is a duplicate of the holotype, collected from the same place, same time and by the same person is called **isotype**.
- Any one of the two or more specimens cited by the author when no holotype was designated, or any one of the two or more specimens simultaneously designated as types is called **syntype**.
- A **paratype** is a specimen cited in the protologue that is neither the holotype nor an isotype, nor one of the syntypes if two or more specimens were simultaneously designated as **types**.
- A specimen or other element selected from the original material cited by the author when no holotype was originally selected or when it no longer exists is called **lectotype**.
- A lectotype is selected from **isotypes, paratypes or syntypes**.
- A specimen or illustration selected to serve as nomenclatural types as long as all of the material on which the name of the taxon was based is missing is called **neotype**.
- **Epitype** is a specimen or illustration selected to serve as an interpretative type when the holotype, lectotype or previously designated neotype, or all original material associated with a validly published name is demonstrably ambiguous and cannot be critically identified for purposes of the precise application of the name of a taxon.
- **Topotype** is often the name given to a specimen collected from the same locality from which the holotype was originally collected.
- When many names are given to the same species, then the name under which the **species was first described is valid**, provided the publication is **effective** and **valid**.

Taxonomic hierarchy or Linnaean hierarchy

- **Taxonomic hierarchy** is the sequence of arrangements of taxonomic categories in a descending order during the classification of an organism.
- The word **taxa** represents taxonomic groups of any rank *i.e.* **any unit of classification**.
- In Linnaean hierarchy, the **number of taxa is five**, namely – class, order, genus, species and variety.
- The rank of species is basic and relative order of the rank of taxa are **species, genus, tribe, family, order, series, class, division** (= **phylum**) and **kingdom**.
- These categories/rank are ranked one over the other called **'hierarchy'**.
- **Kingdom** is the **highest** and **species** is the **lowest** category in this hierarchy.
- **Species** is the **basic unit of taxonomy**.
- **John Ray** introduced the term animal species.
- Species inhabiting the same geographical area (identical or overlapping) are **sympatric**.
- Species inhabiting different geographical areas are **allopatric**.

- Related species which are reproductively isolated but morphologically similar are called **sibling species**.
- A species restricted to a given area is called **endemic species**.
- Classical systematics is based on the 'typological concept' by **Plato** and **Aristotle**.
- The traditional concept of species was given by Linnaeus in *Systema Naturae*; this is based on morphology, and is **also known as 'morphological concept'**.
- **Genetic species concept** was given by **Lotsy** (1918), according to which, **a species is a group of genetically identical individuals**.
- Species that contain two or more subspecies are called **polytypic species.**
- Species that are not subdivided into subspecies are called **monotypic species**.
- Modern concept of species is **biological species concept** introduced by **Ernst Mayr** (1942).
- **Mayr defined species** as groups of interbreeding natural populations that are reproductively isolated from each other group.
- **Genus** is an assembly of related species which evolved from a common ancestor and have certain common characters called correlated characters, e.g., *Solanum tuberosum* and *Solanum melongena* are two species which belong to same genus of *Solanum*.
- A **family** subdivision of an order consists of a group of closely related genera, which in turn are composed of groups of closely related species.
- The taxon **commonly encountered in routine taxonomic work** is the **family**.
- Family with a single genus is called **monogeneric family**.
- An **order** is a **category within a class**. Carnivora is an order of flesh-eating animals within the class mammalia and there are several other orders of mammals like cattle, rodents, bats, seals, whales, etc.
- A **class** is a subdivision within a phylum made of one or more related orders, for *e.g.*, within the phylum chordata there are five classes: mammals, birds, reptiles, amphibians and fishes.
- **Georges Leopold Cuvier** (1769-1832), the French naturalist, added the '**phylum**' in taxonomy.
- In taxonomy, the **correct sequence** is: **class - order - family - tribe - genus - species**.
- Microbiologists and botanists **(Eichler)** use the term '**division**' **instead of 'phylum**'.
- All **kingdoms** have **more than one phylum**.
- The kingdom plantae contains several divisions (=phyla), including flowering plants, conifer trees, mosses, ferns and several other groups.
- Taxonomic hierarchy is useful in that it **provides information about relationships of an organism with others quick identification of a taxon**, all major traits and nonrepetition of correlated traits of various categories.
- According to ICBN different ranks or categories have following specific '**endings**' (*Refer table given below*).

Ranks	Plants	Algae	Fungi	Animal
Division/ Phylum	- phyta		- mycota	
Subdivision/ subphylum	- phytina		- mycotina	
Class	- opsida	- phyceae	- mycetes	
Subclass	- idae	- phycidae	- mycetidae	
Superorder		- anae		
Order		- ales		
Suborder		- ineae		
Infraorder		- aria		
Superfamily		- acea		- oidea
Family		- aceae		- idae
Subfamily		- ordeae		- inae
Tribe		- eae		- ini
Subtribe		- inae		- ina

Table : Taxonomic status of human & pea

Rank	Human	Pea
Domain	Eukarya	Eukarya
Kingdom	Animalia	Plantae
Phylum or Division	Chordata	Magnoliophyta
Subphylum or Subdivision	Vertebrata	Magnoliophytina
Class	Mammalia	Magnoliopsida
Subclass	Placentalia	Magnoliidae
Order	Primates	Fabales
Suborder	Haplorrhini	Fabineae
Family	Hominidae	Fabaceae
Subfamily	Homininae	Faboideae
Genus	*Homo*	*Pisum*
Species	*H. sapiens*	*P. sativum*

System of biological classification

- There are **four different systems of classification**, mainly used by taxonomists. They are (i) **artificial**, (ii) **natural**, (iii) **phylogenetic**, and (iv) **phenetic**.
- A classification based on one or a few superficial similarities is called an **artificial system of classification**.
- Artificial system of classification was adopted by **Pliny the Elder** (first century AD) for animals on the basis of habitats, *e.g.,* land, air and water.
- The plants are classified on the basis of habit into (i) herbs, (ii) undershrubs, (iii) shrubs, (iv) trees in an artificial classification.
- The Linnaean system of classification of plants **on the basis of number and arrangement of stamens is artificial**. Linnaeus used number, union, length and certain other characters of stamens as the basis of classification of plants in his book '*Genera Planatarum*' (1737).
- In **natural systems of classification** organisms are arranged according to their natural affinities through the use of all important permanent characteristics, especially structural, cytological (chromosomal) reproductive and biochemical.
- **The first natural system of plant classification** was proposed by **Schimper (1879)** followed by **Eichler (1833)**.
- The **most important and last of natural systems for classification of seed plants** was **developed by Bentham (1800–1884) and Hooker (1817–1911)** in the treatise called *Genera Planatarum* (1862–1883).
- **The first natural system of animal classification** was developed by **Linnaeus** in his book "*Systema Naturae*". Improvements were subsequently made by Haeckel (1864) and Lankester (1874).
- The classification **based on evolutionary sequence and the genetic relationships among the organisms** is termed **phylogenetic system**.
- Darwin's book "**On the Origin of Species by Means of Natural Selection**" (1859) provided support to taxonomy.
- The phylogenetic classification of the plant kingdom was proposed by **Adolf Engler** (1844–1930) and his associate **Karl Prantl** (1849–1893) in their book *Die Natürlichen Pflanzen Familien.*
- In this system, flowering plants are placed in ascending series related to complexity of floral morphology.
- This classification was also adopted by the English botanist **John Hutchinson** (1884–1972) in two volumes of his book **"Families of Flowering Plants"**.
- "Taxonomy without phylogeny is similar to bones without flesh" is the statement of **A.L. Takhtajan** (1967) who wrote the book **"A system of phylogeny of flowering plants"**.
- According to zoologists, the natural system of classification **includes the phylogenetic and evolutionary trends**.
- A modern method of classification called **cladistics** is based on evolutionary history.
- The phylogenetic tree is also known as **genealogical tree** or **dendrogram**.
- **Phenetic taxonomy (classification)** is based on the overall similarity of organisms evaluated without regard to phylogeny.
- **Phenetic classification** is **based on observable characteristics of existing organisms**.
- Phenetic classification **did not have a strong impact on animal classification** and **scientific interest in this aproach is on the decline**.

Table : Historical accounts

A.P. de Candolle (1813)	–	Term Taxonomy
E.H. Haeckel (1866)	–	Three Kingdom Classification
Copeland (1956)	–	Four Kingdom Classification
Whittaker (1969)	–	Five Kingdom Classification
John Ray (1627-1705)	–	Termed species
Carolus Linnaeus (1753)	–	Binomial System of Classification
Adolf Meyer (1926)	–	Used taxon term w.r.t. animal kingdom
H.J. Lam (1948)	–	Used term taxon in plant kingdom
Haeckel	–	Concept of phylogeny
Turill (1938)	–	Alpha taxonomy
Julian Huxley (1940)	–	Termed New systematics
Cuvier	–	Coined term phylum

System of classification

- **Two Kingdom**
  - Plant Kingdom
  - Animal Kingdom *
  - *(Not approved as fungi and organisms like *Euglena, Chlamydomonas* etc. were not justified in these two kingdoms).
- **Three Kingdom** [Proposed by **Haeckel**, (1866)]
  - Plant
  - Animal
  - Protista (for unicellular organisms)
- **Four Kingdom** [Proposed by **Copeland**, (1956)]
  - Protista (for unicellular organisms)
  - Monera (all plants)
  - Plant (all plants)
  - Animal (all animals)
- **Five Kingdom** [Proposed by **R.H. Whittaker**, (1969)]
  Used three criteria
  – Complexity of cell structure
  – Complexity of body structure
  – Mode of nutrition
  Divided into
  - **Monera** (all prokaryotic organism)
    - Archaebacteria
    - Eubacteria
  - **Protista** (unicellular eukaryotes)
    - Photosynthetic
    - Consumer
    - Protozoa
  - **Fungi** (eukaryotic, heterotrophic organisms)
  - **Plantae (non-mobile and photosynthetic organisms)**
    - Algae
    - Bryophyte
    - Pteridophyte
    - Gymnosperms
    - Angiosperms
  - **Animalia** (Metazoa)

- Organisms are classified according to two, three, four, five and six kingdom system (*Refer flowchart*).
- The **major criteria used for delimitation of kingdoms** are - **modes of nutrition, presence or absence of locomotion, complexity of organisation,** and **cell structure**.
- **Viruses** do not fit neatly into any classification of living organisms because they have a very simple noncellular structure and cannot exist independently of other organisms.
- **Herbarium** is a collection of plant parts that usually have been dried, pressed, preserved on sheets.
- **Largest herbarium** of the world is at Kew.
- **Botanical gardens** are the collections of living plants maintained for reference.
- The **largest botanical garden is the Main Botanical Garden, Moscow** covering an area of 900 acres.
- The Royal Botanical Garden, Kew England covers an area of 300 acres.
- **Indian Botanical garden, Sibpur, Kolkata**, is the **largest botanical garden in India**.
- The collection of plants and animals are preserved and kept in museums for study and reference.
- **Zoological parks** are zoos which help to study wild animals and their food habits.
- **Camerarius** was the person who first recognised **sexuality in plants**.
- If the generic and specific names are same it is called **tautonym**. But tautonyms have been rejected by modern scientists.
- **Angiosperms** are the most advanced type of plants.
- Angiosperms contain **seeds enclosed in fruits**.

End of the Chapter

Chapter 2

Viruses

- The term '**Virus**' has been derived from Latin, which means poison or venom or viscous fluid.
- Viruses are defined as **infectious nucleoproteins**.
- Virus are obligate intracellular parasite which can reproduce only by invading and taking over other cells as they lack the cellular machinery for self reproduction.
- A complete virus particle is called **virion** whose main function is to deliver its DNA or RNA genome into the host cell. So that genome can expressed (transcribed and translated) by the host cells.

Characteristic features

- These are submicroscopic organisms generally less than 200 mm.

Important inventions

- Viruses were discovered after Chamberland developed bacterial filters (1884).
- **Meyer (1886)** describe tobacco mosaic disease but he couldn't isolate the causal organism. Further, he said that the disease is transmissible and infectious.
- Russian botanist **D. Ivanowski** (1892), discovered the causal organisms of tobacco mosaic disease and this causal organisms could pass through the filters which retained bacteria.
- **Beijerinck** (1898) confirmed the earliest studies and named these organisms as "***Contagium vivum fluidum***", living infectious fluid.
- **F.W.T'wort.** (1915) and **F.H.d'Herelle** (1917) discovered certain viruses which infect bacteria or bacteria eaters *i.e.*, bacteriophages or phages.
- **Stanley (1935)** crystallized tobacco mosaic virus and said that these crystals retain their infectivity for a long time if kept in bottles.
- **Bawden and Pirie (1936)** first of all studied the chemical nature of viruses and said that these are nucleoproteins.
- **Edward Jenner (1796)** discovered vaccination against small pox
- **Louis Pasteur (1880)** discovered vaccination against rabies
- **Loeffler and Frosch (1898)** discovered first animal pathogenic virus (Foot and mouth virus of cattle).
- **S. Luria**, **M. Delbruck and Lwoff (1942 - 48)** discovered mechanism of replication in bacteriophages.
- **A. Harshey** and **M. Chase (1952)** said that nucleic acids are infective and proteins are non-infective parts of a bacteriophages.
- **T. O. Diener (1971)** discovered some new infectious agents, which are still smaller than viruses.
- **Stanley B. Prusiner** discovered certain infectious agents or slow viruses which contain only proteins. Prusiner got Nobel prize for this work in 1997.
- **Alliac Issacs and Lindeman** (1957) gave the term interferons to the chemical substances responsible for viral interference.
- Mycophages, viruses infecting fungi, were discovered by **Sinden (1957)** in *Agaricus bisporus*. These are having double stranded RNA and are spherical or polygonal in shape.
- **A. Salk (1957)** invented vaccination against Polio
- **Lu Montagnier** *et. al.* (1893); **R. Gallo** *et. al.* (1984) discovered AIDS virus for HIV.
- **Safferman and Morris (1963)** discovered cyanophages (viruses infecting cyanobacteria like Lynggya).

- **Shape** of virus is variable, eg., brick shaped (**influenza virus**), rod shaped (**TMV**), tadpole like (**bacteriophages**).
- They are **obligate parasites** i.e., can live inside living host only.
- They have **either RNA or DNA**.
- They can **pass through bacterial filters**.
- They have characteristic mode of multiplication, *i.e.*, once a virus enters into the host cell, it takes control of whole biochemical machinery of host cell and orders the metabolic machinery to synthesize their own (viral) components.
- **Non living characters of viruses** are –
  – No protoplasm
  – No enzyme system
  – No respiration
  – They can be crystallized
  – Do not grow in culture medium.
- **Living characters of viruses** are –
  – They contain nucleic acid as a result of which they are capable of synthesizing proteins.
  – They can multiply inside living host cell.
  – They causes diseases.
- On the basis of above characters it can be said that viruses **form a transitional group between living and non-living**.
- Viruses are **divided into two main groups** on the basis of the type of nucleic acid present in them.
  – **Deoxyvira** (having DNA).
  – **Ribovira** (having RNA).
- Deoxyvira are further divided into three classes – **deoxyhelica** (helical), **deoxycubica** (cuboidal) and **deoxybinala** (binal).
- Ribovira is divided into two classes - **ribohelica** (helical) and **ribocubica** (cuboidal).
- F. O. Holmes (1948) divided order - Virales into three sub-orders –
  – **Phytophaginae** – Viruses, infecting plants
  – **Zoophaginae** – Viruses, infecting animals
  – **Phaginae** – Viruses infecting bacteria
- Structurally viruses are made up of **envelope**, **capsid**, **nucleoid** and **occasionally one or two enzymes**.
- Some viruses possesses an outer thin loose covering called **envelope**. It is **composed of proteins** (from virus), **lipids and carbohydrates** (both from host). It has subunits called **peplomeres**.
- The viruses, which do not possess envelope, are called **naked**.
- **Capsid** is the protein coat that **surrounds the central protein of nucleoid and enzymes** (if present). The capsid consists of a specific number and arrangement of small sub-units called **capsomeres**.
- The nucleic acid present in the virus is called **nucleoid**. It is the **infective part of virus** which utilizes the metabolic machinery of the host cell for synthesis and assembly of viral components.
- Nucleoid **represents the viral chromosomes**.
- The **genetic material of viruses** are of **4 types** – **double stranded DNA** (ds DNA), **single stranded DNA** (ssDNA), **double stranded RNA** (dsRNA) and **single stranded RNA** (ssRNA).
- **Double stranded or dsDNA** are – adenovirus, herpes simplex virus, pox virus, cauliflower mosaic, coliphage lambda T_4 (linear), hepatitis B, simian virus SV – 40, polyoma (circular or cyclic).
- **Single stranded or ssDNA** are – coliphage MS 2, coliphage fd (linear), coliphage $\phi \times 174$ (cyclic).
- **Single stranded or ssRNA** are poliomyelitis virus, foot and mouth disease virus, influenza virus, rous sarcoma virus, retroviruses, turnip yellow mosaic viruses, tobacco necrosis virus, TMV, potato mosaic virus, bean mosaic virus (all linear).
- ***ss*RNA** is of **two types** – **negative stranded** (RNA – RNA viruses) and **positive stranded** (RNA – DNA viruses or retroviruses).
- **Double stranded or dsRNA** are reo-virus, wound tumour virus (all linear).
- Only few viruses contain certain enzymes. For eg., lysozyme in bacteriophages, reverse transcriptase in retroviruses.
- **Symmetry of viruses** may be –
  – **Helical symmetry** : Capsomeres are arranged in helical manner in the capsid, e.g., TMV.
  – **Cubical symmetry** : Capsomeres are arranged on the surface to form a 20 side cube, e.g., turnip mosaic virus.
  – **Biosymmetrical or mixed symmetry** : Bacteriophages

TMV (Tobacco Mosaic Virus)

- TMV is the most thoroughly studied virus and was **discovered by** the Russian worker **D. Ivanowski (1892)**.

- It is a rod shaped virus measuring 300 × 18 nm and have helical symmetry.
- Have single stranded DNA which is 330 nm in length and having 7300 nucleotides.
- Number of capsomeres in capsid is 2130.
- 5% RNA and 95% protein is present in TMV.

Bacteriophages

- **Viruses infecting bacteria** are known as bacteriophages or phages. Sea water can hold 100 million bacteriophages per μl.
- Bacteriophages may be **virulent or avirulent**.
- **Prophages or non-virulent phages** or **non-infective phages** are the phages which do not cause lysis of bacteria soon after their formation inside. Such bacterial cells which are having prophages inside them are called **lysogenic bacteria**.
- **Virulent phages or infective phages** are the phages which cause lysis of bacterial cell at once.
- Most studied series of bacteriophages is T-series (T_2, T_4, T_6 etc.).
- **T-even phages** are **characterized by angular head and contractile tail**.
- Bacteriophages have tadpole like structure, *i.e.*, with **head and tail**. Inside the head is present **nucleic acid**, **generally DNA**.
- Head is **prism like hexagonal** having length 950Å and breadth 650Å, tail is also 950Å in length, joined to head by neck and collar, tail is having hollow core of 80Å and is surrounded by tail sheath.
- At the end of tail, end plate is present to which 6 **tail fibres** are attached and each is 1500Å in length.

Lytic cycle (T_4 bacteriophage)

- The multiplication process of virulent phage is called **lytic cycle**.
- The main steps **include adsorption**, **penetration**, **formation of new phages** and **lysis**.
- Bacteriophage **attaches to the surface of bacterium by its tail fibres**.
- Lysozymes creates a hole in the host cell wall.
- The **tail sheath contracts and ejects the viral chromosome/DNA into the bacterium**.
- Viral DNA **controls the metabolic machinery of the host cell**. It produces nucleases.
- **Nucleases degrade DNA and mRNAs of the host**.
- Viral DNA is not affected as its cytosine bases are methylated.
- A **number of copies of viral DNA are produced** followed by **synthesis of capsid protein, polyamines and lysozymes**.
- The components assemble and form phage particles or viruses.
- The host cell ruptures to release viruses (**lysis**).

Lysogenic cycle (λ phage)

- The multiplication process of temperate phage is called **lysogenic cycle**.
- The phenomenon of existence of non-virulent prophage in the host cell is called **lysogeny**.
- The host cell in which lysogeny occurs is called **lysogenic cell**.
- **Lysogen** is a strain of bacteria carrying prophage.
- Lysogenic cycle is shown by 1 (lambda) phage which also infects *E.coli* bacterium.
- **Lytic bacteriophage** multiply in host bacterium which then undergoes complete lysis (degeneration) to release the resulting daughter phages.
- The phage attaches to the surface of bacteria by means of tail, which produces a hole in host cell wall and injects the phage DNA.
- Phage DNA produces a repressor, (C1) becomes nonvirulent or temperate and gets integrated to bacterial chromosome at a specific site by means of enzyme integrase.
- The viral genome is now called **prophage/provirus**.
- It multiplies alongwith bacterial genome and is passed on to the progeny.
- Occassionally the synthesis of repressor is stopped due to ultra violet radiations or chemical factors.
- The temperate/non-virulent phage is now changed to lytic/virulent phage.
- The single strand DNA of f × 174 or coliphage *fd* is known as **plus strand**. It forms its complementary or negative strand. The double strand or replicative DNA takes over the metabolic machinery of host to synthesize plus strands DNAs and protein for assembly of new phages.

Pinocytic reproduction

- The whole virus enters the host cell except the envelope. It is quite common in RNA viruses which are of two types as RNA-RNA virus and RNA-DNA virus.
- In **RNA-RNA viruses** DNA has no role in their multiplication. After entering the host cell the viruses produce enzyme **replicase** which helps in producing more genetic RNA over the template

of parent RNA genome. The latter also produces *m*RNAs for synthesis of viral proteins.

- **RNA-DNA viruses** are also called **retroviruses** (Temin, 1970), *e.g.*, Tumor/Cancer viruses, HIV. The viruses possess enzyme **reverse transcriptase** (Temin and Baltimore, 1972; in Rous Sarcoma Virus or RSV of Mouse). The enzyme builds DNA over RNA genome. The phenomenon is called **reverse transcription** or **teminism**.
- The **copy DNA (cDNA)** builds its complementary strand. The double strand copy DNA attaches to host DNA/chromosome and is now called **provirus**.
- **Application of bacteriophages** are –
  - Studying viral infection mechanism.
  - Control of certain bacterial diseases.
  - Purity of Holy Ganges is due to presence of bacteriophages.

Viroids are sub-viral infectious agents, which contains only very low molecular weight RNA and not protein coat. Viroids cause potato spindle tuber disease (PSTV), citrus exocortis etc. The only human disease known to be caused by a viroids is hepatitis D.
Interferons are protein molecules which prevent viral multiplication. These are produced by cells in mammals, rodents, birds, etc. and provide resistance against viruses.

Diseases caused by viruses

- Virus causes diseases in plants, animals and human brings.
- **Plant diseases caused** by viruses are –
  - Tobacco mosaic disease
  - Leaf curl of papaya
  - Yellow vein mosaic of bhindi
  - Potato leaf roll
  - Vein bandings mosaic disease of potato
  - Grassy shoot of sugar cane
  - Bunchy top of banana
  - Tungro disease of rice
  - Tomato leaf curl
- **Human diseases caused** by viruses are –

Chicken pox	:	*Varicella virus*
Small pox	:	*Variola virus*
Measles	:	*Rubeola virus*
Rabies	:	ssRNA (*Rabies virus - Lassa virus*)
AIDS	:	ARV (*Aids associated retrovirus*)
Yellow fever	:	Transmitted by *Aedes aegypti* mosquito
Dengue fever	:	Transmitted by *Aedes aegypti* mosquito
Polio	:	Transmitted through food, water, contact
Hepatitis-B	:	Transmitted through contact and body fluid.

- **Transmission of viruses** occurs by –
  - Polluted air, water and food stuffs help the dissemination of viruses in man and animals.
  - Fly and mosquitoes usually act as carriers.
  - Such virus transmitting agents are called vectors.
  - Most of the virus diseases of plants are transmitted through insects.
  - Sap sucking insects like aphids and white flys are the important ones among such vectors.
  - Virus diseases are also transmitted through stem cuttings, seeds, tubers, agricultural implements etc.
- **Disease can be controlled** by –
  - Removal of diseased plants and plants parts.
  - Using disinfested seed.
  - Testing the germplasm and selecting virus free seed.
  - Destruction of alternative hosts.
  - Destruction of insect vectors.
  - Practising crop rotation.
  - Growing disease resistant varieties.

End of the Chapter

Chapter 3

Kingdom Monera

- **Monera** are the group of all prokaryotes.
- They are basically unicellular, may be mycelial, colonial and filamentous.
- Cell wall is made up of **peptidoglycan**, **polysaccharides** and **cellulose**.
- They do not contain any organised nucleus with distinct membrane.
- **DNA is naked**, *i.e.,* not associated with histone proteins. It is called **nucleoid**.
- All the membrane bound **cell organelles are absent** like mitochondria, lysosomes, golgi bodies, plastids etc.
- In photoautotrophic forms thylakoids are present - without chloroplasts.
- Spindle apparatus do not develop at the time of cell division.
- Single stranded flagella, **composed of flagellin**, is present.
- Ribosomes are **70S type** (subunit 30S and 50S).
- Reproduction is by **binary fission or budding**.
- They have a **various modes of nutrition** like saprobic, parasitic, chemoautotrophic, photoautotrophic, symbiotic.
- Some are capable of nitrogen fixation.
- Monera occur in all environment, eg archaebacteria live in extreme climates.
- The kingdom includes all prokaryotes like **bacteria**, **actinomycetes**, **mycoplasma** and **cyanobacteria**.

BACTERIA

- Bacteria are the **smallest of free living organism**, **mostly unicellular.**
- Bacteria possess various forms and shapes, and are of **4 different types** – **coccus**, **bacillus**, **vibrio**, and **spirullum**.

Bacteria based on shape

- **Coccus** (round)
  - *Micro* (Occurs singly)
  - *Diplo* (Groups of two)
  - *Tetracoccus* (In groups of four)
  - *Streptococcus* (Forms a chain)
  - *Staphylococcus* (Bunch of grapes)
  - *Sarcinae* (Cubes of 8, 64 or more)
- **Bacillus** (rod shaped)
  - *Diplobacillus* (In groups of two)
  - *Palisade bacillus* (Like a stack)
  - *Streptobacillus* (In chains)
- **Vibrio** (comma shaped, e.g., *Vibrio cholerae*)
- **Spirullum** (spiral like cork-screw, e.g., *Spirochaete*)

Bacteria based on flagellation

- **Atrichous** flagella absent e.g., *Lactobacillus*
- **Monotrichous** single flagella at one end, e.g., *Vibrio cholerae*
- **Lophotrichous** groups of flagella at one end, e.g., *Spirullum*
- **Amphitrichous** single flagella at each end, e.g., *Nitrosomonas*
- **Peritrichous** flagella present all over the body, e.g., *E. coli*

Flow chart : Classification of bacteria

- Bacteria possess a distinct cell wall, with different wall layers like capsule or slime layer, plasma membranes, flagella and pilli.
- Slime layer or capsule is made up of **polysaccharides** and **amino acids** and acts as osmotic barrier.
- Cell wall is made up of **polysaccharides**, **proteins** and **lipids** and **peptidoglycan** or **murein**.
- Plasma membrane is **tripartite** in nature.
- **Mesosomes** are simple infolding of plasma membrane containing respiratory enzymes, like oxidases and dehydrogenase.
- Flagella is made up of **flagellin**.
- **Pili** are small hair like outgrowth present on bacterial cell surface made up of **pilin protein**.
- Pilin **helps in formation of conjugation tube and agglutination**.
- **Based on the nature of staining**, bacteria **may be Gram + ve** (retains the blue stain) or **Gram –ve** (does not retain the stain).

Gram staining
↓
Heat fixed smear of bacteria
↓
Crystal violet
↓
Rinse with water
↓
Add dilute iodine solution
↓
All bacterial cell appears deep blue
↓
Treat with 95% alcohol
↓ ↓

Cells retain purple colour **Gram +ve bacteria**	Destained and appear red in colour **Gram –ve bacteria**

- Inner to the wall layers, there is present matrix or protoplasm which includes **nucleoid**, **plasma**, **episomes**, **ribosomes**, **and granules**.
- In the centre of the bacterial cell, there is present **nuclear material** (DNA) **without any nuclear membrane** (naked). **DNA in bacteria is double helical and circular**.
- This incipient nucleus or primitive nucleus is named as **nucleoid** or **genophore** (sometimes called single naked chromosome).
- Besides this nuclear DNA, there is some extranuclear or extrachromosomal DNA, which is known as **plasmid**.

Table : Difference in the cell walls of gram +ve & gram –ve bacteria

	Gram +ve bacteria	**Gram –ve bacteria**
1.	Cell wall more thick, thickness varies from 25-30 nm.	Cell wall thin. Thickness varies 10-15 nm.
2.	Cell wall is a homogenous layer.	Three layered.
3.	High content of peptidoglycan (20-80% of the dry weight of the cell).	Less content of peptidoglycan (10-20% of the dry weight of the cell).
4.	Teichoic acids may be present.	Teichoic acids absent.
5.	Very little lipid content (0-2%).	High lipid content (10-20%).
6.	Only a few aminoacids are associated with the muramic acid complex.	Large variety of aminoacids are associated.
7.	Lipopolysaccharide layer (LPS) absent.	Present.
8.	Periplasmic space is absent.	Present.

- The plasmid are **small**, **circular**, **double-stranded DNA molecules** that are separate from main bacterial chromosome and replicate independently.
- The term plasmid was given by **Lederberg** (**1952**).
- Plasmids have an independent existence.
- Plasmids **carry genes for fertility**, **antibiotic resistance** (**R-factor**) and **bacterium** (**Colicin**) **production** (**colicinogenic factor**).
- **F-factor** or **fertility factor** is responsible for transfer of genetic material.
- **R-factor** or **resistance factor** provides resistance against drugs.
- **Colicinogenic factor** produces '**colicines**' which kill other bacteria (other than which produces these colicines).
- The term **episome** is applied to extranuclear genetic material which may remain in integrated or free state, e.g., F-factor, temperate phage, etc.
- Ribosomes are evenly distributed in the matrix. Ribosomes are of 70S type (50S + 30S).
- Ribosome are the seat of protein synthesis and are made up of r-RNA and protein.

- There are present different types of granules like volutin granules, fatty acid granules (lipid granules), glycogen and sulphur granules.
- **According to the mode of respiration**, bacteria can be **aerobic** or **anaerobic**. Each of them is further of two types, obligate and facultative.
- **Obligate aerobes** are bacteria which can respire only aerobically. They generally get killed under anaerobic mode of respiration, e.g., *Bacillus subtilis*.
- **Facultative aerobes** are bacteria which respire anaerobically under normal conditions but can respire aerobically when oxygen is available. Most of the photosynthetic bacteria belong to this group.
- **Obligate anaerobes** are bacteria that respire only anaerobically. They generally get killed under aerobic condition, e.g., *Clostridium botulinum*.
- **Facultative anaerobes** are bacteria which generally respire only aerobically but switch over to anaerobic mode of respiration if oxygen becomes deficient.

Nutrition

- Bacteria show both **autotrophic** and **heterotrophic nutrition**.
- **Autotrophic nutrition** consists of manufacture of organic materials from inorganic raw materials with the help of energy obtained from outside sources. It is of two types – **chemosynthesis** and **photosynthesis**.
- The bacteria possess photosynthetic pigments of two types, **bacteriochlorophyll** and **bacteriophaeophytin** (chlorobium chlorophyll). The two types of pigments respectively occur in purple bacteria (e.g., *Thiopedia rosea, Rhodopseudomonas*) in membranes of thylakoids.
- **No oxygen is evolved in bacterial photosynthesis**. Such type of photosynthesis is known as **anoxygenic photosynthesis**.
- Water is not used as a source of reducing power. Instead, hydrogen is obtained either directly (some purple bacteria) or from various types of inorganic and organic compounds, *e.g.*, H_2S (green bacteria), aliphatic compounds (purple nonsulphur bacteria).
- **Chemoautotrophic bacteria** are bacteria which are able to manufacture their organic food from inorganic raw materials with the help of energy derived from exergonic chemical reactions involving oxidation of an inorganic substance present in the external medium. They are of various types.
- **Nitrifying bacteria**, *Nitrosomonas* and *Nitrosococcus* obtain energy by oxidising ammonia to nitrite.
  $NH_4^+ + 2O_2 \rightarrow NO_2^- + 2H_2O$ + Energy
  Nitrocystis and *Nitrobacter* oxidise nitrites to nitrates.
  $2NO_2^- + O_2 \rightarrow 2NO_3^-$ + Energy
- **Sulphur oxidising bacteria**, *Beggiatoa*, a colourless sulphur bacterium, oxidises hydrogen sulphide to sulphur in order to obtain energy for chemosynthesis.
  $2H_2S + O_2 \xrightarrow{\text{Beggiatoa}} 2S + 2H_2O$ + Energy
  Thiobacillus thioxidans, another sulphur bacterium, oxidises sulphur to sulphate state.
  $2S + 2H_2O + 3O_2 \xrightarrow[\text{Thioxidans}]{\text{Beggiatoa}} 2H_2SO_4$ + Energy
- **Iron bacteria**, *Ferrobacillus ferro-oxidans* obtains energy by oxidising ferrous compounds to ferric forms.
  $4FeCO_3 + 6H_2O + O_2 \rightarrow 4Fe(OH)_3 + 4CO_2$ + Energy
- Other chemosynthetic bacteria, bacterium *Methanomonas* oxidises methane into CO_2 and H_2O.
  $CH_2 + 2O_2 \rightarrow CO_2 + 2H_2O$ + Energy
- **Heterotrophic bacteria** may be **saprophytic**, **parasitic or**, **symbiotic**.
- **Saprophytic** are **living bacteria which obtain their food from organic remains**, *e.g.*, corpses, animal excreta, fallen leaves, vegetables, fruits, meat, jams, jellies, bread and other products of plant and animal origin.
- **Symbiotic bacteria** live in mutually beneficial association with other organisms. Enteric bacterium *Escherichia coli*, live as a symbiont in human intestine.
- **Parasitic bacteria**, live in contact with other living beings for obtaining nourishment or special organic compounds required for growth (growth factors).
- Bacteria **show four major phases of growth** in a fresh nutrient rich medium – (i) **lag phase**, (ii) **log phase** (logarithmic or exponential phase), (iii) **stationary phase**, and (iv) **decline phase** (death phase). These phases constitute the standard bacterial growth curve.

Reproduction

- Bacteria show **3 methods of reproduction** – **vegetation reproduction**, **asexual reproduction**, **sexual reproduction**.

- **Vegetative reproduction** includes **budding** and **binary fission**.
- **Binary fission** takes place during favourable conditions. The bacterial cell divides by a constriction into 2 halves. The nuclear material also divides into 2 equal halves.
- **Asexual reproduction** takes place by **endospore formation**, **conidia** and **zoospores**.
- During unfavourable condition, highly resistant single spore is formed inside the bacterial cell, which is known as **endospore**. (*Endo means inside or within + spore*).
- Endospore is having a characteristic structure *i.e.*, having outer thin **exosporium** followed by one or many layered **spore coat**, followed by many **concentric layers of cortex**, which is followed by **cell wall**, **cell membrane** and **matrix**.
- Endospore is **highly resistant to very high and very low temperature**, **strong chemicals and acids**, **etc. due to calcium**, **dipicolinic acid and peptidoglycan in cortex**. Dipicolinic acid (DPA) **helps in stabilizing its proteins**.
- DPA and Ca ions provide resistance to heat.
- When favourable conditions come, outer layers rupture and active bacterial cell comes out. So this is a method of perennation (*i.e.*, to tide over unfavourable condition) and some people say it **"reproduction without multiplication"**.
- **Sexual reproduction** occurs in the form of **genetic recombination**.
- There are **there main methods of genetic recombination** – **transformation**, **transduction**, **conjugation**.
- **Transformation** : Here genetic material of one bacterial cell goes into another bacterial cell by some unknown mechanism and it converts one type of bacterium into another type (non-capsulated to capsulated form).
- This was **first studied by Griffith** (1928) in *Diplococcus pneumoniae* and hence is known as **Griffith effect**.
- **Transduction** : In this method, genetic material of one bacterial cell goes to other bacterial cell by agency of bacteriophages or phages (viruses, infecting bacteria).
- Transduction was first of all reported in *Salmonella typhineurium* by **Zinder and Lederberg (1952)**.
- In abortive transduction the new gene does not integrate with the recipient genome and is lost.
- **Conjugation** : Cell to cell union occurs between two bacterial cells and genetic material (DNA) of one bacterial cell goes to another cell lengthwise through conjugation tube which is formed by sex pili.
- Conjugation was **first reported by Lederberg and Tatum (1946)** in *E. coli* bacteria.
- Conjugation **occurs between donor cell and recipient cell**. Donor cell is having sex pili and F-factor whereas recipient cell is having both.
- In donor cell, F-factor may unite with main genome or nuclear DNA and this donor cell is called **Hfr-donor cell** (High Frequency donor cell) and here transfer of DNA is rapid.

Importance of bacteria

Useful activities

- **Role of bacteria in agriculture in increasing soil fertility**
  - Some free living nitrogen fixing bacteria like *Azotobacter* and *Clostridium* have the capacity of fixing atmospheric nitrogen into nitrogenous substances, hence increases soil fertility.
  - Similarly symbiotic bacteria *Rhizobium* also fix atmospheric nitrogen.
  - *Nitrosomonas* converts ammonia into nitrites, which is further converted into nitrates by *Nitrobacter* (nitrification).
- **In dairy industry**, lactic acid bacteria (*Bacterium lacticiacidi* and *Bacterium acidi-lactici*) convert lactose of milk into lactic acid and hence milk turns sour.
- **In other industries**
  - In vinegar industry, *Acetobacter acetic* converts sugar solution into acetic acid.
  - Butyl alcohol and acetone are produced by activity of *Clostridium acetobutyricum*.
  - Retting or separation of fibres from stalks, *e.g.*, in jute, sunhemp, *Linum* (flax), etc. is done by water inhabiting bacteria *Clostridium butyricum*.
  - Flavouring of tobacco leaves is done by *Bacillus megatherium*.
  - Curing of leaves of tea is done by *Mycococcus condisans*.

- **Role of bacteria in sewage disposal**
  - For the breakdown of sewage in simple substances, bacteria and algae play important role.
  - Sewage oxidation ponds or tanks have luxuriant growth of bacteria and algae.
- **Role of bacteria in petroleum pollution** : Petroleum pollution in water bodies is checked upto some extent by *Pseudomonas*.
- **Role of bacteria in human being** : *E. coli* (gram-ve) bacteria live in colon region of intestine of man and other animals and play an important role in digestion process.
- Many antibiotic are produced from bacteria. **Antibiotics** are substances produced by micro-organisms which in low concentration are antagonistic to the growth of other micro-organisms. Medicinally antibiotics are those organic secretions which destroy or check the growth of different pathogens without harming the host.

Table : Role of bacteria in medicine

	Antibiotics	Bacteria from which obtain
1.	Subtelin	*Bacillus subtilis*
2.	Polymyxin	*Bacillus polymyxa*
3.	Streptomycin and Cycloheximide	*Streptomyces griseus*
4.	Chloromycetin (Chloramphenicol)	*Streptomyces venezuelae*
5.	Terramycin (Oxytetracycline)	*S. rimosus*
6.	Aureomycin	*S. aurefaciens*
7.	Erythromycin	*S. erythraeus*
8.	Neomycin	*S. fradiae*

Harmful activities

- **Spoilage of food** : Saprophytic bacteria causes rotting of vegetables, fruits, meat, bread, souring of milk, cheese, butter, spoilage of jams, jellies and pickles.
- **Destruction of Penicillin** by *Bacillus brevis*.
- **Cotton spoilage** is done by bacteria called *Clostridium botulinum*.
- **Desulphurification of soils** : Soil sulphates is changed to hydrogen sulphide by *Desulfouibrio desulfuricans*.
- **Reduction of soil fertility** : There are some denitrifying bacteria in soil, which convert nitrates into free nitrogen (denitrification), *e.g.*, *Bacillus denitrificans*, *Micrococcus denitrificans* and *Thiobacillus denitrificans*.

Table : Bacterial diseases of plants, animals and humans

Name of disease	Causal organism
Human beings	
Pneumonia –	*Diplococcus pneumoniae*
Typhoid –	*Salmonella typhosa*
Cholera –	*Vibrio cholerae*
Plague –	*Pasteurella pestis*
Meningitis –	*Neisseria meningitides*
Gonorrhoea –	*Neisseria gonorrhoeae*
Syphilis –	*Treponema pallidum*
Diarrhoea –	*Bacillus coli*
Gastroenteritis –	*E. coli*
Diphtheria –	*Corynebacterium diphtheriae*
Tuberculosis –	*Mycobacterium tuberculosis*
Gangarin –	*Clostridium perfringens*
Jaundice –	*Leptospira icterohaemorrhagae*
Whooping cough –	*Haemophilus pertussis* or *Bordetella pertussis*
Tetanus (lockjaw) –	*Clostridium tetani*
Bacterial dysentry –	*Shiegella dysentirae*
Leprosy –	*Mycobacterium leprae*
Animals	
Anthrax –	*Bacillus anthracis*
Black leg disease –	*Clostridium chauvi*
Plants	
Soft rot of potato –	*Pseudomonas solanacearum*
Citrus canker –	*Xanthomonas citri*
Bacterial blight of paddy –	*Xanthomonas oryzae*
Tundu disease in wheat –	*Corynebacterium tritici*
Potato wilt –	*Pseudomonas solanacearum*
Fire blight of apple and peach –	*Erwinia amylovora*
Crown gall of beet sugar –	*Agrobacterium*
Black rot of cabbage –	*Xanthomonas campestris*

Some other types of bacteria

- **Spirochaetes** are free inhabitants of mud and water and are **chemoheterotrophic** bacteria.
  Many diseases are caused by them as *Treponema pallidum* causes syphilis, *Leptospira* causes infectious jaundice and *Borrelia* causes relapsing fever. Besides some spirochaetes are found in teeth.
- **Rickettsiae** are Gram negative obligate pleomorphic but walled intracellular parasites which are resident of or are transmissible from arthropods. They are **intermediate between true bacteria and viruses**.
- **Chlamydiae** are Gram negative intracellular parasites of about 0.25 μm size, often grouped along rickettsiae but differ from them in reproductive cycle that involves formation of initial or **reticulate bodies** (RB) and **elementary bodies** inside host phagosome. *Chlamydia trachomatis* causes conjuctivitis, sexually transmitted nongonococcal urethritis, epididymitis, cervicitis, proctitis and lymphogranuloma venereum. *C. pneumoniae* causes pneumonia and bronchopneumonia.

ACTINOMYCETES

- Actinomycetes are **mycelial (aseptate branched filaments) bacteria which form radiating colonies in culture**. Because of this, actinomycetes were **formerly called ray fungi**.
- Mycelial form is reduced in *Mycobacterium* and *Corynebacterium*.
- Mycelia have a diameter of 1mm or less.
- Wall contains mycolic acid (fatty acid), lipid and wax.
- Different **modes of reproduction** are by **conidia**, **sporangiospores** and **arthrospores** or **oidia** and **fragmentation**.
- Most of the actinomycetes are saprotrophic and constitute an important component of decomposers, e.g., *Actinomyces, Streptomyces*.
- A few are pathogenic in plants, animals and humans, e.g., *Mycobacterium*.
- In pathogenic actinomycetes or *Mycobacterium* a derivative of mycolic acid called **mycoside**/cord factor is involved in causing disease.
- A **number of antibiotics are produced** by actinomycetes, especially the genus *Streptomyces* (streptomycin, chloramphenicol, tetracyclines, terramycin, erythromycin, viomycin, novobiocin, nystatin).

The term **antibiotic was given by Abraham Selman Waksman** (1888 - 1973) **who also extracted first antibiotic** from *Streptomyces griseus* and named it streptomycin. For this Waksman was given Nobel Prize in 1952.

ARCHAEBACTERIA

- They are a group of most primitive prokaryotes which are believed to have evolved immediately after the evolution of the first life. They are also called living fossils.
- Archaebacteria are characterised by **absence of peptidoglycan in their wall**.
- Instead the wall contains **protein and non-cellulosic polysaccharides**. It has **pseudomurein in some methanogens**.
- The **cell membranes** are characterised by the **presence of a monolayer of branched chain lipids**.
- Archaebacteria even now live under extremely hostile conditions where very few other organisms can dare subsist, e.g., salt pans, salt marshes, hot sulphur springs.
- Their rRNA nucleotides are quite different from those of other organisms.
- The archaebacteria are of two broad categories – obligate anaerobes and facultative anaerobes or aerobes.
- Archaebacteria are of **three types** – **methanogens**, **halophiles** and **thermoacidophiles**.

Archaebacteria are **also known as living fossils because** they represented one of the earliest forms of life which experimented on the absorption of solar radiations for the first time, lived comfortably under anaerobic conditions and developed techniques to oxidise the chemicals present in the substratum on the availability of oxygen.

Methanogens

- These archaebacteria are **strict anaerobes**.
- Nutritionally they are "**autotrophs**" which obtain both energy and carbon from decomposition products.
- They occur in marshy areas where they convert formic acid and carbon dioxide into methane.
- This capability is commercially exploited in the production of methane and fuel gas inside gobar gas plants. E.g., *Methanobacterium, Methanococcus*.

- Some of the methanogen archaebacteria live as symbionts (e.g., *Methanobacterium*) inside rumen cow, buffalo and helpful to the ruminants in fermentation of cellulose.

Halophiles

- Halophiles are named so because they usually occur in salt rich substrata (2.5 - 5.0 M) like salt pans, salt beds, and salt marshes, e.g., *Halobacterium*, *Halococcus*.
- They are **aerobic chemoheterotrophs**.
- Their cell membranes have **red carotenoid pigment** for **protection against harmful solar radiations**.
- Under anaerobic conditions, halophiles cannot use external materials.
- At this time they subsist on ATP, synthesized by membrane pigmented system from solar radiations.
- Halophiles growing in salt pans and salts beds gives offensive smell and undesirable pigmentation to the salt.
- Halophiles are **able to live under high salt conditions due to the following reasons** –
  - **Presence of special lipids** in the cell membranes.
  - **Occurrence of mucilage covering**.
  - **Absence of sap vacuoles** and hence plasmolysis.
  - High internal salt content.

Thermoacidophiles

- These archaebacteria **have dual ability to tolerate high temperature as well as high acidity** due to two reasons - branched chain lipids in the cell membranes and presence of special resistant enzymes capable of operating under acidic conditions.
- They often live in hot sulphur springs where the temperature may be as high as 80°C and pH as low as 2, e.g., *Thermoplasma, Thermoproteus*.
- Basically these archaebacteria are **chemosynthetic** *i.e.*, they obtain energy for synthesis of food from oxidising sulphur.
- Under aerobic conditions they usually oxidise sulphur to sulphuric acid.
  $2S + 2H_2O + 3O_2 \rightarrow 2H_2SO_4$.
- If the conditions are anaerobic, the thermoacidophiles may reduce sulphur to H_2S.
- Bicarbonates are also precipitated into the carbonate form by their activity.

MYCOPLASMA (PPLO)

- Mycoplasmas or **mollicutes** are the **simplest and the smallest of the free living prokaryotes**.
- They were **discovered in pleural fluid of cattle**, suffering from pleuropneumonia **by Nocard and Roux**, (**1898**).
- The organisms are **often called MLOs** (*Mycoplasma like Organisms*) **or PPLOs** (*Pleuropneumonia like Organisms*).
- The size ranges from 0.1 - 0.15 mm.
- Plasma membrane forms the outer boundary of the cell. A substantial amount of **polysaccharides** having even **acetyl glucosamine** are associated with cell membrane which is rich in **cholesterol**.
- A cell wall is absent. Due to the absence of cell wall the organisms can change their shape and are pleomorphic – **cocoid**, **cocobacillus**, **helical**, **fine unbranched or branched**.
- Like other prokaryotes, mycoplasmas **possess one envelope system**.
- They **lack organised nucleus, endoplasmic reticulum**, **plastids**, **mitochondria**, **golgi bodies**, **lysosomes**, **centrioles**, **flagella** etc.
- The genetic material is represented by a **single DNA duplex which is naked because of absence of histone association**.
- The **DNA duplex is not compacted as in other prokaryotes but instead lies coiled throughout the cytoplasm**.
- Ribosomes are 70s. Granules of various types occurs here and there in the cytoplasm, mesosomes absent.
- Enzymes lie both freely in the cytoplasm as well as associated with the plasma membrane.
- DNA **possesses a replicating disc at one end to assist in replication** and **separation of the genetic material**.
- Some of them **live as saprophytes** but majority parasites plants and animals.
- The **parasitic habit is due to the inability of most mycoplasmas to synthesize the required growth factors**, e.g., *Mycoplasma gallisepticum*.
- Electron transport system is rudimentary or absent.
- Reproduction occurs by fission or first forming a branching filament with numerous nuclear bodies followed by constriction in between the nuclear bodies and separation of cells as new individuals.

- They mostly produce pleuropneumonia in domestic animals, atypical pneumonia and mycoplasmal urethritis in humans, little leaf disease of brinjal and witches broom in plants.
- Mycoplasmas are not affected by penicillin (inhibitor of wall formation) but are inhibited by tetracyclines.

CYANOBACTERIA (BLUE GREEN ALGAE)

General characters

- Cyanobacteria are **gram –ve prokaryotes** which **perform oxygenic photosynthesis like plants**.
- They were the **first organism to make the atmosphere aerobic**.
- The blue green algae live virtually in all environments that contain water.
- The organisms range from tropics to plains and they occur in soil, fresh water and ocean.
- In lakes and in the ocean they form part of planktons.
- Some cyanobacteria live in the icy water of glaciers others in hot springs where temperatures reach 85°C or more (due to homopolar bonds).
- Some blue-green algae live as symbionts with other organisms, e.g., lichens.
- Cyanobacteria can be **unicellular** (*e.g., Spirulina*), **colonial** (*e.g., Nostoc*) or **filamentous** (*e.g., Oscillatoria*). Filaments **contain one or more trichomes inside a mucilage sheath**.
- Trichomes may be **homocystous** (without heterocysts, *e.g., Oscillatoria* which shows apical oscillations) or **heterocystous** (with heterocysts, *e.g., Nostoc*, *Anabaena*).
- Nitrogen fixing *Nostoc* and *Anabaena* live freely as well as symbionts (in *Azolla*, *Anthoceros*, *Cycas* roots, *Gunnera* stems amd nodules of *Trifolium alexandrintum*).
- The cell wall possesses an **outer sheath** (outside) which is **jelly like**, **slimy and mucilaginous**.
- The cell contents are divided into two regions – **outer chromatoplasm** having photosynthetic pigments in free thylakoids and **inner colourless centroplasm**.
- The **cell wall is two layered** whose **inner wall is made up of peptidoglycan or mucopeptides** built up from amino sugars (eg., glucosamine) and amino acids (eg., muramic, diaminopimelic).
- In the cytoplasm photosynthetic lamellae are present.
- These lamellae or thylakoids contain dominating pigments phycocyanin allophycocyanin and phycoerythrin (phycobilins) in addition to chlorophyll *a*.
- Bacteria and blue green algae lack mitochondria, true vacuoles and endoplasmic reticulum.
- Sterols are absent in bacteria as well as cyanobacteria.
- **True nucleus is absent**. True fibrils of DNA are either distributed throughout the cell or concentrated in the central part. Its chromosome resembles bacterial chromosomes.
- Gas vacuoles are often present to regulate the buoyancy in water.
- The colour ranges from green to deep purple often blue green.
- These colours are produced by different proportions of several pigments like chlorophyll *a*, carotene, xanthophyll, blue phycocyanin and red phycoerythrin.
- Thylakoid membranes contain chlorophyll *a*, carotenes and xanthophylls. Attached to thylakoids are minute structure called **phycobilisomes**. They have three types of water soluble but protein bound accessory pigments – **phycocyanin**, **allophycocyanin** (both blue) and **phycoerythrin** (red).
- Many forms show **Gaidukov phenomenon or chromatic adaptation** where colour changes according to wavelength of light received by the cyanobacteria. *Trichodesmium erythaeum* is reddish coloured cyanobacterium which occurs in such abundance that a sea is named after its colour – red sea.
- Nucleoid is in contact with a group of coiled membranes called **lamellasome**. Lamellasome develops from plasmalemma. Plasmids or additional small DNA rings may occur. 70 S ribosomes are abundant.
- Cell inclusions are α-granules (cyanophycean starch similar to glycogen), β-granules (lipid droplets), volutin granules and polyhedral bodies.
- The **reserve food** is in the form of **cyanophycean (myxophycean) starch**.
- **Flagella are absent** in vegetative as well as reproductive phase.

- Well marked reproductive organs, sexual reproduction and motile reproductive bodies are absent in cyanobacteria.
- Reproduction is very simple and takes place by vegetative means only.
- No trace of sexuality has ever been recorded but **gene recombination** can occur through **conjugation**, **transformation** and **transduction**.
- The vegetative reproduction occurs by mere cell division.
- They **reproduce asexually** by **binary fission** (in unicellular forms) and **fragmentation** (by breaking up and regrowth of filaments).
- **Heterocysts** formation is characterized by the presence of thick walls and yellowish contents.
- Each heterocyst is made up of two walls - an inner thin layer and outer thick gelatinous layer.
- Heterocyst develops from recently divided cells, it may be single or paired.
- On germination, it gives rise to a new filaments.
- In many filamentous forms asexual reproduction occurs by **hormogonia formation**.
- They are identified by presence of biconcave discs or separation discs between two adjacent cells.
- The filaments gets broken from such places into many hormogonia and each of them forms a new filaments, eg., *Oscillatoria*.
- Spore formation also occurs (exospores, endospores, akinetes etc).

Nitrogen fixation in cyanobacteria

- Like many bacteria, several forms of blue-green algae have the capacity to fix atmospheric nitrogen into nitrogenous compounds.
- This capacity is **restricted to filamentous heterocystous forms** like *Nostoc, Anabaena, Aulosira* etc.
- Under anaerobic conditions, some non-heterocystous forms can also fix atmospheric nitrogen (*Gloeocapsa, Oscillatoria*).
- This additional capacity of N_2 fixation alongwith CO_2 fixation makes them truely autotrophic plants.
- In this sense, they are considered to be largely responsible for the maintenance of soil fertility in tropical and temperate regions.
- **Some species** of blue green algae **have a great contribution to increase the fertility of rice fields in tropical countries like India** (e.g., *Anabaena, Tolypothrix*, *Aulosira*).

Economic importance of cyanobacteria

Useful aspects

- Some fifty species of cyanobacteria are capable of fixing atmospheric nitrogen in soil, e.g., *Anabaena, Nostoc*.
- *Spirulina* is being used as a **source of protein rich supplement to diet of human**.
- Bolls of *Nostoc* are **used as food by Chinese and South Americans**. Food is called **yoyucho**.
- Cyanobacteria like *Nostoc, Scytonema* are used for **reclamation of usar** (sterile, alkaline) soil.
- In Sambhar lake of Rajasthan, *Anabaena* and *Spirulina* is produced in large number. Local people use it as **green manure**.
- Some species of *Anabaena*, *Tolypothrix* help in conservation of soil, thus **checking soil erosion**.
- Few cyanobacteria located inside lichens help in **plant succession** due to their growth on barren land.
- *Oscillatoria* is used as pollution indicator.

Harmful aspects

- Forms like *Anabaena* **not only spoil the taste of drinking water but also produce toxic effect**.
- Some cyanobacteria appear on buildings during rainy season and cause **damage to bricks** etc.
- **Skin infections** may be caused by cyanobacteria *Lyngbya*.
- **Toxin secreting cyanobacteria** are mainly **responsible for water blooms**. These on death emit foul smell, water gets contaminated with chemoheterotrophic bacteria and unfit for normal use.
- Some cyanobacteria like *Rivularia* **release toxins which is harmful for aquatic fauna**.

End of the Chapter

Chapter 4

Kingdom Protista

- **Protista** is a kingdom of **unicellular eukaryotes** (except red and green algae).
- The kingdom was created by **Haeckel in 1886**.
- Protists include solitary unicellular or colonial unicellular eukaryotic organisms **which do not form tissue**.
- They are mostly aquatic.
- The unicells may be naked or covered by cell wall, pellicle, shell or cuticle.
- A well defined nucleus is present. Protists can be uninucleate, binucleate or multinucleate.
- The genetic material is **linear DNA**, **enclosed by nuclear envelope**, **complexed with proteins** and **organised into distinct chromosomes**. This character continues in the remaining three kingdoms.
- The cytoplasm contains besides ribosomes, a variety of organelles such as mitochondria, plastids (in photosynthetic protists), lysosomes, cytoskeleton, endoplasmic reticulum and Golgi bodies. Ribosomes are of two types, 80 S cytoribosomes and 70 S organelle ribosomes. Many have centrioles also.
- Cytoplasm is always in motion. The phenomenon is called **cytoplasmic streaming** or **cyclosis**.
- Cell wall, if present, contains cellulose.
- Food reserve is **starch**, **glycogen**, **paramylon**, **chrysolaminarin and fat**.
- All the three types of life styles (plant, animal and fungal) occur in protists.
- **Some protistans are parasitic**. Some **live symbiotically** as in the gut of animals while a few **act as decomposers**.
- Protistans are **connecting link between monerans and rest of the kingdoms**.
- **Asexual reproduction** is quite common and **occurs through budding**, **binary fission**, **multiple fission**, **plasmotomy**, **sporulation**, **cyst formation**, etc.
- **Sexual reproduction** occur with the help of nonjacketed gametangia. It **involves meiosis and karyogamy**.
- Mitotic apparatus is formed during cell division.
- No embryo is formed.
- In many forms, plastids, (9 + 2 strand) flagella and other organelles are present.
- The nutritive modes of these organisms include photosynthesis, absorption, ingestion and combination of these.
- The organisms **move by flagella**, **cilia**, **pseudopodia**, **contraction** and **mucilage extrusion**.
- **Kingdom protista (also called protoctista) is divided into 3 main groups** –
  - **Photosynthetic protists** (Protistan algae) – Eg., **dinoflagellates** or class dinophyceae (certain, *Glenodinium, Gymnodinium, Gonyaulax, Noctiluca* and *Peridinium*); **diatoms** or class bacillariophyceae (*Navicula, Nitzchia, Metosira, Cymbella, Amphipleura, Pinnularia*) and **euglenoids** or *Euglena* like flagellates (*Euglena, Eutreptia, Phacus, Peranema*).
  - **Consumer protists –** Slime moulds or Myxomycetes, eg., *Physarum, Physarella*.
  - **Protozoan protists –** Eg., *Giardia, Trypanosoma, Leishmania, Amoeba, Entamoeba, Plasmodium* (malarial parasite), *Paramecium* etc.

Important groups of protista

Chrysophytes [Diatoms and Golden Algae (Desmids)]

- **Diatoms** included in phylum chrysophyta of algae are also known by the name **golden algae**.
- They have been grouped under two categories, namely pennate types and centric types.

- **Pennate types** are **bilaterally symmetrical and centric types** are **radially symmetrical**.
- Diatoms have cell walls containing **silica**, **constructed in two overlapping halves**, which fit together like two parts of a soap box (pennate types) or pair of petridishes (centric types).
- The **outer wall is called epitheca** and **inner wall is a called hypotheca**.
- They are present in both fresh and salt water and comprise an important food for the aquatic animals. However, out of 5,500 species mostly are marine.
- They **lack flagella** and **float mainly due to light storage lipids** present in them.
- Due to their silica impregnations, the walls of diatoms are indestructible.
- As a result diatomaceous earth formation has occurred due to remains of cell walls of diatoms in the form of fossils.
- Silica wall of diatoms is designed with fine ridges, lines, pores etc.
- These ornamentations are either radially symmetrical or bilaterally symmetrical on either side of the long axis of the cell.
- **Food reserve** is **oil** and **chrysolaminarin** or **leucosin** (β 1 - 3 glucan)
- Multiplication is through **binary fission**.
- Binary fission reduces the size of most daughters due to relation of one valve of the parents. This is corrected through the development of **rejuvenescent cells or auxospores**. Eg - *Coscinodiscus*, *Stephanodiscus*, *Cymbella* etc.
- Diatoms may **exhibit slow gliding movements** produced by streaming of cytoplasm through grooves on the surface of cell wall.
- Due to various designs over the cell wall, they have been **regarded as jewels of the plant kingdom**.
- The oils extracted from some fishes and whales are actually the ones produced by diatoms.
- Diatomite deposits are often accompanied by petroleum fields. Much of the petroleum of today is probably due to decayed bodies of the past diatoms.
- Diatomite is porous and chemically inert. It is therefore, used in filtration of sugars, alcohols and antibiotics.
- Diatomite is employed as a cleaning agent in tooth pastes and metal polishes.
- Diatomite is added to paints for enhancing night visibility.
- Diatomite is employed as insulation material in refrigeraters, boilers and furnaces.
- Diatomaceous earth is added to make sound proof rooms. It is a good industrial catalyst and a source of water glass or sodium silicate.
- Diatomite was at one time employed in handling and storage of dynamite and strong acids.

Dinoflagellates

- They comprise the phylum pyrrophyta of algae, golden brown photosynthetic protists.
- They are single celled, most of them are surrounded by a shell made up of thick interlocking plates covered with cellulose cell wall.
- They are **motile with two flagella** (hence dinoflagellates) one projecting from one end and the other running in a transverse groove.
- Like diatoms they **have fucoxanthin** in addition to chlorophyll.
- They are **autotrophic and photosynthetic** (e.g. *Ceratium*). *Blastodium* is a colourless parasite on animals.
- The **food reserves** is in **the form of oils** and **polysaccharides**.
- Most of the dinoflagellates are marine and important photosynthesizer in the ocean.
- Occasionally members like *Gonyaulax* accumulate in large numbers in some parts of sea, colouring the water red and are responsible for red tide.
- *Gonyaulax* **causes** '**red tides**' because **it shows bioluminescence or phosphorescence** and make the sea look red.
- Some species of dinoflagellates are poisonous to vertebrates and when these accumulate, large number of fish in that region of ocean may be killed.
- A non-contractile vacuole or pusule is present.
- Due to presence of two flagella at right angles to each other, the dinoflagellates show peculiar spinning movement. Hence, they are called **whorling whips**.
- Nucleus is **mesokaryon** with condensed chromosomes even in interphase. Histone is absent. Division occurs through **dinomitosis** in which the **nuclear envelope persists**.
- Microtubular spindle is not formed. **Chromosomes are acentric** and move while attached to inner membrane of nuclear envelope.
- Dinoflagellates may have eye spots, **trichocyst** (*e.g.*, *Peridinium*) and **cnidoblasts** (*e.g.*, *Nematodinium*).

- Some forms show **bioluminescence** or phosphorescence, and are called **fire algae** *e.g.*, *Noctiluca, Gonyaulax*.
- Method of reproduction is **only asexual**. **Sexual reproduction is usually absent** (exception– *Ceratium*).
- Some species of dinoflagellates are taken as food by mussels. These mussels remain unharmed by dinoflagellates but if man eats these infected mussels, he may fall ill.

Euglenoids

- Euglenophyceae includes flagellate protists of fresh water and damp soils.
- Presence of anterior invagination like some ciliates has given the name plant-animals.
- **Euglenoids are more advanced than blue-green algae from evolutionary point of view, for they have a definite easily stained nucleus and the chlorophyll is not scattered in granules but is localized in chloroplasts as in higher plants. The nuclear envelope persists during division**.
- They are free living, found in fresh water ponds and ditches or in the damp soil.
- Euglenoids are **characterised by absence of cell wall**, but they do **contain flexible pellicle made up of protein**.
- All the euglenoids **have one or two flagella** (tinsel and tactellum) by means of which they can swim easily.
- *Euglena* is more readily available protist for laboratory studies.
- *Euglena* bears a flagellum inserted at the anterior end in a cavity.
- They **bear a red pigmented eye spot** and a gullet near the base of the flagellum. The pigment in eye spot is **astaxanthin**.
- A swelling called **paraflagellar body** is found in the region of union of flagellar roots.
- Photosynthetic forms bears many, radiating chloroplasts of various shapes.
- The chloroplasts contain pigments like **chlorophyll a**, **chlorophyll b**, **xanthophyll**.
- Nucleus with one or more prominent nucleoli occurs.
- Pyrenoids may or may not be present.
- Some euglenoids are green and **holophytic** (photo autotrophic) like other plants. Few are non-green and **saprobic** like fungi and bacteria.
- Some capture and ingest the organisms like animals (holotrophic). Green forms have saprobic mode pickup organic matter from outside (myxotrophic).
- Holotrophic or phagotrophic nutrition is absent in *Euglena*.
- Euglenoids **store carbohydrates** in the form of **paramylum chemically**, **distinct from starch and glycogen**.
- Reproduction is usually **asexual by cell division** but sexual reproduction has been reported in one genus.
- Under favourable condition, euglenoids reproduce by simple, **longitudinal binary fission**.
- Flagellum disappears prior to division.
- Most of the species produce **cyst** having thick stratified membranes with **deep red colouration due to synthesis of haematochrome**.
- Besides cyst formation, many of non-flagellate cells may get embedded in a common gelatinous sheath resembling a **palmella stage** (as in algae).
- Eg – *Euglena, Paranema, Trachelomonas*.

Slime moulds

- Slime moulds are **consumer decomposer protists**.
- Asexual reproduction takes place through **binary fission**, **plasmotomy**, **spores**, **cyst** and **sclerotium**.
- Sexual reproduction is **isogamous or anisogamous**.
- Both zygotic meiosis (cellular slime moulds) and gametic meiosis (acellular slime moulds) occur.
- Slime moulds have **characters of plants** (cellulose cell wall), **animals** (phagotrophic nutrition), and **fungi** (spores). They **take part in both decomposition of organic matter** and **feeding of other decomposer organisms**.
- Slime moulds, therefore, **live in contact with organic matter**.
- Slime moulds (500 sp.) **have several features** which are **animal like in their vegetative stages** and **plant like in reproductive stages**.
- The slime moulds are widely distributed, growing in damp and shady places.
- They may be found in the soil rich in humus, damp old planks of wood, rotting logs, decaying leaves etc.
- They **prefer moisture and darkness or dim-light for normal growth**, they move to drier and exposed habitats during reproductive phase.
- More than 100 species, have been reported from India.
- The **vegetative phase** of the thallus is a **free-living**,

naked, **multinucleated mass of protoplasm called plasmodium**.

- The plasmodium consists of **diploid nuclei**, **lacks cell wall** and **secretes lime**.
- The plasmodium shows amoeboid movement **by producing pseudopodia**.
- Chlorophyll is lacking, so these are generally saprophytic, rarely parasitic causing abnormal swellings upon the bodies of hosts.
- They reproduce by means of spores produced in sporangia.
- The spores have cellulosic cell wall and are produced through meiosis.
- The slime moulds are generally holocarpic.
- The spores germinate to produce myxamoebae or biflagellated swarm cells behaving as gametes.
- The swarm cells fuse in pairs showing isogamous types of sexual reproduction.
- Slime moulds may be colourless or variously coloured like yellow, orange, brown etc.
- Slime mould are of **two types** – **acellular** and **cellular**.
- **Acellular slime moulds** have a wall-less multinucleate protoplasm or **plasmodium** without (**protoplasmodium**) or with a number of branched veins showing cyclosis (Phaneroplasmodium).
- Multiplication occurs by plasmotomy.
- Normally when food is about to exhaust, the plasmodium comes to rest and develops sporangium.
- Each sporangium has a noncellulosic covering called **capillitium**. Eg, *Fuligo*, *Physarum*.
- **Cellular slime moulds** are initially in the form of haploid uninucleate wall-less **myxamoebae** which are surrounded by mucilage, move about by pseudopodia and feed on bacteria and other micro-organisms through ingestion.
- Myxamoebae multiply by **binary fission**.
- Sexual reproduction occurs occasionally through **macrocyst formation**. Eg. *Dictyostelium*, *Polysphondylium*.

Protozoa

- Protozoa (also included in the animal kingdom) are unicellular organisms having varied form, structure, and holozoic, saprobic or parasitic nutrition. Reserve food is glycogen, cysts occurs during unfavourable condition. Asexual reproduction by fission or budding and sexual reproduction by conjugation or syngamy.
- Major groups of protozoans based on locomotary organs are –
  - **Zooflagellata** (Flagellated protozoans)
  - **Sarcodina** (Amoeboid protozoans)
  - **Ciliata** (Ciliated protozoans)
  - **Sporozoa**

  [*For more details refer chapter Protozoa*]

End of the Chapter

Chapter 5

Fungi, Lichen and Mycorrhiza

FUNGI

- The **fungi** (*singular*, fungus) are a group of eukaryotic micro-organisms that lack chlorophyll, are unable to synthesize their own food and are therefore, heterotrophic. They live either as saprophytes, obtaining their food from the dead organic matter, or parasites, obtaining food from the bodies of living plants and animals.
- The term fungus is a latin word meaning **mushroom**.
- The branch of science that deals with the study of fungi is called **mycology** (Greek word *mykos* = mushroom and *logos* = discourse), and the branch that deals with the study of fungal disease is called **fungal pathology.**
- **Clausius** (1601) is regarded as the earliest writers who described fungi.
- The founder of mycology is **Antonio Micheli**. He **gave the first systematic account of fungi** in his book *Nova Plantarum Genera.*

General characters of fungi

- Fungi is very large group of over 100,000 species.
- Fungi are **ubiquitous** *i.e* occurs in a variety of habitats.
- Most of them are **moisture loving and terrestrial**, but a few are **aquatic**, *e.g., Monoblepharis* and *Saprolegnia* and these are commonly known as '**water moulds**'.
- A few fungi are **epiphytic**, live on trees, *e.g., Armillaria* on apple tree and causes red rot of apple.
- It is usually defined as a group of those organisms which form the thallus (*i.e.*, not differentiated into root, stem and leaves), built up of single cell or cells (unicellular or multicellular).
- Fungi **lack chlorophyll** and are unable to synthesize their own food by the process of photosynthesis.
- Fungi **obtain their nutrition from the external source by the process of extracellular digestion** and **absorption of the digested material**.
  Such **mode of nutrition** is called **heterotrophic** and the organisms are called **heterotrophs**.
- Heterotrophic organisms either live on dead decaying organic matter or on living organisms.
- **According to their mode of nutrition**, fungi are of **two types** – **parasites** and **saprophytes**.
- **Parasite** may be defined as "an organism existing in an intimate association with another living organism from which it derives an essential part of the materials for its existence". Thus, these organisms grow on living organisms and obtain their food from it.
- **Parasitic fungi** obtain their food from living hosts.
- These may be :
  - **Ectophytic :** These are externally on the host, e.g., *Erysiphe* (Powdery mildew).
  - **Endophytic :** These are inside the tissue of plants, e.g., *Albugo*, *Phytophthora*, *Alternaria*.
- **Saprotrophs** obtain their food from non-living decaying organic matter (such as bread, meat, fruit, vegetables, animal dung etc.). Such mode of nutrition is called saprophytic.
- Some fungi grow in **symbiotic association with algae to form lichens**. Some other grow in close association with the **roots of higher plants and form mycorrhiza**.
- Fungi posses definite cell wall (containing cellulose or chitin or both *i.e.*, fungus cellulose) and true nucleus (eukaryotic) but lack chlorophyll (achlorophyllous) and differentiation of vascular tissue (*i.e.* non-vascular).
- They are spore forming and **reproduce by vegetative**, **asexual** and **sexual methods**.

- The **reserve food material** is in the form of **glycogen** and **oil globules**.
- Fungi grow well at **20-30ºC** and at **acidic pH** (6.0).
- Fungi may be unicellular (yeast), much branch filamentous (*Rhizopus*) type.
- The filamentous thread like structures that make up the fungal body is called **mycelium**.
- **Hyphae** is the **unit structure that make up** the **mycelium** (gk word *hypha* - web).
- Hyphae are of **two types** – **aseptate** or **coenocytic** (multinucleate) and **septate** (number of partitions or septa).
- Aseptate hyphae may form septa during reproduction, eg *Rhizopus*, *Albugo*, *Phytophthora* etc.
- In septate form cell may be **monokaryotic** (uninucleate) or **dikaryotic** (two nuclei) or **multinucleate**.
- Septa are of **3 types** – **complete septum**, **septum with simple pore** and **septum with dolipore**.
- In **complete septum** the cross wall is complete without distinct pores, e.g., *Geotrichum*.
- In most ascomycetes and deuteromycetes, the **septum possesses simple central pore**. Simple central pore may get plugged by crystalline structure called **woronin body**, e.g., trichomycetes. Woronin body is secreted by microbody and covered by membrane.
- In basidiomycetes, the septum becomes barrel-shaped around a central pore called **dolipore septum**, it may be surrounded by pore cap.
- Septal pores **allow quick transport of nutrients from the region of absorption to all parts of the mycelium**.
- The reproductive hyphae are supplied with the nourishment from the vegetative hyphae throughout the septal pores.
- When mycelium is interwoven to form web like structure it is called **plectenchyma**.
- It is of two types – **prosenchyma** and **pseudoparenchyma**.
- **Prosenchyma** is the mycelium in which hyphae are loosely interwoven and lie more or less parallel to each other.
- **Pseudoparenchyma** is the mycelium in which the hyphae are very loosely packed, so individual hypha cannot be identified and appear as isodiametric cells giving the appearance of parenchyma cells in higher plants.
- When mycelium by interweaving forms compact resting structure it is called **sclerotium**.
- When fungal mycelia are interwoven to form thick cord-like structures like roots, that help in absorption, it is called **rhizomorphs**.
- When the plant body is unicelled at one stage and mycelial at the other end then the organisation is described as **dimorphic**.
- When the entire mycelium is converted into reproductive structure, the thallus is called **holocarpic**.
- In **eucarpic forms** only a part of thallus become reproductive. This can be **monocentric** (have single sporangium) or **polycentric** (have many sporangia).
- The hyphal wall is a made up of **fungal cellulose** in which **cellulose is impregnated with chitin and contains nitrogen in addition to carbon and hydrogen**. **Chitin is a polymer of N-acetyl glucosamine**.
- The protoplast is covered by a thin semipermeable plasma membrane.
- The cytoplasm appear granular and contains many minute nuclei scattered in the peripheral layer.
- The nuclei are very small and inconspicious.
- The cytoplasm contains many small vacuoles filled with cell-sap or a number of small gas filled vacuoles.
- The vacuoles are small, few or absent in the actively growing tips of the mycelium.
- The hypha also may be seen to have mitochondria, dictyosomes (golgi bodies), ribosomes, endoplasmic reticulum, oil drops and glycogen, granules etc. under electron microscope.

Reproduction

- The fungi **reproduce by all the three methods** – **vegetative**, **asexual** and **sexual**.
- **Vegetative reproduction** takes place by various methods as fragmentation, fission, budding, sclerotia, oidia and chlamydospores.
- In **fragmentation**, the hyphae of fungus break into small pieces and each piece may later grow into new mycelium.
- **Fission** is common in yeast. The cell divides into daughter cells which separate by constriction or transverse walls.
- In **budding** daughter bud appears from parent cell. After getting the normal size bud break off. When the buds fail to separate, after repeated budding from pseudomycelium.
- **Oidia** are rounded or oval structure having thin

walls. The hyphae undergo segmentation and produce yeast like cells called oidia. Each oidium on germination produces new mycelium.

- Some fungi produce **chlamydospores** which are thick walled resting cells. They are intercalary in position. They are capable of forming a new plant on approach of favourable conditions.
- **Gemmae** resemble chlamydospores in structure but are not very durable and thick walled.
- Many true fungi produce **sclerotia** which are hardened, resistant bodies. Sclerotia are capable of surviving unfavourable periods and as soon the conditions are favourable, they germinate to produce vegetative hyphae.
- Asexual reproduction takes place by means of **spores**.
- The spores in fungi vary in shape. Spores are usually unicellular, thin walled, spherical and diameter ranging from 5-50 m.
- Several types of spores are reported in fungi, eg. zoospores, sporangiospores, uredospores, teleutospores, pycniospores etc.
- Sometimes the spores are produced endogenously in special sac- like asexual reproductive bodies called **sporangia**.
- Spores in such cases are called **sporangiospores**.
- **Zoospores** are uninucleate, thin walled, formed in zoosporangia. They may be **uniflagellate**, *e.g.*, *Synchytrium* or **biflagellate**, *e.g.*, *Saprolegnia*, *Pythium*.
- Biflagellate zoospores are of **two types** –
  - **Pear-shaped** or pyriform, with 2 flagella placed at anterior end, are known as primary zoospores.
  - **Kidney-shaped** or bean-shaped, bearing two oppositely directed flagella inserted laterally in a furrow or concave side (secondary zoospores).
- **Aplanospores** are **thin walled**, **non-motile** spores formed inside sporangium, which **give rise to new mycelium**, *e.g.*, *Rhizopus*, *Mucor*.
- **Conidia** are non-motile, thin walled **exogenously** produced spores on a condiophore and sometimes they are arranged in chains upon the conidiophore, *e.g.*, *Aspergillus* and *Penicillium* or singly in *Pythium*, *Phytophthora*.
- Hyphae bearing conidia are called **conidiophores**.
- The conidiophores in groups may form structures like acervuli, synnemata etc.
- **Pycniospores** are small conidia-like bodies produced in flask-shaped cavities called the pycnia, *e.g.*, *Puccinia*.
- **Ascospores** are uninucleate, unicellular non-motile, usually eight in number produced in sac-like structures called ascus, characteristic of ascomycetes.
- **Basidiospores** are characteristic of basidiomycetes, produced exogenously by club-shaped basidium or sterigma. Usually four basidiospores are produced.
- **Uredospores and teleutospores** are binucleate spores produced in clusters called **uredosori**.
- **Sexual reproduction** in fungi **involves three process** – **plasmogamy** (fusion of protoplast), **karyogamy** (fusion of two haploid nuclei) and **meiosis**.
- Fungi may be dioecious or unisexual some are monoecious or bisexual. Former are heterothallic and latter are homothallic.
- Fungi generally possess **unicellular sex organs** and show **gradual degeneration of sexes**.
- **Male gametangia** is called **antheridium.** It is **smaller in size**.
- **Female gametangia** is called **oogonium** which are comparatively **larger in size**.
- The gametes are formed within gametangium.
- All three types of sexual reproduction is present in fungi as isogamy, anisogamy, oogamy.
- In **isogamy** fusing gametes are exactly alike in appearance and functions.
- Fusion of dissimilar gametes is called **anisogamy**. In anisogamous forms both fusing male and female gametes are usually motile.
- Fusion of male gamete with female gamete is called **oogamy**.
- In **gametangial contact** the two gametangia come close to each other, but do not fuse. The male gametangium sends a tubular outgrowth, called fertilization tube, through which the non-motile male gamete or male nucleus migrates into the female gametangium. Eg. *Phytophthora, Albugo*.
- In **gametangial copulation** two gametangia fuse with each other and lose their identity in the sexual act resulting in the formation of zygospore. Eg. *Mucor, Rhizopus*.
- In **spermatization** some fungi produce numerous, minute, uninucleate, spore-like

bodies called **spermatia**. These are transferred through various agencies to **receptive hyphae** or **trichogyne** of female gametangium. Finally the contents of spermatium is transferred into receptive hypha through a pore. Eg- *Puccinia graminis*.

- In **somatogamy**, the sex organs are not formed and the fusion occurs between two vegetative or somatic cells resulting **dikaryotization**. Eg. *Agaricus*.
- **Homothallism** is the condition whereby thalli are morphologically and physiologically identical. So that fusion can occur between gametes produce on the same thallus.
- **Heterothallism** is the phenomenon in which the fusing gametes belong to two genetically distinct strains of the some species though there may not be any morphological distinction between the gametes or structures bearing them. It was first **discovered by Blakeslee** in 1904.

Blakeslee found that in *Mucor* and *Rhizopus*, certain strains formed zygospores even in pure cultures where different mycelia belongs to the same genetic strain, eg. *Rhizopus sexualis*.
Heterothallism is a mechanism to perform outbreeding and prevent inbreeding. As it involves sexual reproduction between genetically different strains, the product of sexual reproduction comes to have different alleles and different genes linkages. It introduces variations that are helpful in adapting to diverse habitats, unfavourable environments and toxic chemicals.

Classification of fungi

- Fungi are divided into **4-classes**, according to the septation of the mycelium and on the basis of characteristic features of reproduction – **phycomycetes**, **ascomycetes**, **basidiomycetes**, **deuteromycetes** (*Refer table given below*).

Phycomycetes

- **Phycomycetes** are algae like fungi.
- Hyphae of phycomycetes are **coenocytic** and **non septate**.
- Phycomycetes are **entirely aquatic** and **known as water moulds**.
- Phycomycetes are the **most primitive true fungi**.
- In phycomycetes, reproduction takes place by both **sexual** and **asexual methods**.
- Asexual reproduction **takes place by spores**.
- Motile spores are called **zoospores** and non-motile spores are called **aplanospores**.
- **Chlamydospores** are those thick walled resting spores which are formed on the hyphae of some lower fungi.
- Two types of flagella are present in phycomycetes, these are **whiplash** and **tinsel type**.
- Sexual reproduction in phycomycetes takes place by **planogametic copulation**, **gametangial contact** (or **gametangial copulation**.)
- The **most common examples of phycomycetes** are *Saprolenia, Rhizopus, Mucor* etc.

Table : Classification of fungi

Features	Phycomycetes	Ascomycetes	Basidiomycetes	Deuteromycetes
Common name	Algae like fungi	Sac fungi	Club fungi	Fungi imperfecti
Mycelium	Aseptate, coenocytic	Septate, branched unicellular	Secondary, mycelium, dikaryotic	Branched, septate mycelium
Asexual reproduction	Zoospores, aplanospores, chlamydospores, sporangiospore	Conidia, budding	Oidia, basidiospores	Conidia
Sexual reproduction	Isogamy, oogamy	Fusion of compatible nuclei. Ascospores formed in ascus	Somatogamy, Basidiospores formed on sterigmata	Absent or not known
Fruiting body	Zygospore	Ascocarp (cleistothecium, perithecium, apothecium)	Basidiocarp	Absent

Ascomycetes

- Ascomycetes are commonly called as **sac fungi**.
- Ascomycetes are characterised by **well developed thallus** and **production of ascospores**.
- Cell in ascomycetes are **uninucleate** or **multinucleate**.
- Mycelium of ascomycetes are **branched and septate except in** Yeast.
- Yeast is **unicellular** ascomycetes.
- **Ascospores** are formed inside the ascus during sexual reproduction.
- The typical number of ascospores in an ascus is **eight**.
- **No flagellated cells** are found in ascomycetes.
- Asexual reproduction may take place by **budding**, **fission**, **fragmentation**, **oidia**, **conidia formation** etc.
- Sexual reproduction takes place by **plasmogamy** which may be **isogamous** or **heterogamous**.
- Fruiting body of ascomycetes is **ascocarp**.
- Ascocarp may be **cleistothecium** (globose having no natural opening), **perithecium** (globose having one apical opening) or **apothecium** (saucer shaped).
- The **most common examples** of ascomycetes are *Penicillium, Neurospora, Yeast* etc.

Basidiomycetes

- Basidiomycetes are **commonly called as club fungi**.
- Basidiomycetes resembles the ascomycetes in having a **septate mycelium** and **production of non-motile spores**.
- **Dikaryotization** or **diplodization** is the process by which binucleated condition is attained from uninucleated conditions.
- Basidiomycetes have a **short lived uninucleate stage** and a **dominant binucleate stage**.
- Cells of basidiomycetes are made up of **chitin-mannan**.
- Basidiomycetes are characterised by the **dolipore septa and clamp connections** (a hook like clamp is formed which help in passage of nuclei) in the mycelium.
- Basidiospores are **formed over the basidium during sexual reproduction**.
- Fruiting body of basidiomycetes is known as **basidiocarp**.
- **Asexual reproduction** occurs by **fragmentation**, by means of spores such as **conidia**, **oidia**, **arthrospores etc.**
- **No specialised sex organs** are present in basidiomycetes.
- The **life cycle** of basidiomycetes **consists of** three clear and distinguishable phase. These are **plasmogamy, karyogamy** and **meiosis**.
- Common basidiomycetes are *Ustilago, Puccinia Agaricus, Polyporus* etc.

Deuteromycetes

- Deuteromycetes is an **artificial group without any common relationship**.
- Deuteromycetes are commonly called as **fungi imperfecti** due to the absence of perfect sexual stage.
- Deuteromycetes have **septate hyphae** and **reproduce asexually by means of conidia**.
- Beside conidia **thallospores** are – also found in some fungi imperfecti.
- Two types of thallospores are – **chlamydospores** and **arthrospores**.
- Common deuteromycetes are *Cercospora, Collectotrichum, Pyricularia, Fusarium*.

Harmful and beneficial aspects of fungi

- Some fungi are **used as delicious food**. The fructifications of certain fungi are used as nutritious and delicious foods, *e.g.*, *Agaricus bisporus* and *A. campestris* (mushrooms). *Morchella* and *Lycoperdon*, *Clavatia*, *Pleurotus*, *Volvaria*, *Volvariella*, etc., are also edible fungi.
- Yeast is an **important source of vitamin B and D**. *Saccharomyces*, *Endomyces*, *Rhodotorula*, *Torulopsis* are **rich in proteins**.
- A food called '**Sufu**' is produced from *Mucor* and antimucor.
- Fungi are used in the **production of different antibiotics** (substances of microbial origin and having antimicrobial activites).
- In **alcoholic industry** yeast (*Saccharomyces*) is used for **fermentation**.
- In **baking industry** CO_2 evolved raises '**dough**'.
- **Enzymes** like **taka diastase**, **digestin** and **polyzime** are produced from *Aspergillus flavus-oryzae* series.
- **Invertase** is prepared from *Saccharomyces cerevisiae*, **amylase** from *Aspergillus oryzae*, **zymase** from yeast (*Saccharomyces cerevisiae*)
- *Penicillium camemberti* and *P. roqueforti* are **used for flavouring cheese**.

- **Various organic acids** are obtained from fungi, ***e.g.*, citric acid** by *Aspergillus niger* and *A. wentii*, *Mucor*, etc, **gluconic acid** by *Aspergillus niger* and *Penicillium purpurogenum*; **gallic acid** by *P. glaucum* and *A. gallomyces*; **kojic acid** by *A. oryzae*; **fumaric acid** by *Rhizopus stolonifer*.
- **Gibberellic acid** is obtained from a fungus *Fusarium moniliforme* (*Gibberella fujikuroi*).
- **Fungus** widely **used in genetic engineering** is *Neurospora crassa*. While working on *Neurospora crassa*, Beadle and Tatum (1941) proposed **one gene one enzyme hypothesis** and received Nobel prize in 1958.
- *Aspergillus niger* is widely used to **determine available copper, magnesium, potassium and molybdenum in the soil**.
- Saprophytic fungi live upon dead organic matter and thus break down complex substances into simple ones, which are again absorbed by plants has increasing soil fertility.
- Soil inhabiting fungus *Trichoderma* kills *Pythium* fungus (root rot fungus). Similarly *Penicillium vermiculatum* checks *Rhizoctonia solani*.
- **Predacious fungi** like *Dactyllela, Dactylaria, Zoophagus* and *Arthrobotrys*, etc.,destroy certain nematodes, eelworms, etc., causing plant diseases.
- They help in absorption of **water and nutrients** and in turn get ready-made food (symbiosis).
- *Absidia*, *Aspergillus*, *Cladosporium*, *Mucor*, *Penicillium* and *Rhizopus* have soil binding property (by mucilage) and they make the soil good.
- Many **insect pests** can be controlled by use of fungi like *Aschersonia aleyroides*, *Isoria ferinosa*, *Empusa*, etc.
- Few fungi like *Saccharomyces, Rhodotorula* **fix-atmospheric nitrogen in soil**.
- Fungi is the **causative organism** of many diseases in plants, animals as well as in **humans**.
- *Claviceps purpurea* causes **ergotism** and also yield a hallucinogenic drug called **LSD**.
- The potato crop was destroyed in Ireland in the middle of 19th century due to infection of *Phytophthora*.

Diseases associated with fungi

Plant diseases:

- Black wart disease of potato– *Synchytrium endobioticum*.
- White rust of crucifers– *Albugo candida or Cystopus candidus*.
- Late blight of potato– *Phytophthora infestans*. (Famous famine of Ireland (1845) is associated with this disease which caused death of lakhs of people).
- Early blight of potato– *Alternaria solani*.
- Powdery mildews– *Erysiphe* sps.
- Damping of seedling– *Pythium* sps.
- Loose smut of wheat– *Ustilago tritici*.
- Black rust of wheat– *Puccinia graminis-tritici*.
- Apple scab– *Venturia inaequalis*.
- Downy mildews– *Peronospora* sps.
- Red rot of sugar cane– *Colletotrichum falcatum*
- Tikka disease of groundnut– *Cercospora* sps.
- Stem gall of coriander– *Protomyces* sps.
- Wilt of arhar– *Fusarium* sps..
- Leaf rust of coffee– *Haemelia vastatrix*.
- Blast disease of rice– *Pyricularia oryzae*.
- Green ear disease of bajra– *Sclerospora graminicola*.
- Flag smut of wheat– *Urocystis tritici*.
- Maize smut– *Ustilago maydis*.
- Loose smut of oat– *Ustilago avenae*.
- Covered smut of oat– *Ustilago kolleri*.
- Covered smut of jowar (*Sorghum*)– *Sphacelotheca sorghii*. (Severe famine of Bengal (1943) which caused death of a large number of people was due to this disease).

Human diseases:

- Aspergillosis (lung disease)– *Aspergillus niger*, *A. flavus, A. fumigatus*.
- Ring worm– *Trichophyton*, *Microsporum*.
- Neuritis (Infection of nervous system)– *Mucor pusillus*.
- Mental disorder (Cryptococcosis)– *Lipomyces neoformans*.
- Ear infection (Automycosis)– *Aspergillus flavus, A. nidulans*.
- Thrush disease of throat– *Monilia*

Animal diseases:

- Athlete foot– *Tinea rubrum*.
- Ringworm– *Trichophyton, Microsporum, Epidermophyton*.
- Mucomycosis– *Mucor, Rhizopus*.
- Aspergillosis– *Aspergillus*.
- Penicillosis– *Penicillium*.

- *Boletus* and *Amanita* spp.are **poisonous fungi**.
- The **fungus that produces latex** is *Mycena*.
- *Mucor*, *Rhizopus*, *Penicillium*, *Neurospora*, *Amanita*, *Polyporus* are commonly called as **pin bread mould**, **bread mould**, **green mould**, **pink bread mould**, **toad stools and brackett fungi** respectively.
- Spores of *Rhizopus*, *Mucor*, *Aspergillus* germinate on jam, jellies, pickles, bread, etc., and destroy them, *Penicillium*, *Mucor* and *Aspergillus* destroy meat.
- *Polyporus* (Pore fungi) causes **wood rot**.
- *Alternaria, Penicillium, Trichoderma, Mucor, Chaetonium, Cephalothecium* and *Fusarium* destroy leather, cloth, rubber, paper, camera lenses, etc.
- **Aflatoxins** are **mycotoxins** (harmful secretion) produced by *Aspergillus flavus, A. fumigatus*, *Penicillium islandicum*, etc.
- These **bind with DNA** and **prevent transcription**, hence protein synthesis. These **cause liver cancer in animals and men**.
- In **VAM** the hyphae develop an arbuscule (penetrate) within the cortex of root. It **helps mainly in phosphate absorption from the soil**.

LICHENS

- Lichens are formed by a **symbiotic relationship between algae** or **cyanobacteria and fungi**, in which individual photobiont cells are embedded in a complex of fungal tissue.
- The number of lichen genera is 400 and species over 15,000.
- The study of lichens is called **lichenology**.
- Body of the lichen is made of a fungus partner called **mycobiont** and a photosynthetic algal partner called **photobiont** or **phycobiont**.
- In 98% of the lichens, the mycobiont or fungal partners belong to ascomycetes. Few lichen shows basidiomycetes fungal partner also.
- Photobionts or phycobionts **either belongs to cyanobacteria or green algae**.
- **Photobiont performs** photosynthesis, nitrogen fixation and elaborates vitamins and other growth substances while **mycobiont takes part in** protective covering body, attachment, absorption and retention of moisture from dew, rain and wet air, and protection against harmful radiations.

History of Lichen

– The term lichen was first given by **Theophrastus** for superficial growth on bark of *Olea europea* (olive) tree.
– **Morisson** (1699) called lichen as musco-fungus.
– **Schwendiner** (1867) gave **dual hypothesis** and established the composite nature of lichen. He defined lichen as 'fungi parasitizing algae'.
– **Bonnier** (1886 - 89) successfully synthesized a lichen by growing fungal spores with algae.
– **Reininke** (1872) gave the term **'Consortium'** for the association of algae and fungi. The term means mutual growth and interdependence. **De Bary (1879)** termed this association as symbiosis.
– **Crombic (1885)** gave the term **helotism** *i.e.* master and slave relationship to the algal and fungal association in lichen. Helotism is the most accepted term used now a days to describe this relationship.

- Algae are present on the **upper part** of thallus and fungi are present on the **lower part** of thallus.
- Fungal partner provides **protection to algal** partner and are also **responsible for the sexual reproduction**.
- Such a mutually beneficial relationship is called symbiosis or mutualism.
- For proper diffusion of nutrients the algal cells and fungal hyphal tips become surrounded by common extracellular substance.
- At times, the mycobiont send haustoria into algal cells, prevent alga to secrete pectic substances or induces alga to secrete nutrients.
- Consequently, fungus is considered to be controlled parasite. The phenomenon of **controlled parasitism** is called **helotism**.
- As algae and fungi both contain **cell wall** which is the characteristic feature of plant cell, **so lichens are considered as plants**.
- About **12 genera** of cyanobacteria and **21 genera** of green algae are considered as lichen symbiont.
- Important **cyanobacteria** are *Nostoc*, *Gloeocapsa* and *Rivularia*.
- **Green algae** symbiont involves *Protococcus*, *Trentepohlia*, *Cladophora* and *Trebauxia*.

- Lichens generally grow on **old walls, roof of house, trunk of trees** or **exposed rocks**.
- Lichen like *Usnea* hangs from the smaller branches of trees.
- Lichen can withstand extreme of cold, heat and drought.
- They are dominant form of vegetation in alpine and arctic tundras.

Reproduction

- **Reproduction** may be vegetative, asexual or sexual.
- **Vegatative reproduction occurs** by –
  - **Fragmentation** – When thallus break into small fragments develop into new lichen thalli.
  - **Soredia** – Soredia are small masses of hyphae enclosing a few algal cells. Soredia are dispersed by air currents. Each soredium develops into a new thallus.
  - **Isidia** – They are **superficial outgrowths** from the upper surface of the thallus. Isidia consist of an external cortical layer and an internal algal layer.
- **Asexual reproduction**
  - In some lichens pycnidiospores are produced at tips of fertile hyphae inside pycnidium which is a flask shaped structure, opening through a pore called ostiole.
  - These spores germinates to produce a fungi mycelium.
  - The fungal mycelium with corresponding alga form new lichen thallus.
- **Sexual reproduction**
  - It is **performed** mainly by its **fungal component**.
  - Most of the lichens belong to the division ascolichens, in which the fungal partners belong to ascomycetes.
  - The male reproductive organ is flask shaped **spermogonium** which produces non-motile male gametes or **spermatia**.
  - The female reproductive organ is **carpogonium** which is differentiated into basal coiled **ascogonium** and upper long tube like **trichogyne**.
  - The **fruiting body ascocarp** formed after fertilization may be a **apothecium** type or **perithecium** type.
  - The bottom of ascocarp is lined by **hymenium** which consists of asci in spread with paraphysis. The wall of ascocarp (apothecium or perithecium) is composed of the vegetative part of the thallus consisting of algal and fungal layers.
  - Each ascus contains eight ascospores which germinate and form fungal mycelia.
  - The mycelium when comes in contact with a suitable alga, forms new lichen thallus.

Classification of lichens

- **On the basis of their fungal partner** the lichens are divided in **two groups** –
  - **Ascolichens** – Fungal partners belongs to ascomycetes. Gymnocarpae, fruiting body is apothecium type. Pyrenocarpae, fruiting body is perithecium type.
  - **Basidiolichens** – Fungal partners belongs to basidiomycetes.
- **On the basis of habitat** lichens are –
  - **Saxicolous** : Rock-dwellers and adapted to xerophytic adaptation, eg. *Xanthoria*.
  - **Corticolous** : Bark-dwellers and grows in adaptation of plenty of moisture, eg. *Parmelia*.
  - **Terricolous** : Terrestrial species and thus grows in soil, eg. *Cladonia floerkeana*.
  - **Lignicolous** : Lichens which grow on wood directly, eg. *Cyphelleum*.
- **On the basis of thallus** lichens may be –
  - **Leprose lichens** – The lichens are in the form of minute scales, attached superficially over the substratum, e.g. *Lepraria incana*.
  - **Crustose** – Lichens are crust-like, closely attached to substratum due to adhesion at several points, eg. *Graphis, Rhizocarpon*.
  - **Foliose** – Lichen body is like a crinkled and twisted leaf, *ie*. flat, branched or lobed. It is attached to substratum by one or a few points, eg. *Parmelia, Peltigera*.
  - **Fruticose** – The lichen shows branched, erect or pendulous with bushy appearance, An attaching disc is present at the base, eg. *Ramalina, Cladonia, Usnea*.
  - **Filamentous** – The photosynthetic partner is well developed and filamentous. It is covered by a few fungal hyphae, eg., *Racodium*.
- **On the basis of distribution of algal component in the thallus** lichens are of **two types** –
  - **Homoisomerous thalli** – Algal cells and fungal hyphae are uniformly dispersed throughout the thallus, eg. *Collema*.

– **Heteromerous thalli** – The algal cells are found in algal zone only. The bulk of lichen body is formed by fungal partner (mycobiont). It includes the surface, medulla and rhizinae. The algal constituents hardly 5% of the lichen body, eg *Parmelia*.

Economic importance of lichens

- Fresh water species of lichen is *Hymenelia lacustris* and marine water species is *Caloplaca marina*.
- *Cladonia rengiferina*, commonly called as **reindeer moss**, is an **important source of food for reindeer**.
- *Cetraria islandica*, commonly called **iceland moss** is **used as source of food of sheep, cattle as well as human**.
- *Everina* **used for making bread**, *Lecanora* is also edible.
- Lichen *Evernia prunastri* **yields an excellent perfume**.
- *Roccella, Parmelia, Evernia* etc. are **dye yielding** (**orchil**) lichen species.
- **Litmus** is **obtained from** lichen *Roccella montaignei*.
- Medicinal property of lichen is due to a substance **lichein**.
- **Usnic acid**, an important broad spectrum antibiotic, **is obtained from** *Usnea* and *Cladonia*.
- *Xanthoria parietina* is used against **jaundice**.
- *Peltigera canina* is used against **hydrophobia**.
- *Cetraria* is used as **laxative**.
- The **protolichesterinic acid**, obtained from some lichen like *Cetraria icelandica*, has anticarcinogenic properties.
- Lichens **serve as indicator of air pollution**, as they are very sensitive to air pollution, especially SO_2 pollution.
- **Crustose lichens** are pioneers in xerosere (succession beginning in dry condition).
- In **Russia** and **Sweden**, some lichens like *Cetraria* and *Lecanora* are used for **alcoholic fermentation**.
- Lichens secrete some organic acids which break down rocks and thus help in soil formation.
- Some lichens are **poisonous also due to various substance present in them** as :

Lichen	**Poisonous due to**
Letharia Vulpina	Vulpinic acid
Cetraria juniperina	Pinastrinic acid
Parmelia molluscula	Selenium
Xanthoria parietina	Beryllium
Everina fur furcea	Chlorine

MYCORRHIZA

- Mycorrhiza is symbiotic relationship between fungi and roots of higher plants.
- They are thick, irregular with wooly covering devoid of root hair and root cap.
- In a **mycorrhizal association**, the fungus may colonize the roots of a host plant either intracellularly or extracellularly.
- This mutualistic association provides the fungus with a renewable source of food through access to fixed carbon (sugars) from the plant photosynthate.
- These are translocated to the root tissues from their source location (usually leaves), and then to the fungal partners. In return, the plant gains the use of the mycelium's tremendous surface area to absorb mineral nutrients from the soil.
- The **mycelia of mycorrhizal networks have better mineral absorption capabilities** compared to plant roots.
- Mycorrhizal plants are often **more resistant to diseases**, such as those caused by microbial soil-borne pathogens, and are **also more resistant to the effects of drought**, perhaps due to the improved water uptake capability of the fungal hyphae.

Types of mycorhizza

- The two most common types of mycorrhizas are – the **ectomycorrhizas** and **endomycorrhizas** (more commonly known as **arbuscular mycorrhizas**).
- The **two groups are differentiated by the fact that** the **hyphae of ectomycorrhizal fungi do not penetrate the cell wall** of the plant's root cells, while the **hyphae of arbuscular mycorrhizal fungi penetrate the cell wall**.

Ectomycorrhizae

- Ectomycorrhizas, typically form between the roots of woody plants and fungi belonging to the divisions basidiomycota, ascomycota, or zygomycota.
- These are **external mycorrhizae** that form a cover on root surfaces and between the root's cortical cells.
- Besides the mantle formed by the mycorrhizae, most of the biomass of the fungus is found branching into the soil, with some extending to the apoplast, stopping short of the endodermis.

- These are found in 10% of plant families, mostly the woody species, including the Oak, Pine, *Eucalyptus*, *Dipterocarp*, and olive families.

Endomycorrhizae

- Arbuscular mycorrhizas, or VAM (formerly known as **Vesicular-Arbuscular Mycorrhizas**) involves entry of the hyphae into the plant cell walls to produce structures that are either balloon-like (vesicles) or dichotomously – branching invaginations (arbuscules).
- In VAM the hyphae develop an arbuscule (penetrate) within the cortex of root. It helps mainly in **phosphate absorption** from the soil.
- The fungus is generally a zygomycetes.
- The fungal hyphae do not in fact penetrate the protoplast (*i.e.* the interior of the cell), but invaginate the cell membrane.
- The structure of the arbuscules greatly **increases the contact surface area between the hypha and the cell cytoplasm to facilitate the transfer of nutrients between them**.
- Arbuscular mycorrhizas are **formed only by fungi** in the division glomeromycota, which are typically associated with the roots of herbaceous plants, but may also be associated with woody plants.
- Arbuscular mycorrhizas are likely to be very helpful in protecting plants from adverse conditions such as lack of water and nutrients.
- Arbuscular mycorrhizal fungi are quite extraordinary organisms. First they have been asexual for many million years and secondly, individuals can contain many genetically different nuclei (a phenomenon called **heterokaryosis**).
- This type of association is found in 85% of all plant families in the wild, including many crop species such as the grains.

[*For more on mycorrhiza refer chapter Pesticides and Biofertilizers*]

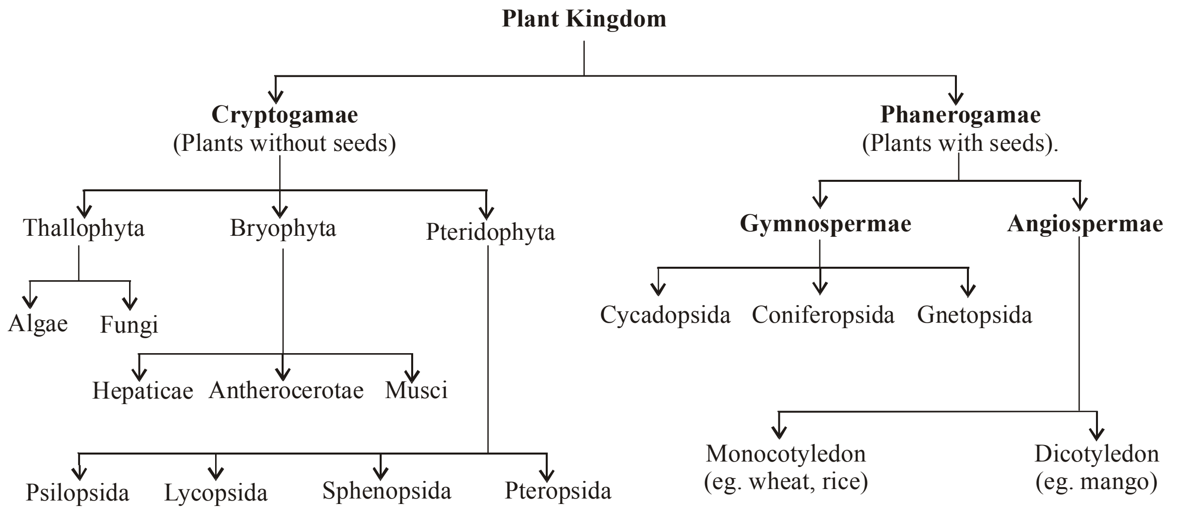
End of the Chapter

Chapter 6

Plant Classification

- **Plant classification** is arrangement of plants into groups and subgroups on the basis of affinities.
- In the two kingdom classification, plants comprise all the photoautotrophic organisms and their non photosynthetic relatives which have absorptive type of nutrition, a wall around the cells and all groups of algae, besides the embryophytes.
- In five kingdom classification, **plant kingdom** comprises only embryophytes and some eukaryotic algae.
- Bacteria, blue green algae, euglenoids, diatoms, dinoflagellates and fungi are excluded.
- **Kingdom Plantae** includes all multicellular, eukaryotic, photosynthetic organisms.
- **Main characters of this kingdom** are –
  - With definite cellulosic cell wall.
  - These are basically non-motile, excepting some aquatic forms.
  - Reproduction is primarily sexual.
  - Presence of definite chloroplasts
  - Photosynthetic mode of nutrition (oxygenic photosynthesis), eg. different types of algae (green, brown, red algae), bryophytes, pteridophytes, gymnosperms and angiosperms.
- In traditional system of classification (Eichler, 1883), plant kingdom is **divided into two subkingdoms** – **cryptogamae** and **phanerogamae**.
- Plants included under cryptogamae are called **cryptogams** while those placed in phanerogamae are known as **phanerogams.**
- **Cryptogams** (Gk. *cryptos* – hidden, *gamos*-marriage) do not bear conspicious reproductive structures like seeds. Therefore, they are called **lower plants or seedless plants**.
- Cryptogams have **three divisions** – **thallophyta**, **bryophyta** and **pteridophyta**.
- **Thallophyta**
  - Plant body not differentiated into root, stem and leaves.
  - They do not have well developed conducting tissues.
  - Sex organs are simple.
  - Thallophyta includes – algae, fungi.
  - **Algae** : Green, autotrophic thallophytes, *e.g. Spirogyra*, *Ulothrix*. etc.
  - **Fungi** : Non-green (achlorophyllous) thallophytes having heterotrophic mode of nutrition, *e.g. Albugo*, *Mucor*, yeast etc. [*Discussed under Fungi chapter*]
- **Bryophyta**
  - Plant body gametophytic, thalloid or foliose.
  - Rhizoids present instead of roots.
  - Conducting tissues absent or represented by thick walled cell. (eg. *Funaria*).
  - Sex organs are multicellular and jacketed.
- **Pteridophytes**
  - Plant body sporophytic, differentiated into root, stem and leaves.
  - Xylem and phloem are conductive tissues hence called **vascular cryptogams**.
  - Reproduce by spores.
  - Sex organs are like those of bryophytes.
  - Embryo is always present.
  - Sporophytic and gametophytic phases are morphologically distinct.
  - Show regular alternation of generation.
- **Phanerogams** (Gk, *phaneros*-visible, *gamos*-marriage) have evident reproductive structure in the form of seeds. Therefore, they are called as **seed bearing plants**.
- Phanerogams have **two divisions** – **gymnosperms** and **angiosperms**.

- **Gymnosperms**
  - Plants having naked ovule in surface of megasporophyll.
  - Flowers-unisexual cone.
  - They are called as phanerogams without ovary.
- **Angiosperms**
  - They are advanced phanerogams
  - Have distinct unisexual or bisexual flowers.
  - Ovules (seeds) are enclosed without ovary wall (fruit wall).
  - The fruit formed as a result of fertilization.
- Angiosperms are divided into **two classes** –
  - **Monocotyledonae** : It is a class of angiosperm having only one cotyledon, eg wheat, rice.
  - **Dicotyledonae** : It is a class of angiosperms having two cotyledons, eg mango.



Flow chart : Classification proposed by A.W. Eichler.

End of the Chapter

Chapter 7

Algae

- The word **algae** was coined by **Linnaeus** (1753).
- The branch of botany dealing with the study of algae is called as **phycology** or **algology**.
- Term phycology is derived from the Greek word *phykos* which means 'alga' or "sea weed".
- Algae are defined as **chlorophyllous**, **thalloid**, **avascular plants with no cellular differentiation**.
- A plant body that is not differentiated into a root stem and leaf is known as **thallus**.
- Algae contains about **18,000 genera** and **29,000 species.**
- Structure and reproduction of algae was written by **Fritsch**. He is known as **Father of algae**.
- Fritsch **divided algae into 11 classes** on the basis of **type of pigments**, **nature of reserve food material** and **mode of reproduction**.

Table : The distinctive features of the major 11 classes of algae

	Class	**Major photosynthetic pigments**	**Reserve food material**	**Number of flagella & their arrangements**
1.	Chlorophyceae	Chl. a & β + carotenoids and xanthophyll	True starch and sugar	Vegetative or gamete cells with two or four equal flagella
2.	Xanthophyceae	Xanthophylls & β-carotenes +Chl. a & e	Oil or leucosin	Two flagella of unequal length
3.	Chrysophyceae	carotene, fucoxanthin, lutein + Chl. a	Leucosin, rarely oil	Flagella when present one or three
4.	Bacillariophyceae	Diatoxanthin, diadinoxanthin, fucoxanthin + Chl. a & c	Oil, volutin	Flagella absent
5.	Cryptophyceae	Chl. a and c, carotenes, xanthophylls	Starch	Two unequal flagella at interior end
6.	Dinophyceae	Chl. a & c, xanthophylls (diadinoxanthin, dinoxanthin)	Oil & starch	Flagella two, lateral in position
7.	Chloromonadineae	Chlorophylls, xanthophylls	Fatty substance or oil	Flagella two, apical or subapical
8.	Euglenophyceae	Chl. a & b, carotenes	Paramylum a starch-like substance but negative to iodine test	Number variable in *Euglena*
9.	Phaeophyceae	Fucoxanthin, flavoxanthin β-carotenes + Chl. a and c	Laminarin, mannitol	In gametes flagella two, unequal and lateral in position
10.	Rhodophyceae	Phycoerythrins + Phycocyanin + Chl. a and d	Floridean starch	Absent
11.	Cyanophyceae	Phycocyanin, Phycoerythrin & chlorophyll	Cyanophycean starch	Absent

Habitat - or **occurrence of Algae**

- Found in mud - eg *Chara*.
- Found at the banks of lakes or ponds - eg *Rivularia* or *Spirogyra*.
- Found in high temperature - *Oscillatoria brewis*
- Found in very low temperature - In snow, providing different colours to snow are –
  - (i) Red snow – It caused by *Chlamydomonas nivalis* (haematochrome pigments present)
  - (ii) Green snow - *Withyellow stonensis*
  - (iii) Black snow - *Scofiella nivalis*
- Epiphytic algae - *Oedogonium*, *Bulbochaete*
- Epizoic algae - *Chladophora* or snail
- Endozoic algae - *Zoochlorella*
- Parasitic - *Cephaleurous virescens*
- Terrestrial - *Fritschiella tuberosa*
- Cryptophytic - *Nostoc*
- Marine - *Fucus*, *Laminaria*
- Halophytic - *Chlamydomonas ehrenbergii*
- Symbiotic - Blue green algae in lichens.

General characters

- Algae are mostly found in **fresh water** as well as **salt water.**
- The plant body is a simple thallus consisting of **parenchymatous cells** or tissues. (*Given in flowchart*).
- **Filamentous form** may be branched or unbranched, free floating or attached to the substratum.
- The cell which is attached to the substratum is called **holdfast**.
- The body of multicellular algae ranges from **small colonial** (*Volvox*) to largest like *Macrocystis* having length of several hundred feet.
- The cell wall is usually made up of **cellulose**.
- The reserve food material is in the form of **starch** mainly.
- Large marine algae are generally known as **sea weeds** or **kelps**.
- Algae lack **vascular differentiation**.
- Sex organs are usually **unicellular and non jacketed**.
- **Dominant plant phase** in algae is **gametophyte**.
- Sporophytic and gametophytic stages are **independent**.
- Most of the algae are **autotrophic**.
- The shape of chloroplast is variable in different algae. These are **cup shaped** in *Volvox*, **girdle shaped** in *Ulothrix*, **ribbon shaped** in *Spirogyra*, **reticulate** in *Oedogonium* and **stillate** in *Zygnema*.
- All kinds of reproduction **vegetative, asexual** and **sexual reproduction** are found in algae.
- Vegetative reproduction occurs through **fragmentation** and **fission**, **hormogonia**, **tubers**, **buds** etc.

Range of vegetative thallus

- **Unicellular**
  - Motile (movement by flagella)
    - Chlorophyceae (equal flagella)
    - Dinophyceae & Xanthophyceae (Unequal flagella)
    - Euglenophyceae (Single flagellum at the anterior end)
  - Non motile (absence of flagella) eg. Cyanophyceae
- **Multicellular**
  - Colonial
    - Coenobial (*Volvox*, *Hydrodictyon*)
    - Palmelloid (*Tetraspora*)
    - Dendroid (*Chrysodendroin*)
    - Rhizopodial (*Chrysidiastrum*)
  - Filamentous
    - Unbranched
      - Free floating (*Spirogyra*)
      - Attached to substratum (*Ulothrix*)
      - Colonial (*Nostoc*)
    - Branched
      - Heterotrichous (*Fritschiella*)
      - Pseudoparenchymatous (*Polysiphonia*)
      - Siphonaceous (*Vaucheria*)
      - Parenchymatous (*Ulva, Fucus*)

- Asexual reproduction occurs through **zoospores, hypnospores**, **akinetes**, **endospores** or **cysts** etc.
- Asexual reproduction occurs in **favourable condition** (by mitospores).
- Under **unfavourable conditions** algae **reproduce sexually**.
- Depending upon the **size of gametes** the **sexual reproduction is of two types - isogamous** and **heterogamous** (anisogamous, oogamous).
- **Isogamy** occurs commonly in unicellular algae, e.g. *Ulothrix*. Here the male and female gametes are **morphologically similar but differ in physiology**.
- **Anisogamy** is the fusion of gametes where male gametes are comparatively smaller in size and more active than female gametes which are larger and sluggish, *e.g. Chlamydomonas brausii*.
- **Oogamy** is the **most advanced type** of sexual reproduction. Here the **male gametes** are **motile** and formed in large numbers whereas **female gametes** are **non-motile** and **bigger in size**.
- Male gametes are produced in **antheridium** whereas female gametes are produced in **oogonium**.
- Some special complex type of reproductive bodies found in Rhodophyceae are called **spermatium** and **carpogonium**.
- **Water** is the **suitable medium for the fusion of gametes** during sexual reproduction.
- Fusion of male and female gametes occur and zygote is formed.

Salient features of some selected classes

Chlorophyceae (green algae)

- Plants fresh water or marine
- The structure is various - unicellular motile (*Chlamydomonas*) non-motile (*Chlorella*), colonial (*Volvox*, *Hydrodictyon*), parenchymatous (*Ulva*), coenocytic (*Volvox*)
- Cell wall is composed of cellulose.
- Chief pigments – chlorophyll a, b, α, β, γ – carotenes, lycopene, lutein, galaxanthin.
- **Reserve food – starch and oils**.
- Asexual reproduction by zoospores, aplanospores and hypnospores.
- Male gamete flagellate
- Flagella identical.
- Sexual reproduction – isogamous, anisogamous or oogamous.
- E.g. *Chlamydomonas*, *Spirogyra*.

Xanthophyceae (yellow green algae)

- Plants generally fresh water
- Forms unicelled to simple filamentous.
- Chief pigments – chlorophyll a, e; β-carotene, violaxanthin, neoxanthin.
- **Reserve food – chrysolaminarin and oils**.
- Zoospore formation occurs.
- Male gametes flagellate, flagella non-identical (unequal).
- Sexual reproduction – isogamy, anisogamy or oogamous.

Phaeophyceae (brown algae)

- Plants marine (except-few)
- The body is differentiated into 3 parts – holdfast, stipe and **lamina**.
- They have holdfasts for attachment but *Sargassum* and *Fucus* become free floating. North Atlantic ocean is often called **Sargasso Sea** because of the abundant growth of Gulf Weed or *Sargassum*.
- Some brown algae are very large. They are called **trees of seas** or **kelps**. Depending upon the size, kelps are differentiated into **giant kelps** (*e.g.*, *Macrocystis* 40 – 60 m; *Nereocystis* 20 – 30 m) and **small kelps**.
- Cell wall contains cellulose and phycocolloids (alginic acid).
- Asexual reproduction by fragmentation and spores.
- Cells showing eukaryotic organization.
- Chief pigments – chlorophyll a, c; β-carotene, fucoxanthin (**for brown colour**), lutein, violaxanthin, diatoxanthin.
- **Reserve food – laminarin, mannitol, fats and oils**.
- Male gametes flagellate, flagella unequal (tinsel and whiplash), lateral.
- Sexual reproduction – isogamy, anisogamy or oogamous.
- **Life cycle** is **diplohaplontic** (eg *Dictyota*) or **diplontic**.
- Eg - *Fucus*, *Sargassum*, *Laminaria* etc.

Rhodophyceae (red algae)

- Plants generally marine.
- The plants are simple filamentous to attaining complexity of structures.
- Some cells show protoplasmic or pit connections.
- Chief pigments – chlorophyll a, d; α, β-carotene, lutein, violaxanthin, fucoxanthin, myxoxanthin, r-phycoerythin, r-phycocyanin, and allophycocyanin.

- Red colour is **due to phycoerythrin**.
- **Reserve food** – **floridean starch**, **galactan - SO_4, polymers**.
- No zoospore formation.
- Male gametes-non flagellate.
- Sexual reproduction by special type of oogamy.
- Life cycle haplobiontic or diplobiontic,
- E.g. *Batrachospermum*, *Gelidium*.

Myxophyceae or Cyanophyceae (blue green algae)

- Plants generally freshwater, a few forms marine.
- Forms unicelled to filamentous. Cell wall made up of mucopeptide.
- Possess some specialised cells called **heterocysts**.
- Cells showing prokaryotic organization.
- Chief pigments – chlorophyll-a, β-carotenes, luteins, xanthophyll, oscillaxanthin, c-allophycocyanin, allophycocyanin.
- **Reserve food** – **cyanophycean starch** (**glycogen**) **and cyanophycin** (**protein**).
- No zoospore formation.
- No flagellate bodies.
- No sexual reproduction.
- E.g. *Nostoc*, *Oscillatoria*, *Anabaena*.

Life cycle patterns found in algae

- It is recurring morphological and cytological phases in an organism that occur in each individual from its birth to death.
- It is of following types – **haplobiontic**, **diplobiontic** and **triplobiontic**.
- **Haplobiontic** : Only one somatic phase is present. It is of two types – **haplontic** and **diplontic**.
- **Haplontic** is a single somatic phase which is haploid. Diploid condition is present only in zygote or zygospore wherein meiosis occurs to produce haploid condition again, *e.g.*, *Spirogyra*, *Chlamydomonas*, *Ulothrix*, *Chara*. Alternation of generations is absent.
- **Diplontic** is a single somatic phase which is diploid. Haploid condition occurs in gametes (formed through meiosis) which fuse to restore diploid state, *e.g.*, *Cladophora glomerata*, *Bryopsis*, *Fucus*, *Sargassum*. Alternation of generations is absent.
- **Diplobiontic.** Two somatic phases are present in the life history – **diplohaplontic** and **haplohaplontic**.
- **Diplohaplontic**. Both haploid gametophytic and diploid sporophytic somatic phases occur in the life history. It has **two subtypes** :
  - **Isomorphic or monomorphic diplohaplontic** : Gametophytic and sporophytic phases are morphologically similar though cytologically they are haploid and diploid respectively, *e.g.*, *Dictyota*, *Ulva*. There is an **isomorphic** or **homologous alternation of generations**.
  - **Heteromorphic or dimorphic diplohaplontic** : Haploid and diploid phases are morphologically dissimilar. One of them is dominant. A **heterologous** or **heteromorphic alternation of generations** occurs, e.g., bryophytes (gametophyte dominant), pteridophytes (sporophyte dominant).
- **Haplohaplontic.** Only haploid cytological stage is present in two somatic phases, *e.g.*, *Porphyra* (dimorphic haplobiontic or diphasic haplohaplontic).
- **Triplobiontic.** Three somatic phases occur.
  - **Haplohaplohaplontic.** Three haploid phases occur in the life history.
  - **Diplodiplohaplontic.** Triphasic or trimorphic life history with two diploid and one haploid stages, *e.g.*, *Polysiphonia*.

SOME IMPORTANT EXAMPLES

Chlamydomonas

- *Chlamydomonas* is a free living aquatic **unicellular** and flagellate green alga (10 – 30 μm) that **occurs in ammonium rich fresh water**.
- Excessive growth of *Chlamydomonas* may impart green colour to water.
- Cell wall **does not contain cellulose**. Instead glycoprotein is present.
- Internally the alga contains a single nucleus, two contractile vacuoles for osmoregulation and excretion, a basin or cup-shaped chloroplast with a red eye spot or stigma and a pyrenoid for storage of starch.
- **Asexual reproduction** occurs **through zoospore formation**, **palmella stage**, **aplanospores** and **hypnospores**.
- **Palmella stage** is **produced in response to toxic chemicals and unfavourable water conditions**. Here the cells lose flagella and enclose themselves in mucilage. They, however, continue to grow and divide. On being flooded with water or removal of toxic chemicals, the mucilage dissolves and each cell forms a flagellate individual.

- Sexual reproduction involves fusion of two compatible gametes.
- Life cycle is **haplontic**.

Ulothrix

- *Ulothrix* is an **unbranched filamentous green alga of fresh aerated waters** which is covered by a thin sheath of mucilage. Lowermost cell is colourless and functions as **holdfast**.
- Cell wall consists of two layers. Inner layer is made up of **cellulose** and outer layer is mostly made up of **protopectin** which is insoluble in water.
- **Due to presence of protopectin**, *Ulothrix* filaments appear as **wet threads**.
- **Asexual reproduction** occurs **through fragmentation**, **zoospores**, **palmella stage**, **aplanospores**, **hypnospores** and **akinetes**. Only green cells take part in reproduction.
- **Sexual reproduction** occurs **through isogamy** (fusion of similar gametes).
- Gametes are **biflagellate** and produced like zoospores. The fusion product is **diploid zygote** which **forms a resting diploid zygospore**.
- Under favourable conditions, meiosis occurs in the zygospore.
- **Life cycle** is **haplontic** as dominant phase in life cycle is haplophase (n) and diploid phase is represented only by zygote or zygospore which undergoes meiosis (reduction division) during its germination.

Volvox

- *Volvox* is a **fresh water green colonial algae first observed by Leeuwenhoek (1700)**.
- *Volvox* is a small hollow green ball of 0.5 – 2.5 mm diameter which is popularly called **rolling ball**.
- The algae rotates on its axis during swimming.
- Reproduction is both **asexual and sexual**. The reproductive cells or gonidia usually occur in the posterior part.
- **Asexual reproduction** occurs through the formation of **daughter colonies**. Each gonidium can form a daughter colony.
- **Sexual reproduction** is **oogamous**. Colonies may be monoecious or dioecious. In monoecious forms, the male and female sex cells mature at different times.

Chlorella

- *Chlorella* is a **nonmotile** (**nonflagellate**) **unicellular green alga** which **occurs in diverse aquatic habitats**, preferably rich in organic matter.
- **Wall contains cellulose**. It is **three layered**. Outer layer may have sporopollenin-like material.
- **Sexual reproduction** is not known. **Asexual reproduction** occurs **through autospores**. Here divisions of the parent protoplast forms 2 – 32 daughter protoplasts, each of which develops a wall and gets transformed into an autospore.
- *Chlorella* can be used as food because it is rich in proteins (50%), carbohydrates (20%), vitamins (A, C, K, B_1, B_2, B_{12}) and minerals. It contains an antibiotic **chlorellin** but can be also cause allergic asthma.
- *Chlorella* is used as experimental plant for physiological records. It is an **important component of sewage oxidation tanks**.

Spirogyra

- *Spirogyra* is an unbranched filamentous green alga of stagnant fresh waters which forms floating masses called **pond scum**.
- *Spirogyra* is also called **pondsilk**, **water silk** or **mermaids tresses**.
- Cell wall consists of two distinct layers. The **inner layer is of cellulose** and the **outer is of pectose** which gets changed into pectin and this pectin dissolves in water to form a slimy or mucilaginous sheath. (It is sometimes referred to as third layer.)
- The protoplast is differentiated into plasma membrane, cytoplast, nucleus, chloroplast with pyrenoids and a large central vacuole.
- **Pyrenoids** are situated in the chloroplasts. They lie **equidistant** from one another and **are the centres of starch formation**.
- All the cells in the free floating species of *Spirogyra* are alike, no differentiation into apex and base. Each cell can synthesize its own food, respire, divide and reproduce. Thus the organism may be looked upon as a '**colony of independent cells**'.
- *Spirogyra* is **autotrophic**.
- **Growth** in *Spirogyra* is **intercalary or diffused**.
- In *Spirogyra* **reproduction takes place by three methods** – vegetative, asexual and sexual.
- Under exceptionally favourable conditions *Spirogyra* multiplies by the method of **fragmentation**.
- Fragmentation may be **brought about in the following ways** –
  – Through accidental breaking resulting from mechanical injury.

- Softening and subsequent dissolution of middle lamella of the septa.
- Due to sudden change in the temperature and acidity of water.

- Normally **asexual reproduction is absent** in *Spirogyra*. It **takes place only in some species**. It is of **3 types** –
  - By aplanospores
  - By azygospores (parthenospores)
  - By akinetes
- **Sexual reproduction** takes place towards the end of growing season usually in the late spring. It commences when the filaments are well mature and have stored sufficient food. The **external conditions which favour the process** are :
  - Nitrogen deficiency.
  - The change in pH of the aquatic medium on alkaline side.
- The sexual reproduction in *Spirogyra* is called **conjugation**. It involves the fusion of two **morphologcally identical** but physiologically dissimilar nonciliated gametes.
- The fusion of these gametes takes place by the following 2 methods.
  - **Scalariform conjugation**.
  - **Lateral conjugation**.
- **Scalariform conjugation** (in both monoecious or dioecious) **takes place during the night** and between the recently divided cells of the conjugating filaments.
- The conjugation tube between the two filaments looks like a ladder, through which gamete from one of the gametangia passes through to fuse with the passive gamete of another filament. The gametes are formed singly and both **active and passive gametes** are considered **male and female gametes** respectively. The **fusion of both kinds of gametes** with each other **results into formation of zygospore**.
- **Lateral conjugation** (monoecious species) **takes place between two nearest cells of the same filament**. Both male and female gametes are found in same filament.
- It is of two types – **indirect lateral conjugation** and **direct lateral conjugation**.
- **Life cycle** in *Spirogyra* is **haplontic** as dominant phase in life cycle in haploid (n) and diploid phase is represented by only zygospore and it undergoes R.D. or meiosis (zygotic meiosis).

ECONOMIC IMPORTANCE OF ALGAE

Beneficial aspects

Algae as food and fodder

- Sea weeds, especially brown algae, are used as food for domestic animals in different parts of the world and their wide scale usage centres in countries like Norway, Scotland, France, Great Britain, Scandinavia, America, New Zealand, etc.
- *Pelvetia canaliculata* is **used as food for young live-stocks**. *Sargassum*, *Fucus* and *Laminaria* are eaten by cattle in Scotland and Island. *Macrocystis* spp. and other kelps being rich in vitamins A and E are served as cattle fodder.
- The marine algae are of considerable importance in food value. They are often mixed with rice and fish and served as base for soups, condiments and eaten alone as salads. The edible forms are called **Limu** in Hawaii, **Tsao** in China and **Rimu** in Tahiti.
- *Chlorella* is **rich in protein and carbohydrates**.
- *Spirulina platensis* is one of the **richest sources of protein**, containing 40-50 percent crude protein on dry weight basis which under favourable condition may reach upto 70 percent.
- The mucoprotein constituents of cell wall are easy to digest and thus making *Spirulina* a good item for both, human beings and animals.
- Algae **serves primary food for fishes and other small aquatic animals**. Such algae may be both a plankton or an attached form in the sea as well as in fresh water.
- In fresh water lakes and ponds, *Oedogonium*, *Spirogyra*, *Microspora*, *Ulothrix*, *Cladophora*, *Pithophora*, etc, serve directly as fish food.

Algae in industries

- **Alginic acid** derivatives are extracted from the members of Phaeophyceae such as *Laminaria*, *Ascophyllum*, *Macrocystis*, *Ecklonia*, *Lessonia*, *Durvillea*.
- **Carrageenin** is the most famous carbohydrate mucilage named after Irish village Carrageenan. The gelatinous carbohydrates are variously used with puddings, eaten with milk or mixed with fruit and even in ice cream. It is also used as clearing agents in beer preparation. It is **extracted from red alga** *Chondrus crispus* – "Irish moss" and to a lesser extent from *Gigartina spp.*
- **Agar**, dried gel-like non-nitrogenous extract from

red algae, is **used as a medium in the cultures of bacteria, fungi and algae** and **also in numerous industrial processes**. Agar was largely prepared from *Gelidium*. Algae such as *Camplaephora*, *Pterocladia*, *Gracilaria*, *Ahnfeldtia*, *Eucheuma*, *Chondrus*, *Gigartina*, *Phyllophora*, *Furcellaria* are used for extraction.

- Brown algae like *Laminaria digitata*, *Ecklonia*, *Easenia* and *Fucus spp*. are **largely known for the extraction of iodine**.
- Other micronutrients useful for human consumption such as iron, copper, manganese and zinc have been found in sea weeds.
- Diatoms and their large sedimentary deposits "diatomaceous earth" are quite useful in industry. Diatomite is **used in industrial filtration processes, sugar refining** and **brewing industries**.

Medicine and antibiotics

- **Because of high iodine content** brown algae are used in various **goiter medicines**, either mixed or directly as a powder.
- *Laminaria stipes* are **used as surgical tool** in the opening of wound owing to its property of gentle swelling subject to moisture exposure.
- **Chlorellin** is extracted for *Chlorella* which inhabits growth of certain bacteria and a few algae.
- *Microcystis* is popularly known for its inhibitory action to *Staphylococcus* and *Chlostridium* and zooplanktons such as *Daphnia* and *Cyclops*.

Water purification

- In water reservoirs, the larger growth of algae creates great nuisance but lesser growth of algae acts as biological filters by forming a microzone of the sand surface which together with bacteria and fungi forms a mucilage layer. By this microzone, harmful bacteria are trapped and water also gets aerated.

Sewage disposal

- The presence of algae facilitates oxygenation of sewage to a great extent. The algae known to grow in sewage are *Euglena*, *Chlorella*, *Scenedesmus*, *Chlamydomonas*, *Pyrobotrys*, *Microactinum*, etc.

Algae in biological research

- Recent knowledge of photosynthesis is based on research carried on *Chlorella* (unicellular green alga).

Algae in space travels

- A spaceman will need a device to get rid of CO_2 and other body wastes and will require sources of O_2 and food. So *Chlorella*, *Synecoccus*, etc., are useful for this purpose and they grow very quickly.

Harmful aspects

- A compound toxin produced by certain algae proves fatal to fishes, e.g. the growth of *Aphanizomenon* and *Microcystis aeruginosa* in fish ponds are poisonous to *Crappis perch* and *Gambusia*, respectively.
- A few blue-green algae such as *Microcystis*, *Anabaena*, *Nodularia*, *Gloeotrichia* and *Aphanizomenon* produce exotoxin and endotoxin causing death of animals, horses, cattle, sheep, etc.
- Several cases of human death have been reported as a result of indirect consumption of dinoflagellates through fishes which have eaten them.
- The pollution caused by algae is well known. They produce effective problems in water supply and purification and become obnoxious in water reservoirs, rivers and oceans. Some **blue-green** and **green algae** grow over the surface of water bodies in abundance, especially in rainy season, and cause **water bloom**. On death and decay, these algae give bad smell. Some dinoflagellates (members of class dinophyceae of algae) secrete poisonous or toxic substances.
  - **Important algae causing water bloom** are *Microcystis*, *Chroococcus*, *Oscillatoria*, etc. These **deplete the water of O_2** and hence animals like fish are killed.
  - Marine algae growing in abundance retard the speed of ships.
- India suffers enough serious problem of blue-green algae causing threat of enormous loss to Indian Government revenue by effecting the quality of salt in Sambhar lake in Rajasthan. Algae (such as *Arthrospira*) produce an offensive smell, impart pink rust red colour to the salt and turn brine into a gelatinous fluid making it impossible to develop crystals.

End of the Chapter

Chapter 8

Bryophyta

- The division Bryophyta (Greek : *Bryon* = moss; *phyton* = plants) includes the simplest and primitive land plants.
- It occupies a position inbetween algae and pteridophyta.
- The group consists of about 960 genera and over 25,000 species, occurring worldwide in distribution.
  - The term Bryophyta was used by **Brown**.
  - The term moss coined by **Jussiau**.
  - **Hedwig** is the **father of Bryology**.
  - **S.R. Kashyap** is the **father of Indian Bryology**.
  - The pteridophytic origin of bryophyte was founded by **Scott**.
  - The algal origin of bryophyte was founded by **Bower**.

Characteristic features

- The bryophytes are fundamentally **terrestrial plants** but required presence of water to complete their life cycle, because they require a moist soil surface for swimming of their sperms and supply of water to all parts.
- Thus, due to peculiar type of their habitats, they are regarded as "**the amphibians of the plant kingdom**".
- Bryophytes are **first amongst land plants which occur in damp and shady habitats**.
- Dominant plant phase in bryophytes is free living thalloid **gametophyte.**
- The gametophyte is **thalloid in primitive forms** (*Riccia*) and **differentiated** into rhizoids, stem and leaves **in higher bryophytes** (mosses).
- From the lower surface of the thallus or from the base of the stem, number of unicellular or multicellular **rhizoids** arise. They are the **organs of absorption and fixation**.
- Many bryophytes, eg. *Riccia*, *Marchantia* etc have scale on ventral surface. Scales are multicellular and to protect the growing point or apical cell of the thallus.
- The plant body has epidermis for protection.
- The thallus has air pores. Moss capsule has stomata for gaseous exchange.
- Nutritionally, the plant body is **independent** and is the conspicuous phase of the life cycle.
- The gametophytes **lack vascular tissues** namely xylem and phloem.
- Stem, leaves and rhizoids of the bryophytes are **analogous** to the stems, leaves and roots rather than root hairs of vascular plants.
- **Scales** or **amphigastria** occur which take part in capillary conduction and protection.
- The higher bryophytes (eg. *Moss*) have primitive vascular strands (conducting tissues).
- They **reproduce by vegetative** and **sexual methods**.

Vegetative reproduction

- Vegetative reproduction occurs by various methods to give rise to new thallus.
- **Death and decay of the thallus** – The older thallus starts dying from lower to upper side. Finally the growing point gets separated and formed fragments develops into a new thallus.
- **Adventitious branches** – Detached from thallus to form new thallus, e.g. *Riccia.*
- **Tubers** – These form during adverse condition, eg. *Anthoceros*.
- **Gemmae** – *Marchantia* thallus has cup like structure, called gemma cup, which bears large gemmae (multicellular).
- **Primary protonema** – Spores on germination give rise to primary protonema which breaks up into segments that give rise to leafy gametophore.
- **Secondary protonema** – Protonema formed from structures other than spores and give rise to leafy gametophore.

Sexual reproduction

- The sexual reproduction is of oogamous type. The sex organs are called antheridia (male) and archegonia (female). They are multicellular and surrounded by a sterile jacket layer.
- **Antheridium**
  - It is stalked (multicellular) pear shaped structure. Its one cell thick jacket surrounds large number of fertile cells called **androcytes**. Each androcyte metamorphoses into a biflagellate antherozoid or male gamete or sperms.
  - Antherozoids are **naked**, **biflagellate** and **motile**. The flagella are long, anterior and whiplash type. They **need water for fertilization**.
- **Archegonium**
  - Archegonium **appears first time in Bryophytes in plant kingdom**.
  - It is a flask shaped structure with swollen base called **venter** and upper elongated **neck**.
  - The archegonium is surrounded by one celled thick sterile jacket layer.
  - The venter contain a ventral canal cell and an egg cell.
  - The neck, made of 4–6 vertical rows of cells, enclosing naked neck canal cells.
  - The tip of neck has 4 covercells or lid cells.
  - During fertilization the cover cells open and neck canal cells and venter canal cell disintegrate to form mucilage which absorb moisture to create pressure which remove lid cells and mucilage comes out of neck.
  - Thus passage is formed for the entry of antherozoids to fertilize the egg.

Sporophytic generation

- Sporophytic generation **starts with zygote**. The zygote immediately secretes cellulosic wall, to develop into embryo or sporophyte.
- The embryo is multicellular. The gametophyte provide protection and nourishment to the developing embryo.
- The **development of embryo is exoscopic**, *i.e.* first division of zygote is transverse and the capsule develops from outer or epibasal cell.
- The embryo is not liberated but is retained within the archegonium where it develops into sporophyte.

Sporophyte or Sporogonium

- The sporangium develops from embryo. It does not has rhizoids, stems and leaves. It is permanently attached to gametophyte and is completely dependent on it.
- But in some Bryophytes like *Anthoceros*, mosses, the sporophyte wall has photosynthetic tissues. Mostly the sporophyte consists of foot, seta and capsule. The **foot** is an **anchorage and absorptive organ** and **remain embedded in gametophyte**.
- The **seta** is small (*Marchantia*) to long (mosses) to **conducts food from gametophyte to capsule**.
- The terminal capsule is either spherical or elongated. Capsule also surrounded by its own jacket (sporophytic in nature) and 2 layered calyptra. The calyptra originate from venter wall, hence gametophytic in nature. The capsule contains large number of spores or meiospores and elaters (absent in *Riccia*). The spores are haploid and wind disseminated. The meiosis is sporogenic.
- The **elaters** are **sterile** and are **diploid**. They **have hygroscopic thickening which helps in dispersal of spores**.
- The haploid spores, germinate to form young gametophyte.
- In mosses, the spores first develop into multicellular, haploid branched filamentous structure called **protonema**, which later gives rise to gametophytic plant.
- The spores are of one kind, hence the bryophytes are **homosporous**.
- All bryophytes exhibit **heteromorphic alternation of generations** *i.e.,* the individuals of each generation are dissimilar.
- Bryophytes resemble pteridophytes in having embryo stage, cuticle, multicellular sex organs with sterile jacket, multicellular sporangia, oogamous reproduction, flagellated male gametes etc.

Similarities between algae and bryophytes

- Both are autotrophic, the plant body is gametophytic.
- Plant body is thallus like and devoid of vascular tissues.
- Root is absent but rhizoids are found for attachment and absorption purpose.
- Both algae and bryophytes have motile sperms and need water for fertilization.

Classification of bryophyta

- Bryophytes have been **divided into three classes** – **hepaticopsida**, **anthocerotopsida** and **bryopsida**.

Hepaticopsida (eg *Riccia*, *Marchantia*)

- The plants for the class **hepaticopsida** are commonly called as **liverworts**.
- The gametophyte is dorsiventrally differentiated without **protonema stage**.
- Internally homogeneous or composed of different kinds of tissues.
- Ventral surface of the thallus shows **unicellular rhizoids** for **anchorage**.
- Sex organs always develop on the **dorsal surface** of the thallus. They are **multicellular**.
- **Water is essential** for the process of fertilization to take place.
- The gametophyte is usually thalloid; it is occassionally leafy (in such forms the leaves are without midrib).
- Rhizoids are without septa.
- Each cell has many chloroplasts; the chloroplasts are without pyrenoids.
- Sporophyte has foot, seta and capsule (except *Riccia*). Growth is determinate and limited. Columella in sporophyte is absent.
- Spore mother cells develop from endothecium of embryo.
- Elaters are hygroscopic and help in dispersal of spores, eg. *Marchantia* (Elaters are absent in *Riccia*)
- Dehiscence is by longitudinal or transverse wall. In *Riccia*, it is by decay of capsule wall.
- The **endothecium** produces sporogenous tissue.
- Sporophyte is **entirely parasitic on the gametophyte**, *e.g., Riccia, Marchantia,* etc.
- *Riccia fluitans* is an **aquatic bryophyte**.
- Thalli of *Riccia* are internally differentiated into upper photosynthetic region and lower storage region.
- The species of *Riccia* may be **homothallic** (monoecious), eg. *R. crystallina* or **heterothallic** (dioecious), eg. *R. discolor.*
- The neck of archegonium is 6-9 cell high and one cell thick. Venter also has one cell thick wall.
- The antherozoid are attracted towards the egg by **chemotactic mechanism**. The chemical stimulus is provided in the form of sugars.
- The venter divides periclinally to form a double layered **calyptra**.
- The species of *Marchantia* are **heterothallic** (dioecious).
- The rhizoids in *Marchantia* are of two **types** – **smooth walled** and **tuberculate**. They are **present in the region of the mid rib**.
- The archegonium in *Marchantia* consists of a neck containing 6-neck canal cells, and a venter containing a ventral canal cell and an egg.

Anthocerotopsida (eg *Anthoceros*)

- "**Hornworts**" is the common name for the members of the class anthocerotopsida.
- The gametophytes are **thalloid, distinctly dorsiventral**.
- Thallus internally shows homogenous tissues, **mucilage cavities** inhabited by some algae.
- Thalloid gametophytes do not possess air chambers and scales.
- Rhizoids are present, scales absent.
- Each cell of the thallus has a single large chloroplast with a pyrenoid.
- Sex organs developed on the **dorsal surface are embedded in the thallus**.
- Sporophyte is horn like. It is long, differentiated into **capsule and meristematic zone**. Instead of seta meristematic zone is present by which its growth is unlimited and indeterminate.
- The wall of the capsule is 4 – 6 layers and consists stomata.
- The amphithecium and endothecium produces **sporogenous tissue and columella** respectively.
- The sporophyte is **partially dependent** on the gametophyte, *eg. Anthoceros.*
- The gametophytes of *Anthoceros* are **thallose**, **dorsiventrally flattened** and **variously lobed**. The dorsal surface is smooth and the ventral is provided with unicelled smooth walled rhizoids. There are **no tuberculate rhizoids** and **scales**.
- The thallus of *Anthoceros* is internally **not well differentiated**. It has **endophytic** *Nostoc* **colonies** and the cavities opening ventrally by slime pores.
- 1 – 3 celled sterile **pseudoelaters** are found in *Anthoceros*.
- **Apospory** is observed in some species of *Anthoceros*.
- Columella is mostly present.
- Dehiscence is by 2-4 longitudinal splits.

Bryopsida or Musci

(eg *Funaria*, *Sphagnum* (bog moss), *Polytrichum*)

- Commonly called **mosses**.

- The gametophyte is differentiated into prostrate protonema and an erect gametophore.
- Gametophore is foliose.
- Rhizoids are multicellular with oblique septa.
- The stem is erect, leafy and bears **radially symmetrical** sexual branches.
- The leaves are arranged in **3-8 rows** on the stem. Each leaf shows a central **midrib only**.
- Sex organs develop near the **tips of sexual branches**.
- The sporophyte is differentiated into **foot, seta and capsule**.
- Sporogenous tissue may be formed from the **endothecium** or **amphithecium**.
- Columella is present. It develops from endothecium.
- Peristome teeth are present in one or two rows and surrounds the terminal opening of the capsule.
- Elaters are absent.
- The sporophyte is **semiparasitic** (as the sporophyte is not completely embedded in the gametophyte.
- The spores on germination produces multicellular, branched, chlorophyllous structure called **protonema**.
- Leafy gametophores grow from protonema, eg. *Funaria, Polytrichum, Sphagnum* etc.
- The sex organs of *Funaria* are of **projecting type and stalked**. They are mixed with sterile hair called **paraphyses**.
- A cluster of **vegetative leaves** surrounds the sex organs.
- The capsule of *Funaria* is distinguishable into an upper **opercular region**, middle fertile or **theca region** and lower **apophyseal region**.
- The opercular region is distinguishable into operculum covering peristome which comprises **sixteen outer** and **sixteen inner teeth**. The outer teeth are thick and **hygroscopic**.
- The **annulus separates** operculum from theca region.
- The fertile region mainly comprises archesporium lined by outer and inner spore sacs. The central sterile region is columella.
- The apophyseal region has **central conducting strands** and stomata in the epidermis.
- The archesporium forms **spore mother cells** which, by meiosis, form tetrahedral tetrads of spores.
- When the capsule is mature, the operculum is removed along the annulus and the spores are dispersed by the **hygroscopic action of peristomal teeth**.
- The spore **forms the chloronema which gives rise to caulonema**.
- Capsule has columella.

Economic importance

- *Sphagnum* is most economically important bryophyte.
- The bryophytes **help in conservation of soil, soil development** and **in succession of plant communities**.
- They are **used in manufacture of paper, fabrics, artificial wood** etc.
- It is **used in horticulture** and added to soil to improve its water holding capacity. It is used as **packing material** for living plants.
- Peat is **antiseptic** and is used in **surgical dressing**.
- *Sphagnum* or peat moss is also known as famine food in China.
- The acidic nature of bog (where *Sphagnum* grows) helps in **fossilization**.
- *Sphagnum* contains sphagnal which is used in skin diseases.
- It is a good absorbant hence also used as bandages.
- As biological material - sex determination in plants was discovered for the first time in *Sphaerocarpus*.

End of the Chapter

Chapter 9

Pteridophyta

- Seedless vascular plants, also known as **ferns and fern allies**, are a diverse group of plants consisting of about **10,000 species**.
- Pteridophyta claims a special position as the **first land plants**.
- Pteridophytes are also called **vascular cryptogams** as they possess **xylem and phloem (vascular tissues)**. Thus they are included as the **first group in tracheophyta**.
- In pteridophytes, xylem lacks **true vessels**. In phloem, **companion cells and sieve tubes are absent instead sieve cells are present**.
- Pteridophytes are nicknamed as **botanical snakes** as they evolved after bryophytes (botanical amphibians).
- During the **carboniferous period**, they were the **dominant land plant**.
- Pteridophytes were the **precursors to** modern seed bearing plants.

General characters

- Pteridophytes are mostly terrestrial.
- Grow well on **moist shady localities**.
- *Salvinia, Azolla* and *Ceratopteris* are **true aquatic ferns**.
- Some species of *Selaginella* and *Adiantum* are xerophytes.
- *Marsilea* occurs as a terrestrial, amphibious as well as an aquatic plant.
- The main plant body is sporophytic.
- They are generally herbaceous, rarely climbers.
- The plant body is differentiated into true roots, stem and leaves.
- The root system is of **adventitious type**.
- The roots possess a stele bound by **endodermis and pericycle**.
- The stem may be **aerial** or **rhizomatous**.
- Vasculature of stem shows different type of **stelar organisation**.
- The leaves are **microphyllous** or **macrophyllous**.
- Leaves may be scaly (*Lycopodium*, *Equisetum*) or simple (*Selaginella*, *Pleopeltis*) or pinnate (*Pteridium*, *Dryopteris*).
- The leaves may possess ligule (*Selaginella*). They may be sessile or petiolate.
- The leaves show **chlorenchymatous mesophyll** which may be uniform in aquatic forms or may be differentiated into **palisade** and **spongy parenchyma**.
- The stomata are generally present on the **abaxial** surface of the leaf.
- In *Isoetes* the plant body is distinguishable into a corm like rhizomorph bearing roots and leaves.
- Secondary growth is absent in pteridophytes except *Isoetes*.

Sporophyte

- Meiospores are formed inside **sporangia.**
- Borne on leaves called **sporophylls**.
- On the basis of development the sporangia have been classified by **Goebel**, (**1881**) into **two categories - eusporangiate** and **leptosporangiate**.
- **Eusporangiate** - A large sporangium developing from **several initial cells** producing many spores. These are sometimes fused to form **synangia**.
- **Leptosporangiate** - Small, specialized sporangia developing from a **single initial cell** producing a small, definite number (< 128) of spores. These often occur in a cluster (sorus) that is often covered by a flap of tissue known as an **indusium**.
- Sometimes sporangia form compact cone like structures bearing spores, called strobili (*Selaginella, Equisetum*).
- Sometimes sporangia are produced inside

specialised structures called **sporocarps** (eg *Marsilea, Salvinia, Azolla*).

- Most pteridophytes are **homosporous** *(Lycopodium, Equisetum)*, which means that they produce one type of spore that contains both male and female parts.
- A few pteridophytes are **heterosporous** (*Selaginella, Marsilea)* which means they produce distinct male and female spores.

Gametophyte

- The gametophytes is called **prothallus**. The prothalli may be **monoecious** or **dioecious**.
- Gametophyte is small or inconspicuous and is usually **independent** and **bear sex organs**.
- The gametophyte are **exosporic in homosporous forms** and **endosporic in heterosporous form**.
- Sex organs are **multicellular** and jacketed.
- Antheridia are **completely embedded** in the prothallus while archegonia are **partially embedded**.
- Archegonia consist of **neck** which usually project from the surface prothallus.
- Archegonia contain **1-2 neck (14 in** *Lycopodium***)** canal cells. Venter is **absent**.
- Antheridia are generally **sessile**.
- The antheridia are having single layered jacket.
- Antherozoids are **uninucleate, spirally coiled biflagellate** or **multiflagellate structures** (ferns).
- Fertilization is affected by **water medium**. The antherozoids are attracted towards the egg by a **chemotactic stimulus** provided by the degeneration of neck canal cells and venter canal cell in the form of **malic acid**.
- The zygote (2n) formed after fertilization undergoes divisions wholly (holoblastic) or partially (meroblastic) to form embryo.
- The **young sporophyte is dependent** on the gametophyte in earlier stages for food which is drawn with the help of its foot.
- They show **heteromorphic alternation of generation**.

Stele

- The **conducting system of pteridophytes consists of xylem and phloem** and **associated parenchyma cells**, all of which are organised into **a stele** (L. *stela*, rod or column) that is generally separated from the outer cortex by a layer of endodermis.
- On the basis of the kind of stelar organisation that occur in different pteridophytes, an evolutionary sequence can be recognised among different groups of them.
- **Protostele** is the **simplest**, and **considered to be the most primitive type of stele**. It consists of a solid core of xylem surrounded by a cylinder of phloem, enclosing no pith.
- All other types of steles have evolved from it in the course of evolutionary specialisation. **Protosteles** are **most common in psilophytes and lycophytes**, but they occur also in the juvenile stems of ferns.
- Variation of the protostele include, the haplostele, actinostele, plectostele, and mixed-protostele.
- **Haplostele** is protostele with central solid and smooth core of xylem surrounded by phloem. This particular type of protostele has been **regarded as the most primitive among the different types**. It occurred in primitive psilophytes like *Rhynia*, and is found in a number of living genera, e.g. *Selaginella kraussiana*.
- **Actinostele** – In a number of pteridophytes, the central xylem core of a protostele is not smooth but is thrown into radiating ribs with the protoxylems at the extremities and phloem alternating with its rays, when seen in a cross section.
- **Mixed-protostele** – In *Lycopodium cernuum*, the xylem when seen in a cross section, appears in the form of irregular groups that are embedded in the ground mass of phloem. This type of protostele is called the mixed-protostele.
- A kind of stele in which there is present a pith in the central region is called a **siphonostele** or **medullated protostele**.
- This type of stele is thought to have been evolved from a protostele by a degradation or reduction of tracheary elements into parenchyma, and represents a stage in evolutionary advance.
- In siphonostele, the vascular tissues are arranged in the form of a hollow cylinder, with a distinct pith in the centre. The siphonostele and its variations are found frequently in the ferns.
- According to the distributional patterns of the xylem and phloem, the siphonostele has been classified into two types – **ectophloic siphonostele**, **amphiphloic siphonostele**.
- In the **ectophloic siphonostele**, the phloem occurs only on the outer surfaces of xylem cylinder. It is

found in *Equisetum* and some ferns, like *Osmunda* and *Schizaea.*

- In the **amphiphloic siphonostele**, the phloem may be both external and internal. An amphiphloic siphonostele is **also known as a solenostele**. It is found in the ferns, like *Adiantum* and *Marsilea*.
- In its simples form, the siphonostele has no leaf gaps, *e.g.,* some species of *Selaginella*. A siphonostele, which has no leaf gap is termed as **cladosiphonic siphonostele**.
- A siphonostele with gaps caused by leaf traces is termed **phyllosiphonic siphonostele**, e.g., *Marsilea*.
- Another modification of the siphonostele is seed in the internode of *Equisetum*. Here, the vascular system consists of collateral or bicollateral vascular strands, that is, they have xylem on the inside and phloem on the outside. Such arrangement is called a **eustele**.
- In some ferns, *e.g., Pteridium*, a complex type of stelar anatomy is seen in which there are two or more concentric vascular systems that are interconnected at intervals and usually all contributing to the leaftraces. Such stele is said to be **polycyclic**.

Classification of pteridophytes

- There are 4 major types of pteridophytes – **psilopsida**, **lycopsida (club moss)**, **sphenopsida (horse tail)**, and **filicopsida (ferns)**.

Psilopsida

- These are the **most primitive and oldest known land inhabiting plants**, which are **rootless**.
- Presence of rhizoids borne over the rhizome.
- Aerial stems are often dichotomously branched, green and photosynthetic.
- Leaf like enations may be present, leaf usually absent.
- Only stem contains vascular tissue – xylem and phloem.
- Sporangia are terminal or axillary, spores produced are homospores.
- Most of the plants include fossil genera – *Rhynia, Horneophyton*;
- **Living representatives** are only 2 – *Psilotum* and *Tmesipteris*, **both of them bear compound sporangia or synangia**.

Lycopsida

- Lycophytes are commonly referred to as **club moss** or **ground pine**, although they are neither moss nor pine, e.g. *Selaginella, Lycopodium.*
- The plant body is a **sporophyte** which is **differentiated into root, stem and leaf**.
- The leaves are **microphyllous** with spiral, whorled or opposite phyllotaxy.
- The stele is a **protostele**. But sometimes siphonostele or polystele may be present.
- Generally the sporophylls aggregate in the form of **cones** or **strobili**.
- The sporophyll bear a single large sporangium on the **adaxial surface**.
- The plants may be **homosporous** (*lycopodium*) or **heterosporous** (*Selaginella*).
- The gametophytes may be **endosporic** (within the spore wall as in flowering plants) or **exosporic** (spore germination with plant development outside the spore).
- Secondary growth absent except in *Isoetes*.
- In lycophytes, the gametophyte generation often depend on fungus for survival, as they **cannot produce their own food**.
- *Selaginella* show great variation in morphology as prostrate, sub-erect, climbers, etc.
- Leaves may be dimorphic or uniform in shape and size, presence of ligule and glossopodium (secretory leaf base).
- A leafless, colourless positive geotropic elongated cylindrical structure growing downward from point of bifurcation of stem is called **rhizophore**.
- Root is protostelic, monarch, with exarch xylem.
- In stem stele is diarch and exarch.
- In leaf stomata are present only on lower epidermis, no differentiation of mesophyll tissues, chloroplasts with pyrenoids.
- Vegetative reproduction is by fragmentation, bulbils, tubers, or apogamy.
- The strobiles or spike bears both megasporophylls (female) and microsporophylls (male).
- Development of sporanguim is eusporangiate.
- The microspore consists of 1 prothalial, 8 jacket cells and 4 primary androgonial cells.
- Antherozoids are spirally coiled and biflagellate.
- Archegonium consists of very short neck, single neck canal cell, a venter having ventral canal cell and an egg.
- Heteromorphic alternation of generation.
- Lycopsida includes both **fossils** and **living forms**.

Sphenopsida

- The members of this class are commonly called **horse tail**. All the forms except *Equisetum* are fossils.
- *Equisetum* is the **sole living representative of a large group of sphenopsids**.
- The sporophyte has true roots, stem and leaves.
- The stems are jointed having distinct **nodes** and **internodes**. The internodes are hollow and are longitudinally ribbed and furrowed.
- The leaves are scaly and found as whorl around the node.
- The stele may be a **protostele** or **siphonostele**.
- The sporangia develop on special structures called **sporangiophores**. The sporangiophores aggregate to form **strobili**.
- All species of sphenophyta are **homosporous** with autotrophic gametophytes or prothalli.
- The prothalli (gametophyte) may be monoecious or **dioecious** and **exosporic**.

Filicopsida

- The members of the class filicopsida are commonly called "**ferns**". These are the widely distributed vascular cryptogams, e.g. *Marsilea, Adiantum, Pteris*.
- The plants are **perennials**, widely distributed in damp shady places of the tropics.
- The plant body has roots, stem and leaves but in some roots may be absent.
- The stem is mostly **rhizomatous** and the **roots are of adventitious type**.
- The leaves are **macrophyllous** and are commonly called "**fronds**".
- Young leaves show **circinate vernation** (spirally coiled).
- **Furcate venation** is a fern character.
- The young leaves, young parts of rhizomes petiole and rachis of mature leaves are covered over by brown to black scales called **paleae** or **ramenta**.
- The stele may be **protostele, siphonostele or dictyostele**.
- Sporangia are born on the margins on the **abaxial surface** of the leaf, forming **sori**.
- In *Marsilea, Azolla, Salvinia* etc. the sori are present in a box like structure called **sporocarp**.
- The sorus may be naked or covered in **indusium** which may be true or false.
- **True indusium** is a membranous sheath of sorus specially developed to cover sorus whereas **false indusium** is formed by curving of the sporophyll margins.
- The plants are **homosporous** (*Pteris*) or **heterosporous** (*Marsilea*).
- Spores on germination gives rise to gametophytes (n) that produce antheridia and archegonia.
- Antherozoids are multiflagellated.
- The prothallus is usually monoecious **heart shaped, small, green** and **independent**.
- Vascular cylinder shows meristele (smaller units), xylem mesarch in *Dryopteris*.
- In roots xylem is exarch and diarch.

> - *Selaginella lepidophylla* is called **resurrection plant**.
> - Almost all coal is formed from the **pteridophytes**.
> - Psilotales like *Rhynia* were **first tracheophytes**.
> - **Smallest** pteridophyte is *Azolla* (an aquatic fern) and **largest** is *Cyathea* (tree fern).
> - Bower and Goebel named **rhizophore** of *Selaginella* as an ***organ sui-generis*** *i.e.,* an organ having the characters of both *i.e.* stem as well as root, but independent in origin.
> - The sporophytes reproduce asexually producing spores in sporangia.
> - When similar type of spores are formed *i.e.* same size, the phenomenon is called as **homospory**.
> - In some pteridophytes, two types of spores are formed which differ significantly in their size as also in function. This phenomenon is called as **heterospory**. Eg, *Selaginella*, *Isoetes*, *Stylites*, *Marsilea*, *Azolla*, *Salvinia*.
> - The term **apogamy** was **coined by De Bary**, 1878. It is defined as formation of sporophyte from a gametophytic cell other than egg without fertilization. It was observed in several plants, eg. *Lycopodium*, *Selaginella*, *Marsilea* etc.
> - The formation of gametophyte from a sporophytic cell without meiosis is called as **apospory**, *e.g. Pteridium*.
> - Formation of sporophyte from egg without fertilization is called as parthenogenesis, *e.g. Selaginella*, *Marsilea*.

- In leaves, both bicollateral or concentric and collateral vascular bundles (in smaller Meres) are seen.
- In *Dryopteris* indusium is true, spores are monolete and bilateral type and homosporous.
- Prothallus is protandrous (antheridia mature first)
- Venter lacks a covering or jacket.
- *Psilotum* is a primitive fern with **no root system**. Leaves are small and veinless.

Table : Common names of some pteridophytes

Rootless pteridophyte	*Salvinia*
Xerophytic fern	*Woodsia elongata, Drynaria, Adiontum insicum*
Annogramma leptaphylla	Smallest fern.
Lycopodium	Club moss
Selaginella	Spike moss
Selaginella rupestris	Bird's nest moss
S. bryopteris	Sanjeevini
Adiantum	Walking fern
Dryopteris	Male shield fern

Economic importance

- Several pteridophytes, particularly the species of *Lycopodium*, *Selaginella*, *Lygodium* are ornamental.
- The plants of *Selaginella* are marketed as curiosities in the name of resurrection plants.
- *Lycopodium* is **used in skin diseases**, a few others species are used as kidney stimulant.
- *Azolla* is a water fern used as biofertilizer.

Evolutionary aspects of pteridophytes

- The **pteridophytes** (**vascular cryptogams**) **resemble the bryophytes in the following features** –
  - Terrestrial habit.
  - Like the bryophytes, they reproduce asexually by means of spores. The spores are formed in the same manner in both the groups.
  - The sex-organs, the antheridia and archegonia are essentially identical as regards to their structure and ontogeny.
  - In both the groups, the sex-organs have sterile jackets around them.
  - The male gametes, *i.e.*, the sperms are ciliated.
  - Fertilization takes place in the presence of water.
  - Encapsulation of embryo in the archegonium.
  - Dependence of early embryo (sporophyte) upon the gametophyte.
  - They exhibit regular alternation of generations.
- **The pteridophytes differ from bryophytes in the** following features –
  - In the bryophytes, the gametophyte is the dominant and conspicuous generation, the diploid sporophyte being nothing more than a spore-bearing structure and is dependent on the gametophyte for the nourishment. In the pteridophytes, it is sporophyte rather than the gametophyte which constitutes a large, conspicuous and dominant phase in the life cycle, while the gametophyte is always small and inconspicuous.
  - Plant body in pteridophytes shows differentiation into true roots, stem and leaves. In bryophytes, there may be stems with leaves but there are no roots.
  - All the vegetative organs of the sporophyte of pteridophyte possess vascular supply whereas bryophytes do not possess vascular tissue.
- The **pteridophytes resemble the seed-bearing plants (spermatophytes)** in the following features –
  - In both the groups, the sporophyte is the large, conspicuous, freely existing, independent and dominant phase in the life cycle. The sophrophytic plant body is differentiated into true roots, stem and leaves.
  - All the vegetative parts of the sporophyte have typical xylem and phloem cells. The xylem consists of tracheids of xylem parenchyma, vessels being absent. Phloem consists of sieve-tubes and phloem parenchyma, the companion cells being absent.
- **Difference between pteridophytes and spermatophytes** –
  - Pteridophytes differ from the spermatophytes in that they do not produce flowers, fruits or seeds.
  - In pteridophytes, excepting few cases, the spores or gametophytes developed from them are invariably liberated from the sporangia, instead of being permanently retained within them.
  - In spermatophytes, water is not necessary for fertilization.
  - Steles are more advanced in spermatophytes than those of pteridophytes.

End of the Chapter

Chapter 10

Gymnosperms

- **Gymnosperms** is derived from Greek words *Gymnos* - naked + *sperma* - seed *i.e.,* naked seed.
- Term gymnosperms was introduced by **Theophrastus**.
- Goebel defined gymnosperms as "**Phanerogams without ovary**".
- Gymnosperms are the small group of plants which constitute the subdivision of **phanerogams** or **spermatophyta.**
- Age of higher gymnosperms is **mesozoic era** though origin of order cycadofilicales of gymnosperms is in **late palaeozoic era**.
- Gymnosperms are **connecting link between pteridophytes and angiosperms**.
- Gymnosperms are **placed in** –
  - **Archegoniate** *i.e.*, having archegonium as female sex organ (bryophytes, pteridophytes, gymnosperms).
  - **Embryophyta** - Embryo is formed in life cycle (bryophyta, pteridophyta, gymnosperms and angiosperms).
  - **Tracheophyta** *i.e.* having vascular tissue or xylem and phloem (pteridophytes, gymnosperms and angiosperms).

The **reason for the extinction of gymnosperms** may be the limited means of dispersal of seeds (only by wind and man) and their failure to grow under varied habitats (*eg.*water). Absence of bisexuality provides lesser chances of self fertilization and a good amount of pollen is wasted during wind pollination.
The numerical scarcity of present day gymnosperms (14 genera and 51 species) in India is due to the fact that they are the dwellers of temperate regions and in India such climate exists only in the Himalayas, and their adjoining hills.

- In the evolutionary point of view gymnosperms are the **most primitive seed plants**.
- There are about **73 genera** and **7000 species** in subdivision gymnospermae.
- Most of the genera are **entirely extinct** and only a few are living.

General characters

- Gymnosperms generally **constitute dominant flora of temperate region**.
- Few gymnosperms, *e.g.*. *Welwitschia* are **xerophyte.**
- The gymnosperms are **predominantly woody plants** represented by trees and shrubs. Few are climbers.
- **Tallest** gymnosperm is *Sequoia sempervirens* (about 366 ft) and **oldest** gymnosperm is *S. gigantea* (about 4000-5000 yrs). **Smallest** gymnosperm is *Zamia* (25 cm).
- **Tap root** system is present. It shows **diarch** to **polyarch nature**.
- Stem are erect, branched and woody with **leaf scars** and **scale scars**.
- Vascular bundles in stem are **conjoint, collateral** and **open**. Secondary growth is present and **annual rings** are formed.
- The xylem consist of **xylem parenchyma** and **tracheids** with bordered pits.
- **Vessels are absent** in gymnosperms **but present in order** – Gnetales (*Gnetum*, *Welwitschia* and *Ephedra*). Therefore **Gnetales are considered as connecting link** between gymnosperms and angiosperms.
- Due to the absence of vessels gymnosperm wood is called **soft wood.**
- In phloem sieve cells and phloem parenchyma are present but **companion cells are totally absent.**
- Leaves may be **dimorphic** or **monomorphic** and **show xerophytic characters** like sunken stomata and thick cuticle.

- In gymnosperms, the reproductive structures are mostly in the form of **compact cones** except female organs of *Cycas*.
- Flowers are **absent**. There are two types of sporophylls – **microsporophylls** and **megasporophylls**.
- The two types of sporophylls are usually aggregated to form distinct **cones or strobili** : pollen cones (male cones) and seed cones (female cones).
- Seed do not occur inside a **fruit** due to absence of ovary. They are **naked or lie exposed** on the surface of megasporophylls.
- The megasporophylls bear ovules. The ovule is generally **orthotropous** and **unitegmic** with three layers (bigemic ovules are found in *Gnetum* and *Ephedra*).
- Endosperm is a **prefertilization product** and hence **haploid**.
- Archegonium (female gametophyte) is with reduced neck (with **no neck canal cell**).
- Pollination is **anemophilous** (by wind) and the fertilization is of **siphonogamous** type (occur by pollen tube).
- **Polyembryony** is the formation of more than one embryo inside a single seed. It occurs in *Pinus*. Pinus ovule has 2-8 archegonia.
- Wood is **manoxylic** (soft and loose), eg. *Cycas* or **pycnoxylic** (compact and hard), eg. *Pinus*.
- Fruit formation does not occur in the embryo of gymnosperms, **2 or many cotyledons** are present, eg. 2 in *Cycas* and 10 - 11 in *Pinus*.
- Seed of gymnosperm **represent three generation** –
  - **Parent sporophyte** - Represented by nucellus and integument.
  - **Gametophyte** - Represented by endosperm.
  - **Future sporophyte** - Represented by embryo.
- Gametophyte generation is **reduced and dependent** upon sporophyte generation.
- Alternation of generation is **distinct**.
- Development of oospore is **meroblastic** *i.e.,* only a part of zygote form embryo, *eg. Pinus.*

Classification of gymnosperms

- Gymnosperms are further classified into three classes. **(Sporne, 1965).** They are **cycadopsida**, **coniferopsida** and **gnetopsida**.

Cycadopsida

- Cycadopsida is **represented by small plants** and are **comparatively primitive**.
- The stems are **erect**, **unbranched** and **stumpy**.
- The wood is **manoxylic**.
- Male cones are **large** and with compactly arranged microsporophylls.
- The megasporophylls are loosely arranged and **does not form a cone**. The megasporophyll **bears large ovule**.
- The seeds are **radially symmetrical**. E.g., *Cycas* (**described in details**), *Microcycas*, *Zamia* etc.

Coniferopsida

- Coniferopsida includes widely distributed **larger dominant gymnosperms** on the earth at present.
- The plants possess profusely branched shoot system which appears in the form of a cone.
- The leaves are **simple** and show many **xerophytic adaptations**.
- The wood is **pycnoxylic**, pith is small.
- Sporophylls form cones. They are **dioecious**, hard and woody.
- The seeds show **bilateral symmetry**, *eg*., *Pinus* (**described in details**), *Ginkgo*, *Taxus*.
- Conifers are **evergreen** in the sense that they do not shed their leaves as compared to deciduous plants which become bare by leaf shedding in winter (autumn).

Gnetopsida

- Gnetopsida includes **advanced gymnosperms** represented by climbers, shrubs or small trees.
- The stems are **branched**.
- Leaves are broad, simple, ovate, or **scaly**.
- Secondary xylem **shows vessels**.
- Sexual structures are **unisexual** situated in compound cones.
- Male sex organs are with **perianth members** and the female sex organs shows single straight ovule.
- The ovules are of **orthotropus type** and show **long tubular micropyle**.
- The embryo is with **two cotyledons**.
- The class **Gnetopsida** includes single order namely *Gnetales*, eg. *Gnetum*.

Table : Common name of some gymnosperms

Ginkgo biloba	–	Maiden hair tree
Sequoia	–	Red wood tree
Araucaria	–	Christmas tree/ Monkey's puzzle
Cycas revoluta	–	Sago palm
Pinus gerardiana	–	Chilgoza pine
P. roxburghii	–	Chir pine
P. insularis	–	Khasi pine

- **Largest egg, sperm and ovule** is found in *Cycas*.
- The fertilization in *Pinus* is **siphonogamous** *i.e.,* by pollen tube. In ferns it is **zooidogamous** *i.e.,* by multiciliated sperm. In *Cycas* both the events occur at the **same time**.
- *Cycas revoluta* and *Gingko biloba* considered as **living fossils**. *Ginkgo biloba* is the single living genus in a big fossilized order **Ginkgoales**. Hence it is called living fossil. *Cycas revoluta* show the primitive characters hence it is also considers as living fossil.

Economic importance

- Some of the gymnosperms like *C. revoluta, C. circinalis, Thuja, Taxus* etc. are used for **ornamental purpose**.
- Stem portion of *C. revoluta*, is a **good source of sago,** a kind of starch **used in making bread by poor people mainly in Japan**.
- *Zamia* is **rich is starch** and is **used by many Indian as food**.
- Seeds and seed kernals of some species are roasted and taken as food.
- Young succulent leaves of some species are **used as vegetables**.
- Seeds and stem of *C. revolula* are **used in making wine in Japan**.
- The leaves *C. circinalis* are medicinally very important. The fresh juice extracted from the leaves is used as medicine in stomach disorders, blood vomitting and other skin diseases.
- Pollen grains of some *Cycas* plants are reported to have some narcotic effect.
- Seeds and crushed bark of *Cycas* and its megasporophylls when mixed with coconut oil are used as poultice for sores and wounds in South India.
- *Thuja*, *Araucaria*, *Abies*, *Cryptomeria*, *Pinus*, *Taxus* are grown in parks.
- **Seeds** of *P. gerardiana* (Chilgoza), *Ginkgo biloba, Gnetum gnemon* are edible.
- **Manila copal** an important varnish resin is obtained from *Agathis sp.*
- **Canada Balsam** (Turpentine), a well known turpentine is obtained from *Abies balsamea* (used as mounting medium for biological preparation).
- *Pinus marittima* is a good source of **bordeus turpentine.**
- **Turpentine oil used in paint industries** is mainly obtained from resin of *Pinus* species.
- Timber is obtained from of *Pinus, Abies, Cedrus, Sequoia*.
- Fossil resin (Amber) is obtained from extinct pine *Pinus succinifera*, used in jewellery and carvel object.
- Wood gas, wood tar and wood alcohol are obtained from various species of *Pinus*. *eg. Pinus sylnestris*.
- Drug **ephedrine** is obtained from *Ephedra* which is used in curing respiratory ailments including asthma.
- A medicine of cancer called "**taxol**" is obtained from the bark of *Taxus*.
- *Gnetum ula* is a common source of edible oil. It is also used as massage in rheumatic pain. A volatile oil extracted from the shoots and leaves of biota (*Thuja*) is used as vermifuge. Oil of *Juniperus* is medicinally important.
- *Gnetum latifolium* yields fibre used in making ropes and nets.

CYCAS

Systematic position

– Phylum	:	Tracheophyta
– Class	:	Gymnospermae
– Subclass	:	Cycadophytae
– Order	:	Cycadales
– Family	:	Cycadaceae
– Genus	:	*Cycas*.

External morphology

- *Cycas* is an **evergreen palm-like plant**. It is the **only genus of family Cycadaceae** represented in India. Hence **also called as living fossil**.
- In India, **four** *Cycas* species are common in Orissa, Bengal, Assam, Tamilnadu, Karnataka and Andaman.

Cycas revoluta	:	Sago palm in India, Tesso in Japan and China.
Cycas circinalis	:	Jangli madan mast-ka-phul.
Cycas rumphii	:	Kama, Paiyindu.
Cycas beddomei	:	–

- Dominant stage in *Cycas* is **sporophyte**.
- Plant body is differentiated into **roots, stem and leaves**.

- Type of root system in *Cycas* is **tap root system**. These roots are **not green**, **positively geotropic with no root hairs**.
- From the lateral branches of the normal roots are formed **dichotomously branched, apogeotropic, bluish green roots** called **coralloid roots**.
- Rough texture of coralloid roots is due to the presence of **lenticels**.
- Coralloid roots show symbiotic association with **blue-green algae** *Anabaena cycadacearum, Nostoc punctiformae***.**
- Young stem of *Cycas* is **underground** and **tuber like**.
- Stem in *Cycas* is **caudex**, an unbranched columnar stem, with a crown of leaves at the top.
- Leaves are of **two kinds** – scale leaves and foliage leaves.
- A **single scale leaf** is a brown, dry, woody, triangular structure, covered with brown hairs or **ramenta.**
- Foliage leaves are **unipinnately compound.** Leaves are leathery and thick, some leaflets at the base of the rachis are reduced to spines.
- Leaves of *Cycas* are **megaphylls** (each leaflet contains a single midvein).
- Leaflets of young leaf show **circinate vernation**.

Anatomy

- Internal structure of normal root of *Cycas* resembles dicot root. Stele of normal root of *Cycas* is **diarch**/ **tetrarch** and **exarch**.
- Old coralloid root of *Cycas* consists of **periderm in the place of epidermis**. Periderm is **formed from cork cambium**.
- Cortex of coralloid root is divisible into – outer **cortex, middle cortex** (algal zone) and **inner cortex**.
- Tips of coralloid roots are **degenerated due to infection by bacteria**.
- Some of the cells of outer and inner cortex contain **tannins**, **sphaeraphides** and **starch materials**.
- Stele of coralloid root is **triarch and exarch**.
- Presence of **girdle leaf traces** is a characteristic feature of *Cycas* stem.
- **Mucilage canals** (of schizogenous nature) are present both in the cortex and the pith.
- Vascular bundles in young stem of *Cycas* are **conjoint, collateral, open** and **endarch**.
- Phloem is devoid of companion cells instead **albuminous cells** are present in phloem.
- **Anomalous secondary growth** is present in *Cycas* stem. Formation of **more than one cambial ring is an anomaly**.
- Large amount of parenchymatous cells are present with secondary xylem tracheids, so the wood is called **soft wood** or **manoxylic wood.**
- Secondary xylem in *Cycas* is **polyxylic** (formation of several rings of xylem).
- In *C. pectinata,* **14 rings** have been reported.
- **Transfusion tissue** (tracheid like and colourless) extends from the vascular bundle to the margin of the leaflet.
- Rachis has epidermis with sunken stomata, chlorenchyma, sclerenchyma, and ground tissue with mucilage ducts.
- Vascular bundles in rachis of *Cycas* **show inverted omega-shaped arrangement**.
- Vascular bundle in rachis and leaflet is **diploxylic** (presence of centripetal xylem and centrifugal xylem is in the same vascular bundle) and **pseudomesarch**.

Xerophytic characters of *Cycas* leaflet
Leaflets are thick and leathery.
Thick cuticle.
Epidermis with thick-walled cells.
Sclerenchymatous hypodermis.
Presence of transfusion tissue.
Absence of lateral veins.
Hypostomatous condition, sunken stomata.

Reproduction

- The *Cycas* plants reproduce both by **vegetative** and **sexual methods**.
- Vegetative reproduction in *Cycas* **takes place by bulbils formed on stem.**
- *Cycas* plant is dioecious *i.e* separate male and female plants.
- Plant of *Cycas* is **sporophyte** ($2n$) and the sexual reproduction is of **oogamous type**, *i.e.,* takes place by the fusion of distinct male and female gametes.
- The male and female gametes are formed by the germination of micro and megaspores which are borne on **microsporophylls** and **megasporophyll**.
- Microsporophylls unite to form a cone.
- Type of growth present in male plant of *Cycas* is

sympodial. *i.e.,*the cone is later pushed to lateral side and the stem continues to grow.

- The arrangement of microsporophylls on cone axis of male cone is **spiral.**
- Each microsporophyll is 5 – 6 cm long, wedge shaped woody structure.
- The terminal sterile part of microsporophyll is called **apophysis**.
- **Microsporangial sori** are **present on the abaxial surface** (**under surface**) of the microsporophyll (**fern character**).
- The number of microsporangia on a single microsporophyll are **900 - 1000**. In *C. media* there are about **1160 sporangia**.
- Microsporangia are shortly stalked, oval or oblong structure and dehisce by longitudinal slits.
- Reduction division occurs in **microspore mother cells**.
- Pollen grains are boat shaped.
- Female cone is **absent** as megasporophylls do not aggregate instead are **loosely arranged round stem tip**.
- Type of growth in female plant of *Cycas* is **monopodial**. Megasporophylls of *Cycas* consist of basal sterile stalk ovule bearing middle part and upper sterile part or apophysis.
- Megasporophyll of *Cycas* is equivalent to the **carpel of angiosperms.**
- **Ovule** of *Cycas* is naked, orthotropous and 2 – 12 reddish brown ovule borne laterally in two rows.
- The ovules of *Cycas* are **largest in nature**, can be seen by naked eyes. In *C. circinalis*, the ovules are largest in size *i.e.,* about **6 cm in length** and **4 cm in diameter**.
- The ovule consists of a micropylar beak, three layered integument, a nucellus and female gametophyte.
- Integument of *Cycas* is divisible into **three layers**– outer fleshy layer (sarcotesta), middle stony layer (sclerotesta) and inner fleshy layer.
- **Number of vascular bundles** that enter into the ovule of *Cycas* is **three**.
- Female gametophyte in *Cycas* acts as **endosperm** with 2 – 8 archegonia.
- Chromosomal condition of endosperm in *Cycas* is **haploid** as it is **formed before fertilization**.
- A pollen chamber is present at the micropylar end of nucellus.
- Ripe ovule secretes **pollination drop** through the micropyle, which trap pollen grain.
- Pollination in *Cycas* is **anemophilous** and **direct**.
- Pollen grains which are at **3-celled stage** (tube cell, generative cell and prothalial cell) reach the pollen chamber due to the **drying of the pollination drop**.
- A large **pollination drop** comes out of micropylar end of ovule by disorganization of **nucellar beak** (The apex of the nucellus develop beak like process. This is called nucellar beak).

Development of male gametes

Microspore
→ Prothallial cell, Antheridial cell
Antheridial cell → Tube cell, Generative cell
Generative cell → Stalk cell, Body cell
Body cell → 2 Sperms

- The **male gametes of Cycas are largest** (300 m) in nature, visible to naked eye oval in form and are **multiciliate** (multiflagellate).
- Water is essential for **fertilization** in *Cycas*.
- **Free nuclear divisions** occur in the zygote of *Cycas*.
- **Proembryo** is formed first from the zygote.
- Proembryo is **divided into 3 regions** –
  - **Haustorial region** for **absorption of food materials** from the endosperm.
  - **Suspensor region** for **pushing the embryo into the endosperm**.
  - **Embryonal region** that **gives rise to proper embryo**.
- Embryo consists of **suspensor**, **radicle**, **two unequal cotyledons** and **plumule**.
- Ovule is converted into seed having 3 layered seed coat (outer, middle and inner).
- Seed in *Cycas* is **naked**, **endospermic** and **perispermic**.
- **Type of germination** in *Cycas* is **hypogeal**, cotyledons remain underground.
- Alternation of generations is **heteromorphic** and life cycle is diplohaplontic.
- The time gap between pollination and fertilization is about 5 – 6 **months**.

PINUS

Systematic position

– Phylum : Tracheophyta

– Class : Gymnospermae
– Subclass : Coniferophytae
– Order : Coniferales
– Family : Pinaceae
– Genus : *Pinus*.

- Only **six species** are found in India.

Scientific name	Common name
Pinus gerardiana	Chilgoza pine
Pinus wallichiana	Blue pine or kail
P. roxburghii (P. longifolia)	Chir pine
P. merkusii	Teenasserim pine
P. insularis (P. khasya)	Khasi pine
P. armandi	Armand's pine

- In addition to above, **some exotic species have also been introduced in India**, *e.g.*, *P. sylvestris*, *P. laricia, P. montana* and *P. strobus* (white pine).

External morphology

- The **plant body is sporophyte** and the plants are **monoecious**.
- The plant body is differentiated into **roots, stem** and **leaves**.
- *Pinus* is an **evergreen, perennial plant of xerophytic nature**. Mostly the species are tall and straight.
- The **whorled branching** gives a typical conical or **excurrent appearanc**e to the plant (due to apical dominance).
- Predominantly **tap root system** is present where primary roots are less developed and lateral roots are well developed.
- The root hairs are poorly developed and hence **ectotrophic mycorrhiza** (symbiotic association of fungal hyphae with the branches of roots) is of common occurrence in *Pinus* **for absorption of water**.
- The stem is tall, erect, cylindrical and the branching is **monopodial type**.
- The stems are branched and the branches are **dimorphic** - (i) **Branches of unlimited growth** or **long shoots** or long laterals and (ii) **Branches of limited growth or dwarf shoots or spur shoots** or short laterals.
- The **dwarf shoots** are **borne on the axis of scale leaves of long shoots**.
- The leaves are also **dimorphic, scaly and foliage**.
- Scale leaves are **green when young** but at maturity they become **brown**.
- **Foliage leaves** are present only at the apex of dwarf shoots. They are long, **needle-like** (acicular) green structures, present for 3 or more years and thus the plants are evergreen.
- The dwarf shoot with needles is called a **'spur'**.
- The number of needles per dwarf shoot is variable – **monofoliar** (with one needle), **bifoliar** with two needles), **trifoliar** (with four needles) and **pentafoliar** (with five needles).

Anatomy

- The primary root is distinguishable into **epidermis, cortex, endodermis, stele** and **pith**.
- Pericycle is multilayered.
- The **cortex** is infected with ectotrophic mycorrhiza.
- Vascular bundles are radial.
- The xylem is **Y-shaped** in T.S. being forked at the protoxylem end.
- There is a **resin canal** in the fork of xylem.
- The xylem is made up of **tracheids only**, vessels are absents.
- The phloem is made up of sieve cells but there are **no companion cells**.
- In young roots, cambium is absent but at maturity below the phloem patches, arches of cambium are formed. It cuts off **secondary xylem on the inner side and secondary phloem on the outer side**.
- In a T.S. the young stem of *Pinus* appears to be a ribbed structure due to the presence of **leaf bases and dwarf shoots.**
- Epidermis of stem is provided with thick cuticle and hypodermis is sclerenchymatous, **resin canal is present in cortex**, some cells contain tannins.
- The vasculature of stem comprises a **eustele** and vascular bundles are **conjoint, collateral** and **open bundles** resembles dicot stem. It is described as an **eustele**.
- Xylem is endarch devoid of vessels after secondary growth and form **non-porous wood**.
- Protoxylem consists of annular and spiral trachieds, metaxylem has uniseriate bordered pits on tracheids.
- Presence of bars of sanio.
- The wood is **pycnoxylic** (compact and hard). Phloem is made up of **sieve cells and albuminous cells**.
- The albuminous cells **are analogus to** companion cells of angiosperms but **not homologous**.
- **Intrafascicular cambium** is **present in between**

xylem and phloem, presence of parenchymatous medullary rays.

- Secondary growth is observed consisting of distinct annual ring containing spring wood and autumn wood.
- Autumn wood is formed during autumn and cells are smaller squarish and thick.
- Spring wood is formed during spring and cells are thinner, larger and polygonal. This is called **pycnoxylic**.
- **Resin canals** are **present in cortex and xylem** and are schizogenous cavities.
- Needles have sunken stomata throughout the surface *i.e.*, **amphistomatic**.
- The stomata comprises of two guard cells surrounded by **6-8 subsidiary cells**. The subsidiary cells enclose a supra stomatal space called as **vestibule**.
- Mesophyll is undifferentiated into palisade and spongy parenchyma.
- Vascular bundles are obliquely placed, collateral, open, endarch.
- Vascular cylinders were surrounded by single-layered endodermis having barrel-shaped cells with **casparian strips**.
- Pericycle is multilayered and composed of four types of cells - **parenchymatous cells, sclerenchymatous cell, albuminous cells, tracheidal cells**.
- **Transfusion tissue** is **composed of 2 types of cells - tracheidal cells** and **albuminous cells**.
- **Tracheidal cells** are tracheid-like cells having pits, **found close to the xylem elements** of the bundles. This is generally referred to as **transfusion tissue**.
- **Albuminous cells** are **living cells** without pits and **help conduction**.

Xerophytic characters shown by *Pinus* are – (i) reduced leaf surface (acicular), (ii) presence of thick cuticle, (iii) thick walled hypodermis, (iv) presence of sunken stomata, (v) special type of mesophyll (arm palisade), (vi) sclerenchymatous sheath inbetween the bundles.

Reproduction

- Vegetative reproduction is **absent** in *Pinus*.
- *Pinus* is a heterosporous, monoecious plant producing micro and megaspores in **micro and megasporangia** respectively.
- The **microsporangia** are borne on microsporophyll which constitutes the **male cone**.
- A male cone consists of a central axis bearing 60-135 microsporophylls in spiral manner. It is, therefore, comparable to **male flower of angiosperms**.
- Each microsporophyll is small, brown, scaly and triangular having a short stalk and leaf-like sterile expansion called **apophysis**.
- Microspores are produced in such a large number that at the time of their dispersal, yellow clouds of pollen grains are produced, which is called **"shower of sulphur"** or **"shower of golden dust"**.
- The **megasporangia** are produced on ovuliferous scales formed along with a bract. The ovuliferous scales and bracts constitute the **female cone.**
- Each female cone **matures in three years**. In the third year it matures with ovules.
- Each female cone is an oval or somewhat elongated structures with an elongated central axis around which a large number of megasporophylls are arranged in an **acropetal and spiral manner**.
- The female cone **represents an inflorescence** because the ovule bearing ovuliferous scales are borne on the bract scales which are directly formed on the central axis.
- A megasporangium or ovule of *Pinus* is **orthotropous**. Ovule has an oblique micropyle, nucellus and female gametophyte having 1 – 8 archegonia.
- Archegonia has 2 – 4 celled neck, ventral canal cell and egg.
- The ventral canal cell **disorganizes before fertilization**. Neck canal cells are absent.
- Integument is differentiated into **3 layers** : **outer fleshy** layer, **middle fleshy layer**, **inner fleshy layer**.
- The pollination in *Pinus* is **anemophilous** (brought out by wind).
- There is a long interval of **about a year** between pollination and fertilization.
- Endosperm of *Pinus* differs from angiosperms as it is a **pre-fertilization structure**, while in angiosperms it is a post-fertilization structure.
- The micropyle of each ovule contains mucilage or pollen drop to catch pollen grains.

- Pollen grain
  - 2 prothalial cell
  - generative cell
    - stalk cell
    - body cell
      - male gametes (non flagellate)
  - tube cell
    - pollen tube

- The zygotic nuclei divide to **form four nuclei**. These four cells divide simultaneouly **thrice** to form **four tiers of four cells each**.
- **Embryonal tier (4 cells)** is the lowermost tier, which **forms the embryo**.
- **Suspensor tier (4 cells) :** Above the lower tier which elongates and gives rise to long **suspensors**.
- **Rossette tier (4 cells) :** Above the suspensor tier and mediates between the suspensor tier and nutritive tier.
- **Nutritive tier (4 cells) :** The cells remain open above and provide nutrition to the remaining proembryo.
- Since **only a part of the oospore** is involved in the formation of the embryo, the development is said to be **meroblastic**.
- All the four cells of the embryonal tier separate from each other and develop independently into four embryos. The formation of more than one embryos from one oospore is called **cleavage polyembryony**.
- **Simple polyembryony** is also found in *Pinus* (where more than one embryos are formed as a result of fertilization of different archegonia).
- Inspite of having polyembryony only **one embryo** is found at maturity.
- The mature embryo consist of **9 – 14 cotyledons**, **plumule** (embryonic shoot) and **radicle** (embryonic root).
- The mature ovule with embryo constitutes seed.
- As the seed of *Pinus* is winged it is **anemochorous** (dispersed by wind).
- These seeds show three generation -
  - **Old sporophytic generation** by testa, tegmen and nucellus.
  - **Gametophytic generation** by endosperm.
  - **Future sporophytic generation** by embryo.
- The germination of seed is of **epigeal type**, *e.g.,* the cotyledons come above the ground by the elongation of hypocotyl.

End of the Chapter

Chapter 11

Angiosperms

- Angiosperms or flowering plants **form the largest group of plant kingdom**, including about 300 families, 8000 genera and 300,000 species.
- They are considered to be highest evolved plants on the surface of earth.
- Angiosperms better known as **flowering plants**, are **vascular seed plants** that produce **flowers** and **fruits**.
- They are by far the most **diverse and geographically** widespread of all plants.
- There are about **250,000** known species of angiosperms.
- As late as the 1990s, most plant taxonomists divided the angiosperms into two main classes – the **monocots** and **dicots.**
- A typical angiospermic plant is **sporophytic** (2n) and have both **vegetative parts** and **reproductive parts**.
- **Vegetative parts or organs** of an angiospermic plant are **root**, **stem and leaves**.
- **Roots** collectively constitute **root system**, which generally constitute the under ground portion of the plant.
- The **stem with its branches and leaves** constitute **shoot system**, which is generally **above ground** or **aerial part** of the plant.
- Flower formation is the **transitional phase** (change from vegetative phase to reproductive phase) in the life cycle of an angiospermic plant.

Forms of angiosperms

- On the **basis of habit** an angiosperm plant can be a herb, shrub, tree creepers, twiners, climber and lianas.
- **Herbs** are small plants with soft and pliable stems. Herbs can be **annual** (*e.g.*, Buttercup), **biennial** (*e.g.*, Henbane) and **perennial** (*e.g.*, *Canna*).
- **Shrubs** are woody plants and are branched near the ground, stem is not much developed into clear trunk.
- **Trees** are woody plants, which are branched at some height and thus have much developed trunk.
- Trees further may be **excurrent or conical** (having basal thicker portion and thinner or tapering portion above), **caudex** (unbranched stem with crown of leaves at apex) or **deliquescent/ decurrent** (sub branches grow after death of apical bud of stem).
- **Trailers** are plants which spread on the ground without rooting at intervals, *e.g.*, *Tribulus terrestris, Euphorbia prostrata.*
- **Creepers** are plants spread on the ground, rooting at intervals, *e.g.*, strawberry.
- **Twiners** are weak-stemmed plants where the stem coils or twines around an upright support, *e.g.*, *Ipomoea cairica* (Railway creeper), *Quisqualis* (Rangoon creeper).
- **Climbers** are plants that climb up an upright support by special clinging or clasping structures like tendrils, roots and hooks.
- Woody twiners and climbers are called **lianas**. They are found in tropical evergreen forests, *e.g.*, *Phanera* (= *Bauhinia*) *vahlii*, *Hiptage*.
- **Epiphytes** are plants which live on other plants for space only. Angiospermic epiphytes commonly live on trees, *e.g.*, *Vanda*, *Dendrobium*. They often possess hanging roots with hygroscopic outer spongy tissue called **velamen**.
- **Culms** are the plants where stem is having very clear nodes and internodes (joined stem). Here nodes are solid and internodes are generally hollow, *e.g.,* grasses (members of gramineae) and sedges (members of cypreceae).
- On the **basis of life span** angiosperm plants can be annual, biennials or perennials.

- **Annual plants** complete their life cycle **within one year**, eg. rice, wheat.
- Such annuals which complete their life within a brief or short (generally 4-6 weeks) period of time, are called **ephemeral annuals** or **ephemerals**, *e.g., Argemone* (pili katili), *Artemisia, Astragalus*, etc.
- **Biennials** complete their life cycle in two growing seasons (*i.e.*, complete their vegetative phase in first season and reproductive phase in second season). Eg Henbane, raddish.
- **Perennial** grow for a number of seasons or for many years.
- Perennial plants may be **polycarpic** *i.e.,* produce flower and fruit every year, eg. mango or **monocarpic** *i.e.,* produce flower and fruit once in life, *e.g., Bambusa bamboos.*
- The **century plants** flowers after about 100 years and after flowering dies.
- Banana (*Musa*) is one of the **largest perennial herbs**.
- On the **basis of mode of nutrition** angiosperms may be **autotrophic or heterotrophic**.
- Plants which can manufacture their own organic food from inorganic substances, are called **autotrophic or autophytes**.
- **Photoautotrophs or photoautotrophic plants** manufacture their food in presence of chlorophyll and light from CO_2 and H_2O by the process of **photosynthesis**, *e.g.,* most of the green plants.
- **Chemautotrophs or chemosynthetic plants** manufacture their food using chemical energy (not light energy) without presence of chlorophyll, *e.g.,* chemosynthetic bacteria.
- The plants which are unable to manufacture their own food and depend upon other green plants for food are called heterotrophic or **heterotrophs.**
- Hetrotrophic plants are of **three types** –
  - **Saprophytes** – obtain nourishment from dead decaying organic matter
  - **Parasites** – obtain nourishment from other living organisms
  - **Carnivorous** – predator plants that grow in nitrogen deficient soil.

Vegetative and floral characters of angiosperms

- Roots are **adventitious** in monocots and **tap root** in dicots.
- Stems may be erect, branched or unbranched, **trailers** or **climbers** or **twiners**.
- Leaves varies like **seed** leaves, **scale** leaves, **bract** leaves, **floral** leaves, **prophylls**, **foliage** leaves.
- Leaves may be **simple or compound**, lamina may be **dorsiventral or isobilateral**.
- **Foliage leaves** are green, expanded, dorsiventrally flattened with or **without stipule**.
- Leaf base in monocots are generally **sheathing without stipules**.
- Flowers may be single or in groups forming **inflorescence**.
- Inflorescence may be **racemose or cymose** or **special type**.
- Flowers may be **complete, incomplete, unisexual, bisexual, sterile** or **naked**.
- **Complete flower** have all the four whorls – calyx, corolla, androecium and gynoecium while **incomplete flower** have one or more of the four whorl missing.
- Bisexual flower have both **androecium** and **gynoecium** while unisexual plant have **either female part (pistillate)** or **male part (staminate)**.
- Essential whorls of flowers are **stamens** and **carpels**.
- Stamens consist of **filament, connective** and **anther**.
- Carpels consist of **ovary, style** and **stigma**.
- Pollen grains are **formed within anther**.
- Ovules are **present within ovary**.
- The development of male gametophyte is completed within the pollen tube **before fertilization**.
- **Double fertilization** occurs and endosperm is **triploid**.
- Seeds always remain within **fruit**.
- Angiosperm seeds may have **one, two** or **many** cotyledons.
- A fruit is a **mature ovary** as seed develop from ovules after fertilization, the wall of the ovary thickens to form the fruit.
- Fruits **protect dormant seeds** and aid in their dispersal.
- Fruits are classified into several types depending on their **developmental origin** as – **simple fruits** (derived from a single ovary), an **aggregate fruit** (results from a single flower with several carpels), a **multiple fruit** (develops from an inflorescence).
- Seeds may be **endospermic** or **non-endospermic**.
- Germination of seeds may be **epigeal** or **hypogeal**.
- Vascular bundles of root are **radial** and **exarch** in angiosperm.

- Number of vascular bundles in root anatomy are **more than six** in monocots and **2-6** in dicots.
- In stem vascular bundles are **conjoint, collateral** or **bicollateral open** (in dicot) or **closed** (in monocots) and **endarch.**
- Ground tissues are **not differentiated** into cortex, endodermis, pericycle and pith in monocots stem while separated in dicots.
- Pith is large in roots of **monocots** while absent or very small in **dicot**.
- **Secondary growth** occur in dicot stem but not in monocot stem.
- Refinements in vascular tissue, especially xylem, probably played a role in the enormous success of angiosperms in **diverse terrestrial habitats**.
- Like gymnosperms, angiosperms have long, tapered **tracheids** that function for **support and water transport**.
- Angiosperms also have **fibres cells**, specialized for support, and **vessel elements** (in most angiosperms) that develop into xylem vessels for efficient uptake of water. While evolutionary refinements of the vascular system contributed to the success of angiosperms, the **reproductive adaptations associated with flowers and fruits contributed the most**.
- One hypothesis for the function of double fertilization is that it synchronizes the development of food storage in the **seed with development of the embryo**. Double fertilization may prevent flowers from **squandering nutrients on infertile ovules**.

Economic importance of angiosperms

- Agriculture is almost entirely dependent on angiosperms, either directly or indirectly through livestock feed.
- Of all the families of flowering plants, the Poaceae, or grass family, is by far the most important, providing the bulk of all feedstocks (rice, corn maize, wheat, barley, rye, oats, millet, sugar cane, sorghum).
- The fabaceae, of legume family, is in second place.
- Also of high importance are the Solanaceae, or nightshade family (potatoes, tomatoes, and pepper, among others), the Cucurbitaceae, or gourd family (also including pumpkins and melons), the Brassicaceae, or mustard plant family (including rapeseed and cabbage), and the Apiaceae, or parsley family.
- Many of our fruits come from the Rutaceae, or rue family, and the Rosaceae (rose family, including apples, pears, cherries, appricots, plums, etc).
- In some parts of the world, certain single species assume great importance because of their variety of uses. An example is the coconut (*Cocos nucifera*) on Pacific atolls. Another example is the olive (*Olea europaea*) in the Mediterranean.
- Flowering plants also provide economic resources in the form of wood, paper, fibre (cotton, flax and hemp, among others), medicines (*Digitalis*, camphor), decorative and landscaping plants, and many other uses.
  [*For more details on economic importance, refer chapter Economic Botany*.]

- The **oldest angiosperm fossils** are found in rocks in the early cretaceous, about 130 million years ago.
- By the end of the cretaceous period, 65 million years ago, angiosperms had **become the dominant plants on Earth**.
- *Scindapsus officinale* (family, araceae) is exceptional angiosperm which **begins terrestrial life** but at maturity becomes **epiphytic**.
- Angiosperms with **haustoria** are parasitic form as *Viscum, Loranthus* and *Cuscuta* etc.
- **Smallest angiosperm** is duckweed (*Lemna*).
- **Smallest flower** belongs to *Wolffia microscopia*.
- **Largest flower** belongs to *Rafflesia arnoldi* (1 m in diameter weigh, 15 kg) a fatal root parasite.
- **Smallest parasitic angiosperm** is *Arceuthobium minutissimum*.
- **Leafless inflorescence** is depicted by *Balanophora dioica*.
- **Largest inflorescence** of the world belongs to *Puya raimondii* (32 ft.) and the **second largest** is *Amorphophallus* (8 ft).
- *Monotrapa* and *Sarcodes* (family pyrolaceae) are **total saprophytic angiosperms** having mycorrhizae.
- **Dicot without cotyledons** is *Cuscuta reflexa*.

End of the Chapter

Chapter 12

Evolutionary Trends & Classification of Animals

- All the present day animals species have originated more than one billion years of evolution.
- **Aristotle (father of biology)** divided animal kingdom into - **enaimia** (vertebrates having red blood) and **anaimia** (vertebrates with no red blood).
- Animal kingdom is the **kingdom of multicellular eukaryotic animals** and is **one of the five kingdom scheme of classification (by Whittaker)**.
- Since biospheres contains enormous diversity of animals so **their classification is based on different important characteristic features** like - habitat, germ layers, coelom, grade of organization, symmetry etc.
- Animals have their own habitat such as land, (**terrestrial animals**), water (**aquatic animals**) and air.
- **Types of aquatic animals** are – **zooplankton, nekton** and **benthon.**
- **Zooplankton** are **passively floating or drifting animals** in a body of water. Eg. many protozoans, protists, small crustaceans and various invertebrates larva.
- **Nekton** are **actively swimming aquatic organisms** in a body of water, able to move independently of water currents, eg. shark, bony fishes.
- **Benthon** living at bottom. **It may be sedentary or motile**, eg. starfish, sea cucumber, sponges etc.
- Both zooplankton and nekton are called **pelagic animals** because they live in open water of a sea or lake.
- **Types of terrestrial animals** are
  – **Cursorial**–Run fast (Kangaroo, dog, horse)
  – **Fossorial**–Live in burrows/underground (Earthworm, rabbit)
  – **Arboreal**–Live on trees (Bats, monkeys)
  – **Scansorial**–Climb walls, rocks etc. (Wall lizard, flying squirrel)
  – **Aerial/flying**–Can fly (Winged insects, birds, bats etc.)
- According to **habit** animals may be–
  – **Solitary** (live alone)–Tapeworm, grasshopper.
  – **Colonial** (live in groups and help one another, shows social life)–Honey bees, termites, wasps, ants.
  – **Gregarious** (live in groups, but can't help)–Horse, dog.
  – **Parasites** (depend on other animals for food, protection etc)–Tapeworm, *Ascaris* etc.
  – **Motile**–Earthworm, cockroach etc.
  – **Mimicry** (Resemblance of another animal for the purpose of concealment, protection or some other advantage).
- **Three basic types of body plan** in animals are– **cell aggregate**, **blindsac** and **tube – with - in a tube plan**.
- In **cell aggregate body plan** an animal can exhibit cell aggregates with no tissue or organs and exhibit loosely arranged cells, eg. porifers.
- **Blind sac plan or hollows sac plan** have a single opening for digestion and egestion in their digestive tube (bind sac), eg. cnidarians and platyhelminthes.
- **Tube – with - in a tube plan** have a complete digestive tract (with mouth and anus) forming a internal tube. *e.g.,* annelids, arthropoda, molluscs, echinodermata and higher chordates.
- In **protostomatic forms** mouth is formed from blastopore region and appears first in the embryo, eg. annelids, aschelminthes, arthropods and molluscs.

Table : Some terms of animal bodies.

Term	**Description**
Oral	The end towards mouth
Aboral	The end opposite to mouth
Anterior	The head end
Posterior	The tail end
Cephalic	Toward the head
Caudal	Toward the tail
Proximal	Toward the point of attachment of a structure on the body
Distal	Away from the point of attachment of a structure on the body
Dorsal	The back of an animal, usually the upper surface
Ventral	The belly of an animal, usually the lower surface
Superior	Above a point of reference
Inferior	Below a point of reference
Pectoral	The chest region– the area supported by fore limbs
Pelvic	The hip region– the area supported by hind limbs

- In **deuterostomatic forms** anus develops from blastopore region and appears first in the embryo, eg. echinoderms and chordates.
- Protostomes and deuterostomes also **differ in the mode of coelom formation**, **early development like cleavage** and **type of embryo**.
- **Metamerism** is body structure having repeated segments. It **help develops specialization of organs**. eg., annelids.
- **False segmentation** or **pseudometamerism** occur through budding in tapeworm. In them body is divided into many segments known as **proglottids**.
- Metamerism **results in the separation of mesoderm into segmented blocks of muscles**. In annelids, there are both external and internal segmentation.
- Arthropods shows **only external segmentation**.
- In chordates **only internal segmentation is present**.
- **Symmetry** refers to the similarity to the arrangement of parts on the opposite sides of the body which make possibility to cut the body into two similar halves by one or more planes.
- **Types of symmetry** are – spherical, radial and bilateral.
- **Spherical symmetry** divides the body into similar halves by any plane passing through the centre. In this the sides of the body are indistinguishable.
- Spherical symmetry is **found chiefly among some of the protozoa** (*e.g.*, *Volvox,* heliozoa, radiolaria) and is **rare in animals**.
- Spherical forms are **best suited for floating and rolling**.
- In **radial symmetry**, body can be divided into equal halves by any plane passing through the centre from top to bottom. This symmetry permits an animal to detect food or danger approaching from any side, eg., *Hydra* and jellyfish.
- Radial animals are **usually sessile**, **freely floating or weakly swimming**.
- The animals, with no front or back end, can interact with their environment in all directions.
- The echinoderms (sea stars and their kin) are primarily bilateral animals (their larvae are bilateral) that have become secondarily radial as adults.
- In **biradial symmetry** the body can be cut into two similar halves by one or two vertical planes only, eg., *Sea anemones* and sea walnuts.
- The **main distinguishing feature between radial and biradial symmetry** is **oral** (which bears mouth) and **aboral side** (which is opposite to the mouth).
- In all vertebrates & most invertebrates the chief organs of the body are paired and are arranged on the sides of a central axis connecting the head with the tail. With the result, the body can be divided into two similar halves by a single plane. Such a symmetry is called **bilateral symmetry.**
- Bilateral symmetry **allows an animals to have more streamlined shape** and to concentrate the power of its muscles and appendages for producing motion in one direction. In this the sides, surfaces & ends of body are clearly distinguishable.
- Bilateral symmetry **developed due to cephalization**.
- **Cephalization** means definite head at anterior end. It involves the concentration of nervous tissues (brain) & sense organs in the head.

- This arrangement is an assest in an adjustment with the environment as the anterior end of a moving animal is the first to encounter changes in the area it is entering. It evolved in the remote past due to creeping habit.
- Cephalization **begins in platyhelminthes**.
- **Coelom** is the name given to the internal body cavity that separates the digestive tract from the outer body wall.
- It is filled with a fluid and lined by peritoneum derived from mesoderm.
- **Function of body cavity** are–
  - Cushion the organs thus preventing injury.
  - Allow internal organs to grow and move independently of the outer body wall.
  - Serve as a hydrostatic skeleton in soft bodies coelomates such as earthworms.
- **Types of coelom** are – acoelom, pseudocoelom and eucoelom.
- **Acoelom** means without body cavity which is due to failure of mesoderm to cavitate during embryogeny, so no coelom, no peritoneum. The area between the digestive tract & outer wall is filled with cells, producing a solid body, eg. porifera, coelenterata, platyhelminthes (flatworms).
- **Pseudocoelom** or **false body cavity** means presence of coelom (that develops from the **blastocoel**) but not lined by mesoderm, eg. roundworms (nematodes), rotifers.
- **Eucoelom** or true coelom *i.e.,* lined by mesoderm, resulting in tube-within-tube design, eg. higher invertebrates (annelids, echinoderms) and chordate.
- True coelom is of **two types** :
  - **Schizocoelom** (develop as a split in the mesoderm sheet), eg. – annelida, arthropod & molluscs.
  - **Enterocoelom** (mesoderm arises from the wall of embryonic gut or **enteron** as hollow outgrowths or enterocoelomic pouches), eg.– echinoderms & chordates.
- In arthropoda and molluscs the **actual or true coelom is reduced** but spaces between viscera grow and form a large cavity filled with blood called **haemocoel** (= haemocoelom).
- **Appendages** are projecting parts of body used for specific functions like feeding, locomotion and sensation, eg. tentacles, setae, parapodia, antennae, legs, wings, fins etc.
- **Skeleton** of animals provide shape, support, protection and help in locomotion.
- **Exoskeleton** is secreted by skin or ectoderm and made of non living materials, eg. calcarious shell of molluscs, chitinous cuticle of arthropods, hair, nail, scale, hoofs, horns, feathers.
- **Endoskeleton** is internal skeleton which is produced by mesoderm or occasionally endoderm, eg. notochord, cranium, skeleton and cartilaginous tissue from most of the vertebrates.
- Endoskeleton **consists of cartilages, bones and connective tissues of various types**.
- **Level of organisation** are of **five types** – **acellular**, **cellular**, **tissue**, **organ** and **organ system**.
- All activities at **protoplasmic grade (or acellular)** level are confined within the limits of a single plasma membrane (plasmalemma), eg. protozoa.
- In **cellular grade** body consists of many cells. They **exhibit division of labour for performing specialized functions**.
- Cellular level of organization are of **two types– cellular colony level of organisation** where all the cells are similar and found in protists and some algae (*Volvox*), and **cellular aggregate level of organisation**, found in sponges where the cells are of different types but are not organised into tissues.
- In **cell-tissue grade** cells are not only specialized for different function but also certain similar cells gather together to form tissues as well. A noteworthy **example** is the nerve net formed by nerve cells & their processes, eg. coelenterate.
- **Tissue organ grade** (or organ level) appears in flatworms with the arrangement of tissues to form organs.
- In **organ system grade** body is multicellular with tissues, organs & system. In this, organs join together in a system to perform some functions. It is typical to all higher invertebrates forms.
- A multicellular body shows organisation into: tissues $\rightarrow$ organs $\rightarrow$ organs system, eg. round worms to chordates.
- A **digestive tract is present** in all those animals which show tissue and higher level organisation is called **enterozoa**.
- Digestive tract may be **incomplete** with single opening both for ingestion as well as elimination,

eg. coelenterate and earthworm; and **complete** with two openings one for ingestion and another for elimination, eg. from roundworm to mammals.

- In many animals the body temperature varies according to surrounding environment for normal vital activities. They are **poikilothermic** & **homoiothermic**.
- **Cold blooded animals (or poikilothermic animals)**, often known as **ectotherms**, do not keep their body temperature constant so when their body temperature is high (on a hot summer day), they can be very active & when it is low (on a cold winter night) they can produce energy only slowly & so are torpid (means very inactive & can move slowly). Eg. invertebrates, fish, amphibians & reptiles.
- **Warmblooded animals** (or **Homoiothermic animals**) often known as **endotherms**, have relatively constant body temperature.
- Their **body temperature is independent of that of their external environment**.
- Body temperature of endotherms is derived from heat produced by their own oxidative metabolism & the presence of insulating hair, feathers & blubbers prevents this internally generated heat from freely diffusing to the external environment. Eg. mammals & birds.
- When both male & female sex organs are found in one individual. Then the individual is called **hermaphrodite** (bisexual or monoecious), eg. earthworm, liver fluke, leech etc.

Table : Modes of respiration.

	Mode of respiration	Respiratory organ	Examples
1.	Body-surface respiration	Body-surface	Sponges (*Leucosolenia*) and coelenterates (*Hydra*)
2.	Branchial respiration	Gills	Crustaceans (Prawn), cartilage and bony fishes.
3.	Cutaneous respiration	Skin	Annelids (earthworm) and amphibians (frog)
4.	Tracheal respiration	Tracheae (ectodermal tubes)	Insects (cockroach), centipedes, millipedes.
5.	Pulmonary respiration	Lungs	Most of tetrapods.
6.	Book-lung respiration	Book-lungs	Arachnids (spiders and scorpions).
7.	Book-gill respiration	Book-gills	*Limulus* (King-crab)

Table : Types of excretory organ.

	Animal groups	Excretory organs
1.	Porifera and Coelenterata	By diffusion through body surface
2.	Platyhelminthes (Flatworms)	Protonephridia (flame cells)
3.	Aschelminthes (Round worms)	Excretory canals (Renette cell)
4.	Annelids (Segmented worms)	Nephridia
5.	Crustaceans (*e.g.* Prawn)	Antennary or green glands
6.	Arachnids (*e.g.*, Scorpion)	Coxal glands and Malpighian tubules (in some spiders)
7.	Insects, centipedes and millipedes	Malpighian tubules and urate cells
8.	Molluscs	Renal organ or renal sac
9.	Vertebrates	Kidneys

Table : Types of nervous system in different animal groups.

	Animal group	Type of nervous system
1.	Coelenterates	**Diffuse type** (nerve fibres not differentiated into dendrons and axon).
2.	Flatworms and roundworms	**Ladder type** (formed of a nerve ring and many nerve cords which are interconnected by connectives).
3.	Annelids	**Central nervous system** (CNS) formed of a circum-pharyngeal nerve ring and ventral solid and ganglionated nerve cord.
4.	Arthropods	CNS formed of a **circum-oesophageal nerve ring** and a double, ventral, solid and ganglionated nerve cord.
5.	Molluscs	Formed of a few ganglia interconnected by some commissures and connectives.
6.	Echinoderms	**Two nerve rings** (oral and aboral) and radial nerves.
7.	Vertebrates	CNS formed of anterior broader **brain** and posterior longer and narrow **spinal cord**. CNS is dorsal, hollow and non-ganglionated.

- **Unisexual (dioecious)** have only one type of sex organ (either male or female), eg frog, lizard, bird, rabbit.
- In **sexual dimorphism** male and female can be distinguished externally, eg. peacock, peahen, lion & lioness & human beings.
- In **protandry** testes mature earlier than ovary, eg. earthworm.
- In **protogyny** ovaries mature earlier than testes, eg. *Amphioxus*.
- **Internal fertilization** takes place in the genital tract of the female, eg. reptiles, birds and mammals.
- **External fertilization** occurs outside the body of female, eg. starfish, frog.
- **Self fertilization** involves fusion of the gametes of same parent, eg. tapeworm.
- **Cross fertilization** occurs when the gametes are from different parents, eg. earthworm, all fishes, amphibians, reptiles, birds & mammals.
- **On the basis of site of development of zygote,** animals may be –
  - **Oviparous**–Egg laying animals, eg. frog, reptiles, birds & mammals (prototheria)
  - **Viviparous**–Fertilization & development internal & nourishment obtained through mother (through placenta), eg. mammals.
  - **Ovo-viviparous**–Fertilization & development internal but no placenta formation, eg. shark, rattle snake.
- **Germinal layers** are ectoderm, endoderm and mesoderm which **differentiate at the time of gastrulation in a developing embryo**, through which the development of all the tissue and organ system takes place.
- **Diploblastic** animals are with **two germ layers–** ectoderm and endoderm, eg. porifera and cnidaria.
- **Triploblastic** animals are with **three germ layers**– ectoderm, endoderm and mesoderm, eg. platyhelminthes to chordates.
- **Development** is of **two types**– **direct** and **indirect**.
- In **direct development** without any intermediate stage the young ones resembles the adult in all respects. Eg. Silver fish.
- In **indirect development** young ones do not resemble the adults. The young ones pass through many intermediate stages before obtaining the shape of the adults. The phenomenon of passing through different juvenile stages during transition from larval to adult stage is called **metamorphosis**.
- Metamorphosis is **found in many invertebrates**, **protochordates**, **some fishes & amphibians**.
- **Animal kingdom** can be **divided into two major groups** – **non chordates** which does not possess notochord and **chordate** which possess notochord at least in some stage of their life.

ANIMAL CLASSIFICATION

Protozoa
- Most are single celled animal like (unicellular)
- Nutrition is mostly heterotrophic but the mode of nutrition may change according to the food available

Divided into 4 subphylums:
- Sarcomastigophora
- Sporozoa
- Cnidophora
- Ciliophora

Metazoa
True Multicellularity

Divided into 3 branches

Agnathozoa
- Nutrition absorptive and ingestive by surface cells.
- Classified under **single phylum— mesozoa** which include minute ciliated worm like animals without tissue differentiation
- Endoparasite of marine invertebrates
- Eg—*Dicyema, Rhopalura* etc.

Parazoa
- Nutrition primarily ingestive by individual cells lining water canal
- Cell with some motility but the organisation non motile
- Classified under single phylum– **Porifera**. Eg. *Sycon, Leucosolenia*.

Eumetazoa
Also called **enterozoa** due to presence of digestive tract.

Divided into two grades on the basis of body symmetry

Radiata
(Radial symmetry; diploblastic *i.e.* two germ layers—ectoderm and endoderm)

Classified under two phyla

Coelenterate or Cnidarian
Eg. *Hydra*

Ctenophora (Comb jellies)
- 8 rows of ciliated comb plates are present
- Free swimming , Marine
- Eg. *Beroe, Pleurobranchia* etc.

Bilateria
Bilateral symmetry; triploblastic *i.e.,* ectoderm, endoderm and mesoderm; cephalization begins; possess organ grade of organisation

Subdivided into **two division on the basis of the pattern of embryonic development**
(cleavage pattern, fate of blastopore and coelom formation)

Protostomia
- Spiral and determinate cleavage
- Fate of blastopore—forms mouth first.
- Mesoderm splits to form schizocoel, so it may be either absent, pseudo coelom or true coelom.
- Trochophore type larva

Divided into **5 phyla on the basis of coelom**

- **Acoelomate**
  Include
  Phylum-**Platyhelminthes**
- **Pseudocoelomate**
  Super phylum
  Aschelminthes
  Divided into **3 phylums**
  - **Rotifera**
    - Wheel animalcules
    - Eg.*Rotaria, Asplanchna*
  - **Nematoda**
    Round worms
  - **Ectoprocta**
    - Moss animals
    - Eg. *Plumateua Rectinaleur*
- **Eucoelomate**
  Divided into **3 phylums**
  - **Annelida**
  - **Arthropoda**
  - **Mollusca**

  Arthropoda and Mollusca: Consists of **haemocoel**

Deuterostomia
- Radial and indeterminate cleavage
- Fate of blastopore—forms anus first and mouth arises anteriorly some distance away from blastopore.
- Shows *enterocoelic coelom* (Means mesoderm pouches off *i.e.* archenterone folds to form enterocoel *i.e.* derived from primitive gut
- Dipleurula type of larva. (tornaria or bipinnaria)

Divided into 2 phylum

- **Echinodermata**
- **Chordata**
  Divided into subphyla
  - Hemichordata
  - Urochordata
  - Cephalochordata
  - **Vertebrates**

  Protochordata: Hemichordata, Urochordata, Cephalochordata

- About 95 percent of animals are without backbone and are called **invertebrates** while the animals having a backbone are called **vertebrates** contributing five percent.
- Animal kingdom is **divided into two subkingdoms–protozoa** and **metazoa** (*Refer flowchart on page 68*).
- **Protozoa** are the most abundant animals in the world in terms of numbers and biomass. Their principal importance is as consumers of bacteria (prokaryotes).
- Protozoa are defined as single-celled eukaryotic organisms, that feed heterotrophically and exhibit diverse motility mechanisms.
- **Metazoa** are multicellular eukaryotes which are divided into 3 branches—mesozoa, parazoa and eumetazoa.
- **Mesozoa** are minute ciliated worm like animals with out any tissue differentiation.
- **Parazoa** are those animals that for the most part lack a definite symmetry and posses neither tissues nor organs. They are mostly comprised of the sponges, phylum porifera.
- **Eumetazoas** are those animals that have a definite shape and symmetry and in most cases tissues organized into organs and organ systems.
- Eumetazoans are further subdivided into two subgroups—**radiata** (having radial symmetry) and **bilateria** (having bilateral symmetry).
- **Radiata** are radially symmetrical, denticulate diploblastic animals with few organs. These are **classified under two phyla** – **coelenterata** and **ctenophora**.
- **Bilaterally** symmetrical triploblastic animals with organ system, subdivided into two divisions– **protostomia** and **deuterostomia**. These divisions are based on the differences in embryonic cleavage patterns, fate of blastopore and coelom formation.

Table : Few important infective stages in animal kingdom.

1.	**Sporozoites**	:	Infective stage of *Plasmodium* which infect man and transmitted from salivary gland of mosquito (♀ *Anopheles*)
2.	**Microfilariae**	:	Infective stage of filaria worm (*Wuchereria bancrofti*). It is transmitting stage from blood of man to *Culex* mosquito and again into the blood of new host (man)
3.	**Quadrinucleated cyst (cystic stage)**	:	Infective stage of *Entamoeba histolytica* from old host to new host through contaminated food and water.
4.	**Trophozoites**	:	Infective stage of *Entamoeba gingivalis* which is directly transmitted by kissing or contaminated tooth brush.
5.	**Embryonated egg (egg with IInd stage juvenile)**	:	It is infective stage of *Ascaris lumbricoides* from soil to new host (man)
6.	**Metacyclic stage**	:	*Infective stage* of *Trypanosoma gambiense* from salivary gland of tse-tse fly to man.
7.	**Bladder worm/ cysticercus**	:	Infective stage of *Taenia solium* (Tape worm) from pig muscle to man *i.e.*, from secondary host to primary host.
8.	**Onchosphere/ Hexacanth**	:	Infective stage of *Taenia solium* (Tape-worm) from primary host (man) to secondary host (pig)
9.	**Miracidium Larva**	:	Infective stage of *Fasciola hepatica* (liver fluke) from sheep egg to the secondary host (snail)
10.	**Metacercaria**	:	Infective stage of Liver fluke to primary host (sheep)

Table : Types of larvae

1.	**Amphiblastula**	Hollow larva with posterior end having granular archaeocytes and anterior end having flagellate cells.	*Sycon*/porifera
2.	**Rhagon**	Bun shaped type of sponge stage with an apical osculum and large gastral cavity.	Porifera
3.	**Mullers larva**	Larva with 8 ciliated process around mouth.	Marine polyclad/platyhelminthes
4.	**Nauplius**	Common larval stage in crustacea having unsegmented body but differentiated into three parts. Swimming setae borne on appendages.	Prawn (crustacea)/arthropoda
5.	**Trochophore**	Free swimming pelagic larval stage with pre-oral whorl of cilia.	Nereis/annelida, *Chiton*, *Dentalium*/mollusca.
6.	**Veliger**	Second larval stage developed from trochophore where head bears a velum.	*Dentalium* (scaphopoda)/ mollusca
7.	**Bipinnaria**	A larva with band of cilia.	*Asterias* = Starfish(asteroidea) / echinodermata
8.	**Dipleurula/ Echinopaedium**	Bilaterally symmetrical early larva of echinoderms, hemichordates and chordates.	*Asterias* (asteroidea) / echinodermata
9.	**Pluteus**	Free swimming larva resembling an upturned easel. (a) **Echinopluteus** - pluteus larva of echioidea (b) **Ophiopluteus** - pluteus larva of ophiuroidea.	 *Echinus* = Sea Urchin (echinoidea)/echinodermata *Ophioderma*/brittle star (Ophiuroidea)/echinodermata
10.	**Tornaria**	Free larval stage of some hemichordates with two ciliated bands and an apical plate with sensory cilia.	*Balanoglossus* - Tongue worm/ hemichordata
11.	**Axolotl**	Aquatic larva of Salamander which may develop sex organs and start breeding (neoteny).	*Ambystoma* = Salamander/ (Urodela)/Amphibia

Table : Summary of some key features of evolutionary significance in animal phyla.

Phylum	Radial Symmetry	Diploblastic	Bilateral symmetry	Triploblastic	Acoelomate	Coelomate	Haemocoel	Metameric segmentation
Cnidaria	•	•	×	×	–	–	–	–
Platyhelminthes	×	×	•	•	•	×	×	×
Nematoda	×	×	•	•	body cavity develops differently		×	×
Annelida	×	×	•	•	×	•	×	•
Arthropoda	×	×	•	•	×	•	•	•
Mollusca	×	×	•	•	×	•	•	×
Echinodermata	•	×	×	•	×	•	×	×
Chordata	×	×	•	•	×	•	×	•

(•) *represent the presence of character and* (×) *absent.*

End of the Chapter

Chapter 13

Protozoa

- Protozoa are **single-celled microscopic eukaryotic** organisms that are noted for their ability to move independently.
- Protozoa are **members of the kingdom protista, along with algae (plant-like), and slime molds, and water molds (Fungi-like)**.
- Protozoa are sometimes referred to as **animal-like protists**.
- Biologist have identified about **65,000 species** of protozoa, almost half which are extinct species from fossils.
- **Protozoology** is the scientific study of protozoa.
- **Goldfuss (1817)** coined the phylum name protozoa.
- Protozoa exhibit **protoplasmic level of organization**.
- The **complexity** of protozoa sets them apart from the relatively simple structures of bacteria and viruses.
- Protozoa **live in many different environments**; they can **drift** in the ocean, **creep** across vegetation in fresh water rivers and ponds, **crawl** in deep soil, and even **reproduce in the bodies of other organisms**.
- **Majority of protozoa** are **solitary** but some like *Volvox* & *Proterospongia* are **colonial**.
- Most protozoa are **heterotrophic** *i.e.*, obtain their nutrients by ingesting small molecules or cells.
- These particles are usually broken down in **food vacuoles** which is a membrane-bound chambers that contain digestive enzymes.
- Many species are **free-living**, while others are **parasites**.
- **Free-living species** live in any habitat where **water or moisture is available** at some time during the year.
- **Parasitic or commensal protozoa** usually **have complex life cycles** that take place in the cells, tissues and bloodstream of their host. Several species cause serious human diseases, including **malaria**, **amoebic dysentery** and **giardiasis**.
- Common **parasitic protozoa** are *Entamoeba*, *Trypanosoma, Giardia*, *Trichomonas*, *Leishmania*, *Plasmodium* etc.
- Many **free-living species** have a localized region of **pigment** called an **eyespot**. Eyespots **detect changes in the quantity and quality of light**.
- Common **free living protozoans** are *Amoeba, Euglena, Volvox* and *Paramecium.*
- Many species make up **zooplankton**, a population of organisms that constitutes one of the primary sources of energy in aquatic ecosystems. They are the beginning of the food chain.
- All protozoa can reproduce **asexually**, usually by **binary fission.** During binary fission, a protozoan **divides into two identical individuals**.
- Some species reproduce by **multiple fission**, a form of cell division that **results in a number of identical individuals**.
- While all species can reproduce asexually, a few also reproduce **sexually**, through **conjugation**.
- During conjugation, individuals from **opposite mating strains pair** and **exchange genetic material (DNA)**. Conjugation in protozoa is **more complex than in bacteria**.
- Many species have **physiological mechanisms** for monitoring conditions in their environment.
- Certain protozoan species also **sense physical and chemical changes** or obstacles in their environment.
- Most protozoa are separated from their environment only **by their cell membrane**.
- They can **survive in extreme (harsh) conditions due to their ability to form cysts**. A **cyst is a dormant form** characterized by a hard external covering in which metabolic activity has ceased.

- Many species form cysts **in response to changes in the environment**, such as nutrient deficiency, drought, decreased oxygen concentration, or pH or temperature changes.
- When favourable environmental condition return, a **protozoan emerges from the cysts and resumes metabolic activity**.
- **Osmoregulation** takes place in protozoa **with the help of contractile vaccole** (present in the free living forms but **absent in parasites**).
- **Locomotor organelles** in protozoa are– finger like **pseudopodia** or whip like **flagella** or hair like **cilia** or absent.
- **Gaseous exchange** and **excretion** occurs **by diffusion through body surface**.
- The **first prokaryote** evolved more than **3.5 billion years ago** and about **1.5 billion years ago the first eukaryotic organisms evolved**. Protozoa are the **descendants of these early eukaryotes**.
- The **first eukaryotes** probably **evolved through endosymbiosis**, a process in which one prokaryote lives inside another and gradually both host and guest become dependent on one another.
- A convenient way to classify protozoans is based on the **way they move** *i.e.*, **locomotion : the four phyla** of protozoans are :
  – Phylum **sarcomastigophora**, move by **flagella** and **pseudopodia**.
  – Phylum **ciliophora** (ciliophorans) or ciliates, move by **hairlike cilia**.
  – Phylum **cnidospora**, a **spore producing** protozoa.
  – Phylum **sporozoa** (sporozoans) **do not move** by themselves at all.
- Sarcomastigophora is **divided into 3 classes** - **mastigophora**, **sarcodina** and **opalinata**.

MASTIGOPHORA

- Mastigophora is divided into **phytoflagellata** and **zooflagellata**.
- The **2,500 species** that make up the **phylum zoomastigina** are characterized by the presence of one or more **flagella**, long, hairlike structures that are **made up of microtubules**.
- Zooflagellates are protozoans that move by means of **flagella**.
- Some zooflagellates are **free-living**, **freshwater or marine organisms**.
- Many can live inside other organisms in **symbiotic relationship** (a relationship in which two different organisms live closely together; it can be either beneficial or harmful to the organism).
- The symbiotic relationship may be : **mutualistic relationship** - both organisms benefit, **parasitic relationship** - causes harm to the host.
- *Euglena* is called **phytoflagellate** as it **possesses both chloroplasts as well as flagella**.
- *Euglena* is a **connecting link between animals & plants**.
- **Nutrition** in *Euglena* is **myxotrophic**, when light is available it is photosynthetic, in darkness it is saprophytic absorbing food from surrounding water.
- *Euglena* (**commonly called plant animalcule**) **contains chlorophyll**, yet it resembles animals, because it possesses a contractile vacuole near cytopharynx.
- **Reaserve food** is stored in the form of **paramylum or paramylon** in *Euglena*.
- Asexual reproduction in *Euglena* occurs by **longitudinal binary fission**, **no sexual reproduction observed**.
- Some zooflagellates are **parasitic organisms** that cause disease in humans.
- The zooflagellate *Trypanosoma* causes african trypanosomiasis, "**african sleeping sickness**", in humans. It produces toxins that destroy red blood cells, causing the host to become weak. This disease if left untreated eventually attacks the host's **nervous system, causing death**.
- This disease effects all large mammals, including humans in some parts of Africa. The disease is **spread by the bite of the tsetse fly**.
- Another species called ***Trypanosoma cruzi***, causes **Chagas' disease**. It is transmitted by an insect called the **"kissing bug"**, patients suffer from fever, and heart damage.
- The *Trichonympha* lives in the **guts of termites**, and help the termite **digest cellulose** in wood. This is a mutualistic relationship, they both benefit from the relationship.
- **Euspundia**, characterized by lesions upon skin and mucous membrane of nose, mouth, pharynx, (hence called naso-oral leishmaniasis) is caused by *Leishmania brasiliensis*.
- *Leishmania donovani* causes **kala-azar** (**also called dumdum fever**). Infection chiefly occurs in spleen

Protozoa

Divided into 4 subphylums on the basis of locomotory organelles

Sarcomastigophora

Sporozoa (Apicomplexa or parasitic protozoa)
- Locomotory organelles and contractile vacuole are **absent**
- All members of these groups are **endoparasites**
- Eg. *Plasmodium, Monocystis, Babesia, Eimeria, Toxoplasma* etc.

Cnidospora
- **Intracellular endoparasites**, especially of insects
- **No locomotory organelles & contractile vacuole**
- Classes, on the basis of spore formation
  — Myxosporidea (*Myxidium*)
  — Microsporidea (*Nosema*)

Ciliophora (Ciliates)
- Largest group of protozoa
- Locomotory organelles are **cilia or ciliary organelles** which is replaced by sucking tentacles in adult
- **Dimorphic** (2 different types of nuclei :- micro & macro)
- Class : Ciliata (Eg. *Paramecium, Balantidium*)

Divided into 3 classes (Sarcomastigophora)

Mastigophora (Flagellates)
- Locomotory organ is thread like flagella (as food capturing organelles) Eg. *Euglena, Trypanosoma* etc.
- Contractile vacuole is present for osmoregulation
- Types of **flagella**
  – **Phytomastigna**; with chloroplast, plant like Eg. *Euglena*, *Chlamydomonas* etc.
  – **Zoomastigna**; without chloroplast, animal like Eg. *Trypanosoma, Leishmania, Giardia* etc.

Sarcodina (= Rhizopoda)
- Commonly known as **amoebas**
- Locomotory organ is **pseudopodia**
- Body shape is changeable due to presence of pseudopodia which brought about the temporary outpushings of cytoplasm
- Types of pseudopodia are
  – **Lobopodia** (*Amoeba*)
  – **Filopodia** (*Euglypha*)
  – **Reticulopodia** (*Globigernia*)
  – **Axopodia** (*Actinophrys sol*)

Opalinata
- Intestinal parasites of amphibians (frogs and toads)
- Locomotory organs are short, **cilia like**
- Gametes are flagellated, involve in sexual reproduction Eg. *Opalina*

Flowchart : Classification of Protozoa.

and liver, secondarily in bone marrow & intestinal villi.

- *Leishmania* is a **digenetic blood flagellate** whose **intermediate host (vector) is sandfly** belonging to genus *Phlebotomus*.
- *Giardia*, commonly nicknamed as the **Grand old man of the intestine** is a diplomonadid parasitic flagellate occurring in the intestine of man and other animals.
- *Giardia* was **discovered by Leewenhoek** in his own stool in 1681.
- *Giardia* causes **diarrhoea or giardiasis** (very loose and frequent stool containing large quantity of fat), which is accompanied by flatulence, abdominal pain, loss of appetite, weight loss etc.

SARCODINES

- Biologists have classified **40,000 species of protozoa** in the phylum **sarcodina**.
- **Sarcodines** are grouped into **four types– amoebids** (eg. *Amoeba*, *Entamoeba* etc), **radiolarians** (eg. *Acanthometra* etc), **foraminiferans** (eg. *Elphidium*, *Globigerina* etc) and **heliozoans** (eg. *Actinophrys*).
- Sarcodinians are protozoans that move by **extending lobes of cytoplasm**.
- The lobes of cytoplasm that sarcodinians extend are called **pseudopods** (**pseudopodia**), which means **"false foot".**
- A pseudopodia forms when **endoplasm**, the inner portion of cytoplasm, pushes the **ectoplasm**, the outer layer, forward to create a blunt, armlike extention.
- Sarcodines **include hundreds of species of *Amoebas***, which inhabit fresh water, salt water, and soil. Some can even live on mud, rocks, and other surfaces in shallow, slow moving streams and ponds.
- Sarcodines live on other protists, which they **engulf (eat) by phagocytosis**.
- When a sarcodine feeds, it surrounds the food with its pseudopodia. A portion of the cell membrane then pinches together and surrounds the food in a food vacuole, in a process called **endocytosis**. Enzymes from the cytoplasm then enter the vacuole and digest the food. Undigested food leaves the cell in a reverse process called **exocytosis**.
- Most fresh water sarcodines have **contractile vacuoles**, an organelle that **removes excess water from the cell**.
- When conditions are unfavorable, **amoebas survive by becoming hard cysts**. The cysts can withstand drought, heat, or being eaten by other organisms.
- Not all sarcodinians are soft "naked"; **many have hard shells or test** of calcium carbonate or silica and are called **foraminiferans** and **radiolarians**.
- **Most petroleum bearing regions shows the presence of foraminiferans and radiolarians** in the fossil state.
- Most hard shell sarcodinians **live in the ocean**, and **are important food sources** for many marine animals.
- **When hard shelled sarcodinians die**, their shells sink to the bottom of the ocean making huge deposits of limestone called **chalk**.
- The most famous chalk deposits are **the Cliffs of Dover on the coast of England**.
- The **great Pyramids of Egypt** were built with stones quarried from limestone beds that are made from a large foraminiferan.
- *Amoeba* was discovered by **Russel von Rosenhoff** in 1755.
- Body of *Amoeba* is covered by **plasmalemma**, a trilaminar and selectively permeable membrane.
- Plasmalemma is **excretory** as ammonia diffuses out through it and **respiratory** as diffusion of oxygen and carbon dioxide takes place through it.
- The **type of pseudopodium** found in *Amoeba proteus* is **lobopodium**.
- Pseudopodium at its forward end gets its firm consistency by **hyaline cap** which is made of ectoplasm.
- Pseudopodia in *Amoeba* are **meant for feeding and locomotion**.
- Pseudopodia are found in *Amoeba* and leucocyte of higher animals.
- Locomotion of *Amoeba* is known as '**amoeboid movement**'.

Table : Theories of amoeboid movement

Theory	Scientists
Surface tension	Berthold (1886)
Rolling movement	Jennings (1904)
Walking movement	Dellinger (1906)
Sol-gel	Hyman (1917)
Folding and unfolding	Goldacre and Lorch (1959)
Contraction-hydraulic	Rinaldi and Jahn (1963)

- Amoeboid movement is a form of **cytoplasmic streaming**, the internal flowing of a cell's cytoplasm.
- *Amoebas* move by extending part of their cell membrane into a lobe, or pseudopodia, that can attach to a surface. Then, cytoplasm streams into the pseudopodia and pulls the organism forward. This movement is called **amoeboid movement**.
- Sol-gel theory of amoeboid movement was first given by **Hyman** supported by **Pantin** and **Mast**.
- *Amoeba* has **no skeleton**.
- Contractile vacuole in *Amoeba* is concerned with **osmoregulation**, *i.e.*, removal of excess of water.
- If an *Amoeba* is **placed in distilled water**, its **contractile vacuole works faster**.
- If an *Amoeba* is **placed in salt water**, its contractile vacuole will disappear.
- If marine *Amoeba* is **shifted to fresh water**, **it swells and may burst**.
- **Contractile vacuole** of *Amoeba* is **analogous** (**similar in function**) **to uriniferous tubules of frog**.
- An *Amoeba* transferred from a container X to another container Y developed a new contractile vacuole, but the vacuole disappeared again when the *Amoeba* was transferred back to the container X. The containers X and Y respectively contain marine and freshwater.
- **Mode of nutrition** in *Amoeba* is **holozoic** *i.e.*, *Amoeba* is **heterotrophic**.
- *Amoeba* **ingest food by import, circumfluence, circumvallation or invagination**.
- Digestion in *Amoeba* is **intracellular**.
- **Food vacuole** of *Amoeba* is **analogous to the alimentary canal** of an animal or gastrovascular cavity of *Hydra*.
- The contents of food vacuole in *Amoeba* first becomes acidic then alkaline.
- The behaviour of *Amoeba* involves the manner in which responds to the environmental conditions (called **taxes**).
- **Different taxes with respect to kind of stimuli** are – **thermotaxis** (temperature), **phototaxis** (light), **thigmotaxis** (touch), **chemotaxis** (chemicals), **galvanotaxis** (electric current), **geotaxis** (gravity) and **rheotaxis** (water current).
- *Amoeba proteus* **does not reproduce sexually**.
- **Binary fission** in *Amoeba* takes place when food is abundant and temperature is suitable. It is completed in **30 minutes.**
- **Multiple fission** or **sporulation** takes place during unfavourable condition after encystment. There are three layers of cysts.
- Lack of oxygen and food **induces encystment**, products of **multiple fission** are called **'amoebulae'**.
- *Amoeba* regenerates **from nucleated bits**.
- **Lamble** (1859) discovered *E. histolytica*. **Friedrick Losch, a Russion zoologist**, discovered its pathogenic nature in 1875.
- *E. histolytica* is a **pathogenic intestinal parasite occurring in the colon of man** and causes '**amoebic dysentery** or **amoebiasis**.
- It **lives in the large intestines**, where it secretes enzymes that attack the intestinal lining and causing deep ulcers.
- Affected individuals feel **intense pain**, and complications arise when the amoebas are carried by the **blood to the liver and other organs**.
- *E. histolytica* **has only one host** and so **monogenetic** and completes its life cycle in humans.
- *E. histolytica* **occurs in two forms**: **magna** (trophozoite) which is **pathogenic** and found in the mucosa and sub-mucosa of intestine forming ulcers, and **minuta** which is **nonpathogenic** form and found in the lumen of intestine.
- Its adult is called **trophozoite** and is **monopodial**.
- Trophozoite of *Entamoeba* **reproduces by binary fission**.
- Minuta form encysts. A mature cyst is called **quadrinucleate cyst**. It has four nuclei and two **chromatoid bodies**.
- The reserve food material in cyst of *E. histolytica* is **glycogen**.
- **Quadrinucleate cyst** is the **infective stage**.
- **Contractile vacuoles are not present** in *E. histolytica* **since it inhabits an isotonic environment of intestine**.
- The **tetranucleate cysts** of *E. histolyitca* **constitute the transmittive or infective stage**. It damages the intestinal wall by enzyme **histolysin**.
- *Entamoeba coli* inhabits human colon. It is a commensal parasite and does not produce any disease.
- *Entamoeba histolytica* causes **amoebic dysentery or amoebiasis**.

- *Entamoeba gingivalis* is a **parasite of human teeth**, found in the abscesses of gum and in pus pockets of **pyorrhoea** bleeding gums.
- Cyst is not formed in *E. gingivalis* and infection occurs by direct contact like kissing.

CILIATES

- The **8,000 species** that make up the phylum ciliophora swim by means of **cilia**, which are **short**, **hairlike cytoplasmic projections** that line the cell membrane.
- The cilia is **used for movement by beating like oars** (= a long shaft of wood for propelling a boat by rowing) **to propel the protists**.
- Some kinds of ciliates have **specialized cilia shaped like teeth**, paddles, or feet.
- Ciliates have the **most elaborate organelles** of any protozoa.
- Most ciliates **live in freshwater**. A common freshwater ciliate is the *Paramecium*.
- Protozoan both eats and swims **through water** with it's cilia.
- When eating, the cilia sweeps food particles, such as microscopic algae and bacteria, into the **oral groove**. In the oral groove, the **mouth pore** opens into a **gullet**, which pinches off around them to form a **food vacuoles**.
- The food vacuoles move inside the cytoplasm where nutrients are extracted, it ejects the waste through an opening called the **anal pore**.
- All protozoans have **contractile vacuoles**. These are an important adaptation for living in water. Contractile vacuoles **collect excess water (osmosis)** and **pump it outside the cell body**.
- *Paramecium* is a **holotrichous ciliate protozoan**.
- **Hill** (1752) discovered *Paramecium*.
- *Paramecium* is commonly called as **'Slipper animalcule'**.
- *Paramecium* have a protective covering over their cell membrane, it is a clear, elastic layer of protein, called a **pellicle**.
- **Trichocysts** are peculiar bottle-shaped organelles present in the ectoplasm of *Paramecium*.
- Trichocysts are the **organelles of offence and defence**.
- *Paramecium* is **heterokaryotic** (dimorphic nuclei).
- **Micronuclei**, one (*P. caudatum*), two (*P. aurelia*) and several (*P. multimicronucleatum*) are **only concerned with reproduction.**
- Oral apparatus or food apparatus consists of **cytopharynx** and **cytostome** (mouth), **cytopyge** or **cytoproct** (anus).
- Nutrition or food intake in *Paramecium* is **holozoic**.
- *Paramecium* is a **filter feeder**.
- *Paramecium* **has two contractile vacuoles which control osmoregulation**.
- Most favourite food of *Paramecium* is *Tetrahymena*, another ciliate protozoa used in biological research.
- **Digestion is intracellular** in *Paramecium*.
- **Respiration and excretion** of *Paramecium* are **through general body surface**.
- *Paramecium* shows **negative response** and moves against water current.
- *Paramecium* also have two distinct kinds of nuclei (**multinucleate**) – **macronucleus** and **micronucleus**.
- The large **macronucleus** (containing multiple copies of DNA) controls **ongoing metabolic functions** of the cell (the brain) and asexual reproduction.
- The smaller **micronucleus** is involved in **genetic exchange during sexual reproduction** by conjugation - the joining of two opposite mating strains and exchanging genetic material.
- *Paramecium* reproduces asexually by **transverse binary fission** and **nuclear reorganisation**.
- In binary fission, macronucleus divides amitotically and micronucleus mitotically.
- Binary fission occurs during favourable condition. It is faster multiplication, completes about in half an hour (upto three divisions per day).
- *Paramecium* undergoes several kinds of nuclear reorganization such as **conjugation**, **autogamy**, **cytogamy**, **endomixis** and **hemixis**. In all these processes the macronucleus breaks into many parts and disintegrates.
- In *Paramecium* nuclear reorganization takes place for rejuvenation.
- Conjugation occurs between two mating types of same species of *Paramecium*. It is a modified form of cross fertilization.
- **Conjugation** of *Paramecium* **involves exchange of micronuclei**.
- Each *Paramecium* (**exconjugant**) at the end of the conjugation produces four daughter paramecia.
- Autogamy is a **process of self-fertilization**. It occurs in a single animal of *P. aurelia*.

- Autogamy **results in the production of two daughter paramecia from each**.
- **Cytogamy** occurs in *P. caudatum*. The two cytogamonts do not exchange their male pronuclei.
- **Endomixis** occurs in *P. aurelia*. It is asexual reproduction and one individual produces four daughter paramecia.
- *Paramecium* has **Kappa**, **Lambda**, **Mu** and **Pi particles in cytoplasm**. They differentiate paramecia between sensitive and killer forms.
- Although genetic material is exchanged during conjugation, **no new cells are produced**.
- Following conjugation, each *Paramecium* divides, producing **four genetically identical paramecia**.
- Exchange of genes can enable organisms to adapt better to changing environments, **the four offspring are genetically different from either original paramecium**.
- *Balantidium coli* is a ciliate protozoan parasite in **colon and caecum of man**.
- *Balantidium* cause '**Balantidial dysentery** or **Balantidiasis**'.

SPOROZOA

- The name sporozoan comes from the fact that when they are immature, **they are surrounded by thick, sporelike walls**.
- All species in the phylum sporozoa have adult forms with **no means of movement**.
- Most sporozoans are **spore-forming parasitic** (harmful) **protozoans**.
- Adult sporozoans have no structures for movement. Immature sporozoans, called **sporozoites**, can be **transmitted through fluids from one host to another**.
- Sporozoans cause many human diseases, including **malaria**. The protozoan that causes malaria is named *Plasmodium*, and is transmitted by female mosquitoes (*Anopheles*).
- **Malaria means 'bad air'**. It is a communicable disease.
- There are about 60 species of *Plasmodium*. Only four species causes malaria in man. They are : *Plasmodium vivax* (the most common species), *P. ovale, P. malaria* and *P. falciparum*.
- Malaria is a very serious disease **characterized by severe chills**, **fever**, **sweating**, **fatigue**, and **great thirst**.

Table : Types of malaria

Disease	**Causative agent**
Tertian malaria	*Plasmodium vivax*
Benign tertian malaria	*Plasmodium vivax*
Vivax malaria	*Plasmodium vivax*
Mild tertian malaria	*Plasmodium ovale*
Ovale malaria	*Plasmodium ovale*
Subtertian malaria	*Plasmodium falciparum*
Estivo-autumnal malaria	*Plasmodium falciparum*
Malignant tertian malaria	*Plasmodium falciparum*
Cerebral malaria	*Plasmodium falciparum*
Black water fever	*Plasmodium falciparum*
Quartan malaria	*Plasmodium malariae*
Quotidian malaria	Mixed infections

- One way to reduce human deaths (2.7 million annually) from malaria is to control mosquito populations. **Without the mosquito host**, the *Plasmodium* protozoan cannot complete their life cycle.
- *Plasmodium* was **discovered by Charles Laveran in 1880**.
- **Lancisi** first **suspected a relationship between mosquito and malaria**.
- **Ronald Ross** (1897) **discovered** (**confirmed**) **relationship between malaria and mosquito**.
- In 1897 Ross discovered oocytes of *Plasmodium* in the stomach of mosquito at Secunderabad in India. He got Nobel Prize in 1902.
- **Grassi** (1898) described the life history of the parasite in female *Anopheles* mosquito.
- **Shortt** and **Garnham** (1948) are associated with the discovery of life cycle of malarial parasite.
- *Plasmodium* is an **endoparasite**, **blood parasite**, **intracellular parasite**, **pathogenic parasite** and **digenetic parasite**. (**Principle host** : man; and **secondary/intermediate/primary host** : mosquito)
- **Asexual cycle** is passed in man by a process termed **schizogony** (schizogony in liver and RBCs).
- Schizogony is a type of **multiple fission**.
- Pre-erythrocytic and exo-erythrocytic cycles occur in **liver cells** and involve **schizogony**.
- **Cryptozoites** and **metacryptozoites** are produced in respective cycles.
- Exoerythrocytic cycle is absent in *Plasmodium falciparum*.
- **Sexual cycle** is completed in **mosquito** involving **gametogony** and **sporogony**.

- Stage of *Plasmodium* infective to man is, or the stage of *Plasmodium* injected by mosquito into human blood is **sporozoite**.
- Sporozoite directly goes to parenchyma cells of liver.
- **Incubation period** is the duration between the initial sporozoite infection and the first appearence of malarial symptoms. It is about 14 days in *P. vivax*, 30 days in *P.malariae*, 14 days in *P. ovale* and 12 days in *P. falciparum*.
- **Erythrocytic cycle occurs in RBCs.**
- Signet ring stage, amoeboid stage (adult trophozoite) and schizogony **occurs in RBCs.**
- **Haemozoin** is the unused hematin, it **forms toxic malarial pigment**.
- The cytoplasm of RBCs with trophozoite contain various pigment granules: **Schuffner's dots** in *P. vivax*, **Ziemann's dots** in *P. malariae* and **Maurer's dots** in *P. falciparum*.
- Haemozoin **causes chill and body pain**. Malarial parasites can be obtained in large numbers in blood from a person when temperature rise with rigor.
- **Gametocytes** of malarial parasite are **developed from merozoites in RBCs of man**.
- There are two types of gametocytes : **megagametocyte** (female) and **microgametocyte** (male).
- **Sexual phase** in the life cycle of *Plasmodium* occurs in the gut of mosquito.
- Gametocytes reach the stomach of female *Anopheles* mosquito by sucking human blood.
- Megagametocyte produces only one gamete from each.
- Microgametocytes undergo **exflagellation,** produce 6–8 motile **microgametes** having haploid nuclei.
- The motile zygote formed by fertilization (anisogamy) of macrogamete by a microgamete is called **ookinete**.
- Ookinete penetrates the stomach wall and forms encysted zygote called **oocyst** or **sporont**.
- Oocyst undergoes sporogony which is meiosis followed by mitosis.
- Sporogony produces about 10,000 **sporozoites** from each oocyst and they migrate to the salivary gland.
- **Cerebral malaria** is drug resistant and fatal.
- *Gambusia* (mosquito fish) feeds on larvae and pupae of mosquito. This fish is **used in biological control of mosquito**.
- 20th August is **malaria day**. Ministry of Health, Government of India started **National Malaria Eradication Programme** (NMEP) in the year 1953.
- Malaria is usually cured with a drug derived from the Cinchona tree, (native to the America), called **quinine**.
- A **biolumniscent protozoa** is *Noctiluca*.

End of the Chapter

Chapter 14

Non-Chordates

- Non-chordates **are** animals without notochord**.** Notochord **is an elastic skeletal rod lying lengthwise beneath the nerve cord and above the alimentary canal in the embryos or adults of all chordate animals.**
- Notochord is **found in both adult and larval lancelets** but in **adult vertebrates it is largely replaced by the vertebral column**.
- Hence **all the non-chordates are invertebrates whereas all the invertebrates are not non-chordates**. This means →
  Invertebrates – **Protochordates** = **Non-chordates**.
- Invertebrates are **essential for maintaining the functions of ecosystem** for many reasons. *For example* :
  - They form an integral part of the food web.
  - They recycle organic matter, feeding on faeces or dead plants and animals.
  - They make up the bulk of parasite species (along with micro-organisms such as bacteria that regulate animal and plant numbers).
- **Invertebrates** is a term coined by **Jean Baptiste Lamarck** to describe any **animal without a spinal (vertebral) column or backbone**.
- Lamarck **divided invertebrate into two groups**– the **insecta** and the **vermes**, but they are now classified into over 30 phyla, from simple organisms such as sponges and flatworms to complex animals such as arthropods and molluscs.
- All the phyla **which are non-chordates** (like **porifera, cnidarians, platyhelminthes, nematodes, annelida, arthropoda, mollusca & echinodermata**) are **invertebrates along with two** of the **three subphyla in phylum chordata**: **urochordata** and **cephalochordata**. These two, plus all the other known invertebrates, have only one cluster of Hox genes, while the vertebrates have duplicated their original cluster more than once.

PORIFERA

- The phylum name porifera was coined by **Robert Grant**.
- The **sponges or poriferans** (from the Greek poros "*pore*" and Latin ferre "to *bear*") are **primitive, sessile** (attached), **aquatic (mostly marine** and few fresh water), **water dwelling filter feeders** that pump water through their bodies to filter out particles of food matter.
- The study of sponges is **parazoology**.
- Sponges are **asymmetrical** or **with radial symmetry** and **diploblastic** [ectoderm **(pinacoderm)** and **endoderm (choanoderm)**].
- Between pinacoderm and choanoderm lies the interconnecting gelatinous matrix, the **mesenchyme or mesohyl**.
- Mesenchyme **consists of skeletal elements** and **free amoeboid cells**.
- Sponges have **several cell types** –
  - **Choanocytes** (also known as "**collar cells**") : Flagellated cells which **function as the sponge's digestive system**, are remarkably similar to the protistan choanoflagellates. The collars are **composed of microvilli** and are **used to filter particles out of the water.** The beating of the choanocytes' flagella creates the sponge's water current.
  - **Porocytes** : Tubular cells that make up the pores into the sponge body through the mesohyl. Special cells for passage of water.
  - **Pinacocytes** : Form the pinacoderm, the outer epidermal layer of cells. This is the **closest approach to true tissue in sponges**.
  - **Myocytes** : Modified pinacocytes which

control the size of the osculum and pore openings and thus the water flow.

- **Archaeocytes (or amoebocytes)** : Are **totipotent cells** which can transform into sclerocytes, spongocytes, or collencytes. They **also have a role in nutrient transport and sexual reproduction**.
- **Sclerocytes** : Secrete calcareous or siliceous spicules which reside in the mesohyl.
- **Spongocytes** : Secrete spongin, collagen-like fibres which make up the mesohyl.
- **Collencytes** : Secrete collagen.
- **Spicules** : Stiffened rods or spikes made of calcium carbonate or silica which are **used for structure and defence**.

- With **no true tissues (parazoa),** sponges **lack muscles, nerves, and internal organs**. Their **similarity to colonial choanoflagellates shows the probable evolutionary jump from unicellular to multicellular organisms.**
- Sponges are **multicellular grade organisms** and **exhibit cellular level of organization**.
- Sponges usually have a **skeleton consisting of spicules** (may be either calcareous or silicious) **or spongin fibres**.
- The cavity common to all sponges is **spongocoel** or **paragastric cavity** lined with **flagellated choanocytes**.
- **Choanocytes (or collar cells)** are present only in sponges.
- Sponges have numerous mouthlets (**ostia**) and one exit (**osculum**).
- Sponges **have no real circulatory system**, however the water current is used for circulation. Dissolved gases are brought to cells and enter the cells *via* simple diffusion. Metabolic wastes are also transferred to the water through diffusion.
- Sponges **have no respiratory or excretory organs**; both functions occur by diffusion in individual cells.
- **Digestion** is **intracellular** like protozoan. Digestion of food takes place partially in choanocytes and partially in wandering amoebocytes.
- The food is constituted by protozoans, diatoms, bacteria, etc., coming in with water current.
- The chief **nitrogenous waste** of the sponge is **ammonia**.
- Contractile vacuoles are found in archaeocytes and choanocytes of freshwater sponges. The **only visible activities and responses in sponges**, other than propulsion of water, **are slight alterations in shape and closing and opening of incurrent and excurrent pores**, and these movements are very slow.
- Sponges have **great regenerating power** due to archaeocytes which are **totipotent cells**.
- All sponges are **hermaphrodites**. **Most sponges** are **monoecious** *i.e.* male and female reproductive cells or gametes are formed in the same individual.
- Sponges are able to **reproduce sexually** (involving gamete formation and their fusion) **or asexually** (involving **fragmentation, reduction bodies, external budding** and **gemmules**).
- **Gemmules** (**mostly found in fresh water sponge**) are made up of amoebocytes surrounded by a layer of spicules and can survive conditions that would kill adult sponges. When the environment becomes less hostile, the gemmule resumes growing.
- Sex cells (sperm and ova) **arise from undifferentiated archaeocytes**.
- **Sperm** are **formed from choanocytes**; and **oocytes derive from choanocytes in some sponges**, and **archaeocytes in others**.
- Sperm are **released into open water**.
- Some sponges have **oviparous fertilization** where sperm and eggs meet in open water. In other species sperm are taken into the bodies of other sponges and fertilized inside; this is known as **viviparous fertilization**.
- The **free-swimming larvae**, known as **parenchymula** (*Leucosolenia* & *Clathrina*) and **amphiblastula** (sycon) serve as one of the **main form of dispersal for this largely sessile phylum**.
- **Vidabarine,** found in sponges, is a compound which may attack the AIDS virus directly.
- Sponges have **a canal system** and they need a continuous current of water flowing through their bodies **for respiration, excretion, nutrition and reproduction**.
- Sponges have **three types or canal systems**: **asconoid** (**simplest type**), **syconoid** and **leuconoid**.
- **Asconoid sponges** are tubular with a central shaft called the **spongocoel** (or **paragastric cavity**, cavity common to all sponges). The beating of choanocyte flagella force water into the spongocoel through pores in the body wall. **Choanocytes line the spongocoel and filter nutrients out of the water**.
- **Syconoid sponges**, similar to asconoids, have a

Canal System in Sponges

Ascon type (Simplest) (e.g., *Leucosolenia* and in olynthus stage in the development of all syconoid sponges)
Ingressing water → (Ostia) → **Spongocoel** → (Osculum) → **Outside**

Sycon type (Complex) [e.g., Scypha and *Grantia*]
Ingressing water → (Dermal ostia) → **Incurrent canal** (nonflagellated, lined by pinacocytes) → (Prosopyles) → **Radial canal** (flagellated chamber, only they are lined by choanocytes) → (Apopyles (internal ostia)) → **Spongocoel** → (Osculum) → **Outside**

Leucon type (More complex) [e.g., *Spongilla*]
Ingressing water → (Dermal ostia) → **Incurrent canal** → (Prosopyle) → **Flagellaged chamber** → (Apopyle) → **Excurrent canal** (developed as a result of shrinkage and division of spongocoel which has disappeared) → (Osculum) → **Outside**

tubular body with a single osculum, but the **body wall is thicker and more complex** than that of asconoids and **contains choanocyte-lined radial canals** that empty into the spongocoel.

- **Leuconoid sponges** lack a spongocoel and instead **have flagellated chambers**, containing choanocytes, which are led to and out of *via* canals.
- **Rhagon type** is found in few sponges **during larval stage**. This will be transformed to leuconoid type during adulthood.
- **Spongin fibres** are elongated protein fibres secreted by spongioblasts which form a fibrous network.
- **Spicules** are calcareous or siliceous hard spine – like structures.
- **Types of spicules** are – **monaxons** (straight or curved rods with a single axis), **triaxons** [with three axes crossing one another resulting in **hexactinal spicules** (in hexactinellida)]; **tetraxons** (spicules with four rays radiating from a central point. Its modifications include **diaene spicule** and triradiate/**triactinal spicule**); **polyaxons** (several rays radiating out from a central point).
- Skeleton of sponges is secreted by **scleroblasts**.
- **Three types of scleroblasts** are: **calcoblasts, silicoblasts** and **spongioblasts**.
- **Smallest sponge** is *Leucosolenia* and **tallest sponge** is *Poterionpatera*.
- *Chalina* is popularly known as '**the mermaids gloves**' or **'dead-man's fingers.'**
- *Proterospongia* with both amoeboid and collar cells acts as **connecting link between protozoa and porifera**.
- Sponges are **divided into 3 classes based on the type of spicules in their skeleton**.

Table : Classification of porifera

Calcarea	Hexactinellida	Demospoiangiate
Skeleton consist of calcareous spicules	6-rayed siliceous spicules	1 or 4 rayed siliceous spicules or spongin fibre or both.
Choanocytes relatively large	Choanocyte small	Choanocyte small
Marine and shallow water inhabitant	Marine and inhabit deep water	Show adaptation to fresh water, shallow and deep as well as in fresh water
Canal system is asconoid or leuconoid type.	Syconoid like type body	Leuconoid type canal system
E.g. *Leucosolenia*	E.g. *Euplectella*	E.g. *Spongilla*

Table : Some important examples

	Example	Important notes
		Class – Calcarea
1	*Scypha* [Urn or Crown sponge (sycon)]	• Vase shaped, radially symmetrical. • Resembles the **'olynthus stage'** (solitary hypothetical ancestral sponge) in the ontogeny. Shows protogyny • Have **stomoblastula** and **amphiblastula**.
2.	*Leucosolenia*	• Vase like colonical, marine and sessile sponge. • Has **radial symmetry** and **ascon type of canal system**. • Further development results in the formation of **stereogastrula or parenchymula larva**.
		Class – Hexactinellida
3.	*Euplectella* [Venus flower basket]	Exhibit commensalism with shrimps. Given as a wedding gift in Japan, symbolizing the idea "till death us do part".
4.	*Hyalonema* [Glass rope sponge]	Looks like a ball of glass wool with projecting tufts of glassy spicules.
		Class – Demospongiae
5.	*Cliona* [Boring sponge]	Its larvae bores into the shells of oyster. Hence harmful to oyster industry.
6.	*Spongilla*	Fresh water sponge. Canal system is essentially of rhagon type. Shows various shades of green colour due to presence of symbiotic algae (*Zoochlorella*).
7.	*Euspongia* [Bath sponge]	• Its skeleton is used for bathing found in warm shallow water of mediterrian sea. • Also called **horny sponge** due to consistence of their skeleton made of spongin fibres, forming a close-meshed reticulum • Skeleton is used for removing dirt from the body surface while bathing.

- The **three classes of sponges** are - **bony (calcarea or caliispongiae),** eg, *Scypha*; **glass (hexactinellida),** eg, *Euplectella*; and **spongin (demospongiae),** eg, *Euspongia.*

COELENTERATE

- Cnidaria or coelenterate is a phylum containing some 11000 species of relatively simple animals found **exclusively in aquatic, mostly marine environments.**
- **Leuckart** (1847) coined the term coelenterate.
- They are the **simplest metazoans**.
- Cnidarians get their name from **cnidocytes** (the **nettle cell**), which are **specialized cells that carry stinging organelles** (**nematocysts**).
- The **nematocysts** are the cnidarian's **main form of offence or defence** and **function by a chemical or physical trigger** that causes the specialized cell to eject a barbed and poisoned hook that can stick into, or entangle prey or predators, killing or at least paralysing its victim. It **also plays an important role in locomotion, food capture etc.**
- Out of 17, 4 **common types of nematocysts** are - **penetrant** or **stenotele** (**largest cnidoblast**, containing poisonous proteinaceous fluid called **hypnotoxin**), **volvent** or **desmoneme**, **streptoline glutinant** (large glutinant = holotrichous isorhizas) and **steroline glutinant** (small glutinant = atrichous isorhizas).
- Another important cell type is the **interstitial cell**, pluripotent cells that can transform into other cell types such as spermatozoa, adenocytes or nerve

cells, though not into epithelial or feeding muscle cells; the latter two can only be produced by cells of the same type. These **give many cnidaria an extraordinary capacity for regeneration. In particular the genus *Hydra* serves as a model for the research of pattern formation processes**.

- Nematocysts or cnidoblasts (**derived from interstitial cells of epidermis**) are **mainly present on tentacles**, a group of nematocyst is known as **cnidom**. They are **absent on basal disc**.
- **Nematocyst** is the **characteristic feature** of coelenterate.
- It contains a poisonous substance called **hypnotoxin**.
- **Sensory structure** of cnidoblast is **cnidocil**.
- Cnidocil is a **hair like structure at the opening of nematocyst**.
- **Contractile structure** of a nematoblast is **lasso**.
- Lasso is **contractile bundle of myonemes** which **prevents the nematocysts from collapse**.
- Cnidarians are **highly evident in the fossil records**, having **first appeared in the precambrian era**.
- The basic body shape of a cnidarian consists of a sac (*i.e* **blind sac body plan**) with a **gastrovascular cavity or coelenteron**, with a single opening.
- It is composed of **two layers of tissue**, known as the **ectoderm** and **endoderm (or gastroderm),** with a gelatinous non-cellular **mesoglea** in between them containing only scattered cells. Thus the organisms are considered to be **diploblastic**, though the mesoglea may be homologous with the mesoderm in other animals.
- The ectoderm surrounds the cnidarian's 'stomach', or **gastrovascular cavity** which **functions as both mouth and anus**.
- Ectoderm **also serves along with the mesogloea as a hydrostatic supporting skeleton**. Firm skeletons are only found among polyps, which produce lime for that purpose.
- **Gastrodermis** lines the coelenteron **has five types of cells - nutritive** (endothelio-muscular/gastrodermal) **cells, nerve cells, interstitial cells,** secretory **endothelio-glandular cells** and **sensory cells**.
- Nerve cells are **apolar**.
- **Epidermis** is made of epithelio-muscular cells, glandulo-muscular cells (adhesive material in pedal disc), interstitial cells, cnidoblasts, sensory cells, nerve cells and germ cells.
- Coelenterates **radially symmetrical animals** with **cell-tissue grade of body organisation**.
- **Radial symmetry**, means that whichever way it is cut along its central axis, the resulting halves would always be mirror images of each other.
- The animals have **blind sac body plan** *i.e.*, consists a single opening which serves both as mouth and anus.
- The distal end of body is produced into a conical elevation called **hypostome**.
- Mouth, surrounded by tentacles, is situated at the **apex of the hypostome**.
- The cnidarian **does not possess a true circulatory system**.
- **Respiratory** and **excretory organs** are **absent** as all the cells are in direct contact with water.
- **Respiration** takes place **through diffusion of oxygen directly through their tissues without specialised organs such as tracheae, gills or lungs**.
- The **gastrovascular system plays a role in the digestion and dispersion of food and the removal of metabolic waste**: it surrounds the gastrovascular cavity as well as its extensions in the tentacles of polyps. Thus the gastrovascular system serves two separate functions, digestion and transport.
- **Digestion** is both **intracellular** and **intercellular or extracellular.**
- Extracellular digestion occurs with the help of digestive enzymes poured into the gastrovascular cavity by secretory cells.
- Most cnidarians are **carnivores** and **mainly feed upon small crustaceans or zooplanktons**.
- Animals are **ammonotelic.**
- The **movement of cnidaria is controlled by a decentralised net of true nerve cells.**
- Nervous system is **primitive** and **diffuse type without brain** and is found in the form of an intra-epidermal nerve net.
- Sense organs are **statocyst**, **tentaculocyst** which occur in free swimming forms (medusa).
- Concentrations of nerve cells are **found in the mouth area of polyps (the hypostome), on the tentacles and stem (pedunculus),** and with jellies a ring of nerves is often found around the screen.
- Members of cnidaria have life-cycles that alternate between **asexual-polyps** and **sexual, free-swimming forms** called **medusae.** This phenomenon is called **metagenesis** or **alternation of generation** (e.g., *Obelia*).

- **Polyps** are anchored to the substrate by their basal discs, although a few species can move in curious slow-motion somersaults. By nature they display their tentacles upwards, away from the substrate. Polyps **often live in large colonies**.
- Polyp is **concerned with feeding and protection also**.
- **Medusae** have a hat or bell-shaped appearance and mostly swim passively with the current. Their tentacles hang freely below their bodies. However, they can actively swim by means of co-ordinated muscle contractions against the water contained in their gastrovascular cavity.
- Medusa stage is advanced to polyp because it has **great power of contractility**.
- In metagenesis, the **adult polyp forms male or female medusae (diploid) asexually**. There are three principal asexual events:
  - budding
  - **strobilation** occurs when a medusa forms on the higher (oral) end of the polyp, and is **common among scyphozoa**.
  - finally complete metamorphosis, from polyp to medusa form can also occur.
- **Asexual reproduction** *via* budding is **common** among cnidaria, particularly among the **hydrozoa class.**
- During their life cycle flagellated **planula larva** (*Obelia*) is formed which swims until it encounters a firm substrate on which it anchors itself and then passes through metamorphosis to the polyp stage.
- The life cycle also possesses a number of immature stages like **hydrula, hydratuba, scyphistoma** (= scyphula) and **ephyra** etc.

  Some groups such as **coral** live symbiotically with algae, mostly dinoflagellata but sometimes chlorophyta. By absorbing the carbon dioxide produced by the cnidarian, utilising sunlight *via* photosynthesis and releasing the oxygen, the algae produce energy-rich carbohydrates which the cnidarian uses as its main source of food.
- **Planula** is the **larval form** of coelenterates.
- **Classification of cnidarians** is mainly **based on dominance of polyp and medusoid stage**.
- There are **three main classes** of cnidaria: **hydrozoa** (Portuguese Man o' War, *Obelia*, *Hydra* etc.) **scyphozoa** (jellyfish) and **anthozoa** (anemones, corals, etc.)

Hydrozoa

- In **hydrozoa**, **polyps is the dominant or only stage of the life cycle**, though it usually have both polyp and medusa stage. *Eg.*- *Hydra*, *Obelia*, *Physalia* etc.
- Food of *Hydra* is **water fleas** (*Daphnia* and cyclops).
- *Hydra* **does not have any free larval stage** in the development.
- Real discoverer of *Hydra* is **Abraham Trembley**.
- *Hydra* has **four type of nematocysts** serving different functions. These are **penetrants, volvents, stereoline glutinants** & **streptoline glutinants**.
- The nematocysts which are mainly used for offence and defence are known as **penetrants** or **stenoteles**.
- These are the **largest** and **most complex type** of nematocysts in *Hydra*. They are open and inject **hypnotoxin**.
- The movement of the prey is impeded by **volvents** or **desmonemes**.
- **Penetrants** and **volvents** are useful in **capturing the prey**.
- **Volvents** or **desmonemes** are **spineless** and closed. They **helps in capturing prey by coiling round them**.
- **Stereoline glutinants** are **thread like tubes without spines**.
- **Streptoline glutinants** are **used both in food capture and locomotion**.
- The action of nematocyst depends on enzymes, which bring about increased osmotic pressure inside the capsule of cnidoblast.
- Some *Hydras* have **green or brown colour due to presence of green algae** *Zoochlorellae* and **brown algae** *Zooxanthellae* in their nutritoepithelial cells.
- Gonads in *Hydra* are formed temporarily from **interstitial cells of epidermis**.
- *Hydra* is a **solitary polyp found in freshwater** (stagnant).
- *Hydra* is **diploblastic** and **radially symmetrical**.
- The **tentacles** of *Hydra* **help in locomotion and food capture**, so **analogous** (correspond functionally) **to pseudopodia of** ***Amoeba***.
- Myofibrils of *Hydra* are all smooth.
- Mesogloea of *Hydra*, secreted by both ectodermal and endodermal cells, is a thin, acellular consisting of a proteinaceous matrix and it can be crossed by interstitial cells.
- Body cavity of *Hydra*, called **coelenteron**, **serves**

the double purpose of digestion and circulation.

- **Various types of locomotion** in *Hydra* are **gliding, floating, walking** (erect movement with all tentacles directed downwards using them as legs), **looping** and **somersaulting**. etc
- Locomotion in *Hydra* is **not connected with mating**.
- *Hydra* is **carnivorous** feeding on small crustaceans.
- *Hydra* **engulfs only those animals which have glutathione in their body tissue fluid of the prey**.
- Digestion in *Hydra* is **first extracellular** (in gastrovascular cavity) and **then intracellular** (in endoderm cells).
- *Hydra* has **no enzymes to digest starch.**
- **Nitrogenous excretory product** in *Hydra* is **ammonia** and it is removed through general body surface.
- *Hydra* has a nervous system, but **no brain.**
- *Hydra* has nerve cells but no nerves.
- *Hydra* possesses a very **primitive nervous system** consisting of synaptic network of bipolar and multipolar nerve cells.
- *Hydra* is **negatively chemotropic**, it avoids chlorinated water.
- In *Hydra* reproduction is **both asexual and sexual**.
- *Hydra* reproduces asexually by **exogenous budding,** a type of vegetative propagation, and sexually by **formation of gametes.**
- *Hydra* is **monoecious** or **dioecious**. Most species (*e.g., Pelmatohydra oligactis*) are dioecious or unisexual.
- Fertilization **occurs externally on the body** by the entry of sperm into ovum.
- *Hydra* has **great regenerating capacities**. A piece of *Hydra* will regenerate into a full *Hydra* if it contains a part of epidermis and gastrodermis and size is not less than 1/6 mm in diameter.
- *Hydra* have **single ovary** in lower half and **few testes** in distal/upper half.
- *Hydra* **does not have any free larval stage** in the development.
- *Obelia* (**sea fur**) colony exhibits **trimorphism containing three types of individuals** namely **hydranth**, **blastostyle** and **medusae**.
- **Hydranth** is also known as **gastrozooid** and are **nutritive in function**.
- **Blastostyle** is **asexual reproductive zooids** with reduced gastrovascular cavity.
- **Medusae** is free swimming zooid with a mouth, large number of marginal tentacles, sense organs (statocyst), marginal nerve ring and four gonads for sexual reproduction.
- *Physalia* is also known as **Portuguese Man of War**.
- *Physalia* **has a bladder like pneumatophore** which contains a gas gland. The **gas secreted by the gas gland helps the animal to float over the water surface**.
- Secretion of nematoblasts in *Physalia* is **neurotoxin**.
- **Cormidia** is a group of zooids in *Physalia*.

Scyphozoa

- **Scyphozoa** are mostly marine, some are freshwater forms.
- **Medusa is dominant** in scyphozoa **with polyp either absent or ill developed**, *eg*.- *Aurelia* (jelly fish), *Cyanea* (sun jelly).
- **Nematoblast are present in both epidermis and gastrodermis** in class scyphozoa.
- **Ephyra** is the **larval form of** *Aurelia*.
- The sensory organs in *Aurelia* are the **rophalia**.
- *Aurelia aurita* is commonly known as **moonjelly**.

Anthozoa

- **Anthozoa** have only **polyp phase**. *eg*.- sea anemone (*Admasia*), corals animals.
- All anthozoa are **marine**.
- **No alternation of generation** occur in anthozoa.
- Sea anemone (*Metridium*) **shows commensalism with** *Euspagurus* (**hermit crab**).
- Sea anemone is also known as **sea flowers**.
- The gastrovascular cavity of sea anaemone is divided into chambers by endodermally formed mesenteries.
- **Cnidoblasts** and **germ cells** are **endodermal**.
- **Importal corals** are - *Tubipora* (organ pipe coral), *Fungia* (mushroom coral), *Madrepora* (stag horn coral), *Astraea* (star coral), *Favea* (stony coral), *Heliopora* (blue coral), *Corallium* (red coral) etc.
- **Coral reefs** may be defined as the extensive mass of coral colonies which grow continuously in size by budding of polyps. Eg. **fringing reef**, **atoll** and **barrier reef**.
- Coral animals **secrete external skeletons** of **calcium carbonate**.
- Coral is the rock-like external skeletons.
- **Corals** may be **solitary** or **colonial**.
- **Solitary coral** is *Fungia* (also called **mushroom coral**).
- **Colonial corals** are *Astraea* (star coral), madrepora (stag horn coral), *Pennatula*, *Gorgonia*.

- Pennatula is also known as **sea pen**.
- **Largest tentacle** is present in *Cyanea arctica* (about 1 m in length).
- **Important reef forming corals** are millepora, tubipora, heliopora etc.
- **Sea pancy** is the **common name** of *Ranilla*.

CTENOPHORA

- **Ctenophora** was **established by Hatscheck** (1839).
- Ctenophora is a **small phylum of marine coelenterates** like **free swimming** and **biradially symmetrical animals** having **8 meridional row of ciliary comb ribs**.
- They are **popularly called as comb jellies, seacombs** and **seagoose berries**.
- **Cnidoblast are absent** with the exception of *Euchlora rubra.*
- They possess **photocytes** or light producing structures, therefore are **luminescent**.
- Tentacles, when present, are solid and possess adhesive cells called **colloblasts** (= **lasso cells**).
- Ctenophores are **acoelomates**.
- Body plan is **intermediate between blind sac and tube within tube**.
- Animals are usually **monoecious**. An immature ciliated stage larva called **cydippid larva** is found in some forms.
- Ctenophora has **two classes – tenticulate** (with tentacles), eg. *Hormiphora* and **nuda** (without tentacles), e.g., *Beroe.*

PLATYHELMINTHES

- The term platyhelminthes (also called **flatworms**) was first proposed by **Gegenbaur**.
- The **platyhelminthes** (Greek "platy"': flat; "helminth": worm) are a phylum of relatively **simple soft-bodied invertebrate animals.**
- Flatworms are found in **marine, freshwater**, and even **damp terrestrial environments**. Most are **free-living forms**, but many are **parasitic on other animals**.
- Cephalization (**differentiation of head**) **begins in the flatworms.**
- The flatworm's cephalized soft body is **ribbon-shaped, flattened dorso-ventrally (from top to bottom), and bilaterally symmetric.**
- Flatworms are the **simplest triploblastic animals with organs**. This means their organ systems are formed out of **three germ layers**: an outer **ectoderm** and an inner **endoderm** with a **mesoderm** between them.
- There is also **no true body cavity (coelom)** except the gut and hence they are **acoelomates** which is filled with somewhat loosely spaced mesodermal tissue called **parenchyma tissue.**
- With about 25,000 known species they are the **largest phylum of acoelomates.**
- Animal possesses **tissue organ level of organization** and **blind sac body plan**.
- Extracellular body fluids (interstitial fluids) percolate between cells to help distribute nutrients, gses, and waste products.
- There is **no true circulatory**, **skeleton or respiratory system**, but like all other animals, flatworms do take in oxygen.
- Flatworms respire at their integument; gasses diffuse directly across their moist outer surface. This type of system is called **integumentary exchange**.
- Digestive system is **incomplete** due to possessing only one opening, **reduced or absent in parasitic form** (e.g., *Taenia*).
- **Excretion and osmoregulation** are brought about by **flame cells** or **solenocyte and protonephridia**.
- Flatworms possesses **high power of regeneration.**
- Flatworms do have a **bilateral nervous system**; they are the simplest animals to have one. Two cordlike nerves branch repeatedly in an array resembling a ladder (*i.e* **ladder like nervous sytem**). The head end of some species even has a collection of ganglia acting as a rudimentary brain to integrate signals from sensory organs such as eyespots.
- Sense organ are **better developed in free living forms** like *Planaria*.
- Flatworm reproduction is **hermaphroditic or monoecious**, meaning each individual produces eggs and sperm.
- **Fertilization** is **internal** and **cross fertilization is predominant.**
- They **usually do not fertilize their own eggs**.
- **Life cycle** is **indirect** or complicated with one or many larvae.
- **Classifications of flatworms**, primarily **based on differing degrees of parasitism**, is divided into three monophyletic classes – **turbellaria**, **trematoda** and **cestoda**.

Platyhelminthes

Divided into 3 classes

Turbellaria (Eddy worm)	**Trematoda**	**Cestoda**
• Freeliving in both fresh and marine water, but some are commensals & ectoparasites • **Cilia on body surface** • Epidermis is cellular, syncytial, characterised by presence of special hyaline rod shaped bodies called **rhabditis** producing chemical secretions • Body is **unsegmented & leaf like** • Suckers absent. Adhesive organs are glanduloepidermal & glandulomuscular • Alimentary canal with 2 branches • Simple life cycle. **Development** is usually direct **without any larval stages**. • Eg. *Planaria, Bipalium, Thysanozoon* etc.	• Endoparasites or ectoparasites • **Cuticle present**, no cilia • **Unsegmented & leaf like body** • Sucker and some times hooks present • Alimentary canal with 2 branches • Complicated life cycle with larval stages. • **Development** is **direct in ectoparasites** & usually **indirect in endoparasites** with alternation of host. • E.g. Liver fluke (*Fasciola*), *Schistostomata*, *Opisthorchis* etc.	• **Advanced class** • Endoparasites in alimentary canal of vertebrates • Cuticle presented, no cilia & epidermis • Body is segmented & **ribbon like** • **Every segment** is **hermaphrodite** • Suckers, hooks (on scolex) present • No alimentary canal • Complicated life cycle with larval stages. • E.g. Tapeworm (*Taenia*), *Echinococcus* etc.

- *Bipalium* is the **largest terrestrial turbellarian**.
- Trematodes with only oral suckers are called **monostomes**.
- The liver fluke has a dorsoventrally flat, unsegmented body with **two suckers**, **oral sucker** (anterior sucker) and **acetabulum** (ventral sucker).
- *Fasciolopsis* (= *Fasciola*) *buski*, is a fluke that lives in human **stomach** and **duodenum** in South-East Asia.
- *Opisthorchis sinensis* (Chinese/Oriental Liver Fluke) **causes jaundice and liver damage** in human beings in China, Japan and Vietnam. It has **two intermediate hosts - snail** and **fish**. Cats, dogs and pigs can also be infected.
- *Fasciola gigantica* (*F. indica*) is **liver fluke of cattle**.
- *Paragonimus westermani* is **lung fluke**.
- Body of *Taenia* is divided into three parts namely **scolex**, **neck** and **strobila**.
- **Scolex** has a rostellum bearing two circlets of chitinous hooks and four suckers or acetabula for holding onto the host.
- **Neck** is the unsegmented part, new segments are formed in this region.
- **Strobila** is the main body **made of proglottids**.
- Proglottids are of **three types** : young, mature and gravid.
- **Young or immature proglottids** are behind neck and are **without reproductive organs**.
- **Mature proglottids** are in the middle **having reproductive organs**, both male and female gonads.
- **Gravid proglottids** (rectangular in shape) are **with branched uterus containing fertilized eggs**.
- **Apolysis** is the process of separation of gravid proglottids.
- Body cavity is **absent** in tape worm, hence they are **acoelomate**.
- *Taenia* has **no digestive system**. It completely depends upon predigested nutrients absorbed from the host's gut through the cuticle.
- **Complete absence of an alimentary canal** is a **unique parasitic adaptation** in tapeworm.
- The **cuticle** protects the tape worm from the host's digestive enzymes.
- Main excretory products are **ammonia** and **fatty acids**.
- **All tapeworms** are **hermaphrodites**, and a complete reproductive system occurs in each mature proglottid.

Table : Some important examples

	Example	Important notes
		Class - Turbellaria
1.	*Dugesia* (*Planaria*)	• Has **great power of regeneration** • Carnivorous, omnivorous and hermaphrodite, Gregarious (live in groups) • Eggs are **ectolecithal** *i.e.,* yolk is deposited on the outside, direct development

If *Planaria* is cut across into two, three or more parts, each part regenerates into a complete and normal individual. Regeneration, thus, involves two complementary processes, viz., *epimorphosis*, in which the missing parts are formed, and *morphollaxis,* in which the original parts are fit to function with regenerated parts in the new individual. A note-worthy observation is that a piece from the middle always regenerates a head towards its anterior side and tail towards its posterior side. In other words, each piece maintains its original *linear polarity.* This can be explained by the theory of metabolic or axial gradient by C.M Child .The theory holds that **metabolic activity is highest in head and gradually decreases towards the tail end**.

	Example	Important notes
		Class - Trematoda
2.	*Fasciola hepatica* (Sheep liver fluke)	• Digenetic endoparasite. Primary and secondary host are **sheep** and **snail** (*Limnaea* or *Planorbis*) respectively. • **Laurer's canal** is present and **acts as sperm duct**. During breeding season it serves as vagina during copulation (which take place in bile ducts of hosts) and receive the sperms. • Hermaphrodite, hence **cross fertilization is preferred** • **Correct sequence of various larva** : **miracidium** (ciliated, free swimming stage) $\rightarrow$ **sporocyst** (elongated sac like) $\rightarrow$ **redia** (elongated, cylindrical) $\rightarrow$ **paedogenesis** $\rightarrow$ **cercaria** (shows close resemblance with the adult fluke) $\rightarrow$ **metacercaria** (juvenile fluke, also called **marita**) • **Miracidium** is the stage when it infects the intermediate host and primary host is metacercaria. • Causes **liver rot or cirrhosis (fascioliasis)**
3.	*Schistosoma* (Blood fluke)	• It is dioecious with well defined sexual dimorphism • Lives in hepatic portal vein of human body vessels of urinary bladder • **Female** permanently **lodged in Gynaecophoric canal of male** • Life cycle involves single intermediate snail host • **Digenetic**, **primary host** is **man** and **secondary host** is **snail** • **Different larval stages - miracidium** $\rightarrow$ **sporocyst** $\rightarrow$ **cercaria** (no redia and metacercaria stage) • Infection causes **schistosomiasis** or **bilharziasis**, symptoms include skin rash bronchial cough, anaemia, abdominal pain, diarrhoea.
4.	*Elonorchis sinensis* (Chinese liver fluke)	Life cycle involves two intermediate hosts - a fresh water snail and a fresh water fish.
		Class - Cestoda
5.	*Taenia solium* (Pork tape worm)	• Endoparasite in small intestine of human beings. • Digenetic. **Primary host** is man and **secondary or intermediate host** is pig or cattle. • **Larval stages - oncosphere**, **hexacanth** (with six hooks) and **cysticercus** (bladder worm). • Secondary host **acquires infection** by ingesting oncospheres. • Cysticercus is the **infective stage to man**. • Causes **taeniasis disease**.

contd ...

		• Human bladder worm infection is called **cysticercosis**, symptoms include necrosis of brain and epilepsy. Larvae settle in brain. It is caused because of auto infection by antiperistalsis & man is the accidental intermediate host. It is **more dangerous than taeniasis**. • Self fertilization occur in mature proglottids
6.	*Taenia saginata* (Beef tapeworm)	• Inhabits the beaf eating population • Longer than *T. solium* (12m) • Scolex **lack rostellum and chitinous hook** and uterine branches are absent, hence called **unarmed tape worm**. • **Digenetic**, man is **primary host** and **intermediate host** is cattle (sheep) and buffaloes
7.	*Echinococcus* (Hyadit worm or dog tapeworm)	• Endoparasite, primary host (dog, wolf, cat) and secondary host (cattle, sometimes man) • Causes **hydatid cyst** in liver, lungs and other parts
8.	*Hymenolepis nana* (dwarf tapeworm)	Smallest human tapeworm. 3 testes in each proglottids. No intermediate host.

NEMATODES

- Nematodes are commonly referred to as **non-segmented roundworms, threadworms or pinworms.**
- They constitute the **largest phylum of pseudocoelomates group** combined under the **superphylum aschelminthes**.
- The name aschelminthes was proposed by **Grobben** (1910) in place of the older name nemathelminthes.
- Phylum aschelminthes is **divided into 5 classes** : **rotifera, gastrotricha, kinorhyncha, nematomorpha** and **nematoda**.
- **Rotifera** are commonly called **wheel** (corona) **animalcules**.
- These are **microscopic animals** of ponds, lakes & streams, rarely in oceans.
- Body wall thickened into **plates or lorica** into which head may retreat.
- In class rotifera **males are smaller than females**, so, female reproduce parthenogenetically, eg. *Philodina*, *Rotaria*.
- **Gastrotricha** are microscopic & marine animals.
- Body wall have cuticle bearing short spines, eg.- *Chaetonotus*, *Lepidodermella & Macrodasys*.
- Body wall of **kinorhyncha** have spiny cuticle without cilia.
- These are **monoecious** and **gonads are present as paired tubular sacs**, eg.- *Echinoderes* & *Pycnophyes*.
- **Nematomorpha** are commonly called **hair worms**, found in springs, eg- *Paragordius* & *Nectonema*.
- Thick cuticle bearing small papillae is present in the body wall.
- **Digestive system** is **complete in larva** but **degenerate in non feeding adults**.
- **Nematodes** are commonly called as **round worms** which are **aquatic**, **terrestrial or parasitic**.
- Body wall have **cuticle**, **epidermis** & **longitudinal muscles**.
- **Examples of nematodes** are – *Ascaris, Wuchereria, Enterobius, Trichuris* etc.
- The nematodes were originally named nematoidea by **Rudolphi (1808).** They were renamed nematodes by **Burmeister (1837).**
- The **science dealing with the study of worms** especially parasitic flatworms and roundworms is called **helminthology.**
- Nematodes are **bilaterally symmetric, triploblastic protostomes** with a **tube-within-tube plan, organ system level of organization** and **a complete digestive system**.
- Roundworms **have no circulatory or respiratory systems** so they use diffusion to breath and for circulation of substances around their body.
- The **body cavity is a pseudocoel** or false coelom **(persistent blastula),** which lacks the muscles of coelomate animals used to force food down the digestive tract. Nematodes **thus depend on**

internal/external pressures and body movement to move food through their digestive tracts.

- Pseudocoelom contains **hydrolymph** and some cells called **pseudocoelomocytes**.
- The epidermis (may be **cellular** and **syncytial**) **secretes a layered cuticle made of keratin** that protects the body from drying out, from digestive juices, or from other harsh environments, as well as in some forms sporting projections such as cilia that aid in locomotion.
- There are **no circular muscles**, so the body can only undulate from side to side. **Muscles usually are present longitudinal**.
- Digestive system is **complete** with mouth and anus.
- Digestion is mainly **extracellular**, generally feeds on predigested food present in host's intestine.
- **Reserve food** is **in the form of glycogen stored in syncytial epidermis**.
- **Excretion** is brought about by **gland cells or H-shaped intracellular excretory tubes/canals** or both. Some forms have **protonephridia**.
- The animals **possess fixed number of cells & nuclei throughout life** (called **eutely**).
- Nematodes **have a simple nervous system**, with **circumpharyngeal nerve ring** and **six longitudinal nerve cords**. Sensory structures (which are **poorly developed**) at the anterior end are called **amphids,** while sensory structures at the posterior end are called **phasmids.**
- Sexual dimorphism is common.
- Reproduction is **usually sexual.** There is **no asexual reproduction**.
- Males are usually **smaller than females** (often very much smaller) and often **have a characteristically bent tail for holding the female for copulation**.
- During copulation, one or more chitinized spicules move out of the cloaca and are inserted into genital pore of the female. **Amoeboid sperm** crawl along the spicule into the female worm.
- **Eggs** may be **embryonated** (**infective second stage juvenile** in *Ascaris*) or **unembryonated** when passed by the female, meaning that their fertilized eggs may not yet be developed.
- In **free-living roundworms**, the eggs hatch into larva, which eventually grow into adults; **in parasitic roundworms**, the life cycle is often much more complicated.
- The **early larval stage of nematodes** is called **rhabditiform** or **rhabdioid larva**. It is **generally non-infective**.
- In free-living species, development usually consists of **four moults of the cuticle during growth**.
- Nematodes **commonly parasitic on humans include whipworms, hookworms, pinworms, ascarids**, and **filarids**.
- One form of nematode is **entirely dependent upon the wasps** which are the sole source of fig fertilization. They prey upon the wasps, riding them from the ripe fig of the wasp's birth to the fig flower of its death, where they kill the wasp, and their offspring await the birth of the next generation of wasps as the fig ripens.
- Nematodes are classified into two classes - **phasmida** (eg. *Ascaris, Dracunculus*) and **aphasmida** (eg., *Enoplus*, *Mermis* etc.) on the basis of presence or absence of phasmids (Chitwood 1933).

Nematodes

2 class

• Phasmids (caudal sensory organ) absent • Amiphids (anterior sense organs) of various types, rarely pore like • No excretory system • Mesenterial tissue well developed • Eg. *Enophus*, *Paramermis* etc.	• Phasmids present • Amphids pore like • Excretory system developed • Mesenterial tissue weekly developed • Eg. *Trichuris*, *Oxyuris*, *Ascaris* etc.

Plant parasitic nematodes

Plant parasitic nematodes include several groups causing severe crop losses. The most common genera are: *Aphelenchoides* (foliar nematodes), *Meloidogyne* (root-knot nematodes), *Heterodera*, *Globodera* (cyst nematodes) such as the potato root nematode, *Nacobbus*, *Pratylenchus* (lesion nematodes), *Ditylenchus*, *Xiphinema*, *Longidorus*, *Trichodorus*. Several phytoparasitic nematode species cause histological damages to roots, including the formation of visible galls (Meloidogyne) which are useful characters for their diagnosis in the field. Some nematode species transmit plant viruses through their feeding activity on roots. One of them is *Xiphinema index*, vector of GFLV (Grapevine Fanleaf Virus), an important disease of grapes.

Table : Some important examples

	Examples	Important notes
1.	*Enterobius vermicularis* [*Oxyuris* (Pin worm or seat worm)]	• Found in large intestine and appendix. **Monogenetic parasite**. • Causes **enterobiasis** or oxyurasis characterised by anal itching, appendicitis, nervous problem. • **No intermediate host**
2.	*Ascaris lumbricoides* [Roundworm] There are **three types of migration** by *Ascaris* larvae–*primary*, *secondary* and *aberrant migration*. **Primary migration** (from wall → hepatic → portal → liver → hepatic vein → heart → pulmonary artery → lungs) **Secondary migration** (from lungs back to intestine of the host *i.e.*, lungs → bronchi → trachea → pharynx → gullet → oesophagus → stomach → intestine) **Aberrant migration** (from lungs to brain, spinal cord, eyes etc.)	• Most common, monogenetic **intestinal parasite of humans**. • Have **telogonic gonads** which means only the anterior part of testis is functional. Female *Ascaris* is **didelphic** (has two ovaries) • Causes ascariasis, **characterised by** anaemia, diarrhoea, pneumonia and bronchitis, they are found world wide. • **Common in children**. • **Male is smaller** than female **with curved tail**, two pineal setae & cloaca. • Mouth is terminal in both & **triradiate** (surrounded by three denticulate lips, one median dorsal & two ventrolaterals) • **Embryonic development takes place in soil** (due to low temperature, more oxygen and suitable moisture) • Larva of first stage is not infective, **second stage larva** (rhabditiform) **is infective**. • **Transmission** of infective stage through embryonated egg takes place **by contaminated food and water**. • Life span in host is of **9 - 12 month**. • **Most pathogenic larva** is the **fourth stage in lungs**.
3.	*Ancylostoma duodenale* [Hookworm]	• Found in the human intestine. **Monogenetic**. • Causes itching and inflammation of skin, anaemia, retarded physical and mental growth. Migratory larva **causes pneumonia** because of foreign body larva reaction while it is in alveoli of lungs. • Their larvae enter the human body by boring the skin through feet. • Infective juvenile stage is **filariform larvae** (**non feeding**).
4.	*Dracunculus medinenis* [Guinea worm or madina worm of fiery serpent]	• Largest nematode parasite. Gravid female are **found in the subcutaneous tissues** of body and **form blisters**. • Female is **long** and **male is short**. • **Intermediate host** is *Cyclops* or water flea like *Mesocyclops* and *Themocyclops* and **primary host** is **man**. • Parasite causes itching, eosinophilia, nausea and vomiting.
5.	*Wuchereria bancrofti* [Filarial worm]	• **Found** in the **lymph vessels**. • Parasite is **digenetic** having secondary host - *Culex fatigens*, *Culex–pipens* and *Culex unique fasiatus*. • Causes **lymphatic filariasis** or **elephantiasis** by blocking lymphatic vessel and glands. Oedema typically begins in the ankle and progresses to foot and leg. • **Third stage juvenile** is **infectious stage**. • Larva is called **microfilariae** which **show day and night periodicity**. • By day they live in large deep seated blood vessels, but at night or during sleep they come into superficial or peripheral vessels in skin to be sucked by nocturnal mosquitoes.

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6.	*Loa loa* [The eye worm]	• Found in the subcutaneous tissues of eyes. Its **intermediate host** is *Chrysops*. • Causes **lymphatic conjunctivitis**.
7.	*Trichinella spirialis* [Trichina worm]	• **Intestinal endoparasite** of human. • Causes **trichnosis**, characterised by muscular pains and pneumonia or trichiniasis. • **Transmitted by eating infected pork**. **Intermediate host** is **pig or cattle**.
8.	*Trichuris trichura* [Whip worm]	• **Found** in the **caecum and appendix**. Monogenetic. • Causes **trichiurisis**, **characterized by** anaemia, bloody stools and pains.

ANNELIDA

- **Lamarck**, coined the term annelida for ringed animals.
- The annelida **comprising the metamerically segmented worms** including the well-known earthworms and leeches.
- **Metamerism** is the division of body into similar parts which is evident in the external feature of worms.
- Metamerism **increases the efficiency of body movement** by allowing the effect of muscle contraction to be extremely localized, and it makes possible the development of greater complexity in general body organization.
- Each segment is marked externally by one or more rings, called **annuli**. Each segment also has an outer layer of **circular muscle** underneath a thin cuticle and epidermis, and a system of **longitudinal muscles**.
- In **earthworms**, the **longitudinal muscles are strengthened by collagenous lamellae**; the **leeches have a double layer of muscles** between the outer circulars and inner longitudinals.
- Anterior to the true segments lies the **prostomium** and **peristomium**, **which carries the mouth**, and posterior to them lies the **pygidium, where the anus is located**.
- They are **found in most wet environments**, and **include many terrestrial**, **freshwater**, and **especially marine species** (such as the polychaetes), **as well as some which are parasitic or mutualistic**.
- Annelids are **triploblastic protostomes with a coelom** (**or coelomate**), **closed circulatory system** and **true segmentation**.
- Annelids are the **first animals to have a closed circulatory system**.
- Annelids **have organ system level of organisation.**
- During evolution, **true coelom appeared for the first time in annelids,** which is **formed by the splitting of mesoderm.** Therefore it is **schizocoel.**
- Oligochaetes and polychaetes typically have spacious coeloms; **in leeches, the coelom is largely filled in with tissue** and **reduced to a system of narrow canals**; **archiannelids may lack the coelom entirely**.
- The coelom is divided into a sequence of compartments by walls called **septa**. In the most general forms each compartment corresponds to a single segment of the body, which also includes a portion of the nervous and circulatory systems, allowing it to function relatively independently.
- **Respiration** is **cutaneous**, therefore annelids **must live in moist and aquatic environments**. Some times gases are exchanged through specialized gills or modified parapodia.
- There is a **tube within a tube plan** of the body because animals of this phylum have a wide, fluid filled body cavity containing other viscera that deals with internal functions between body wall & alimentary canal. Body wall (outer tube) and alimentary canal (inner tube) are specialised to their respective functions. Alimentary canal starts with mouth & ends with anus to ingest and egest food respectively. Whereas outer tube forms protective structures.
- The digestive system is a **complete tube with mouth & anus** at both ends.
- The **vascular system includes a dorsal vessel** conveying the blood toward the front of the worm,

and a **ventral longitudinal vessel** which conveys the blood in the opposite direction. The two systems are connected by a vascular sinus and by lateral vessels of various kinds, including in the true earthworms, capillaries on the body wall.

- Blood is **red due to presence of** respiratory pigment **haemoglobin or erythrocruorin** dissolved in plasma. **RBC's are absent**.
- Circulation (**open type**) is **caused by peristalsis or activity of heart**.
- **Excretory system** consists of metamerically disposed coiled tubes called **nephridia** (ectodermal in origin).
- All annelids **except leeches** also have **chitinous** hair-like structures, called **setae** (used to grip the ground during locomotion), projecting from their cuticle. Sometimes the **setae** are located on paddle-like appendages called **parapodia** (among polychaetes).
- **Hydrostatic pressure** is maintained across segments and **helps maintain body rigidity, allowing muscle contractions to bend the body without collapsing it**.
- The **nervous system** has a **solid, ventral nerve cord** from which lateral nerves arise in each segment.
- Annelids **may be monoecious or dioecious**. Larva may or may not be present, if present they are of the **trochophore type**.
- Annelids can reproduce **both sexually and asexually by fission**.
- Sexes separate, **trocophore** larva when present during development, undergoes, metamorphosis to reach the adult stage.
- Mostly **cross fertilization** takes place. They are **oviparous** and the eggs are laid in ootheca/cocoons/ egg case.
- **Clitellum** present in bisexual annelids is **useful in the formation of cocoon**.
- Fertilization is **external** except in *Hirudinaria*.
- **Classification of annelida is based on position & arrangement of setae** when present, **absence and presence of sense organs**.
- Annelida is divided into **four classes – archiannelida, polychaeta**, **oligochaeta** and **hirudinea**.
- Archiannelida are all **marine, small with internal segmentation & no parapodia & setae,** eg. *Dinophilus, Polygordius.*
- In the development of archiannelida, **lovens larva** is seen.
- **Polychaeta** is the **biggest class of phylum annelida**, eg *Nereis*, *Aphrodite* etc
- **Nectochaeta** is **free swimming larva** of some polychaetes which bears rings of cilia and 3 pairs of parapodia. Late trochophore larva of *Nereis* resembles nectochaeta.
- **Oligochaeta** are commonly called **earthworms**, mostly terrestrial, some in fresh water.
- *Pheretima* is the **biggest genus in the class oligochaeta**.
- **Hirudinae** are commonly called as **leeches**, eg *Hirudu* and *Hirudinaria*.
- These are **terrestrial**, **fresh water** and **marine ectoparasitic**, **blood sucking** or **carnivorous animals**.
- **Other examples of annelida** are *Drawida grandis* (longest earthworth of India); *Eunice* [pacific palolo worm (exhibit lunar periodicity)]; *Glycera* (smooth blood worm); *Sabella* (peacock worm); *Serpula* (fan worm); *Eutyphoeus* (earthworm of gangetic plains); *Ozobranchus* (leech with gills); *Haemadipsa* (land leech).

Table : Some important examples

	Example	Important notes
	Class - Polychaeta (Almost all marine, occur in greatest abundance near the seashore; locomotary structures and parapodia)	
1.	*Aphrodite* (Sea mouse)	During movement body colour changes from gold to peacock blue.
2.	*Polynoe* (Scaleworm)	• Close ally of *Aphrodite*. • Several species are bioluminescent, luminescent material is secreted by the gland cells located on surface of elytra.

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3.	*Chaetopterus* (Paddle worm)	• Lives in U-shaped parchement tubes. • Smallest oligochaetes.
4.	*Arenicola* (Lungworm or lobeworm)	• Lives in mud or sand in U or J-shaped burrows, lined by mucus. • Used as fish bait.
5.	*Neries* (Sandworm/ragworm/clamworm)	• Lives in U-shaped burrows in tidal areas of seashores. • Has chitinous jaw for capturing prey. • **Sexual stage of animal** is called **heteronereis** which develops in response to hormones and possesses enlarged eyes, swimming foliaceous parapodia and swollen gonad containing posterior half of body called epitoke (normal anterior part is called atoke). Trochophore larva.
	Class - Oligochaeta (Commonly called earthworms, mostly terrestrial, hermaphrodites, no larval stages and therefore no metamorphosis)	
6.	*Pheretima posthuma* (*Earthworm*) [For *more detail* refer *chapter Morphology and Anatomy of Animals*]	• Common earthworm of India, hermaphrodite. • **Ureotelic** under normal soil condition but urine contains small quantities of ammonia and creatine. They are **ammonotelic in water saturated soil**. • Lives in burrow in moist human rich soil. • Called **Nature's of ploughman**, cross fertilization.
7.	*Tubifex* [Blood worm (because of its bright red colour)]	• Reproduces only sexually. • Helps in purification of polluted fresh water. • It can carry on anaerobic respiration.
	Class - Hirudinea (Commonly called leeches; sanguivorous, botryoidal tissue present)	
8.	*Hirudinaria granulosa* (Cattle leech) The process of letting out blood by using leech is called **phlebotomy**.	• Sanguivorous (feeds on blood). Ectoparasite on cattle and humans. • Hermaphrodite. • Possess an anticoagulent - **hirudin or anticoagulin.** Hirudin is secreted by the salivary glands & prevents coagulation of blood of host thus ensuring a continous supply of blood. • Coelom is filled with **botryoidal tissue**. Botryoidal tissue is a pigmented and richly vascular masses of connective tissue & excretory in function.
11.	*Pontobdella* (Skate sucker or marine leech)	*P. muricata* **lays velvetty eggs in empty shells of molluscs** and mount to guard over them for more than 100 days till they hatch.

ARTHROPODA

- Phylum arthropoda (means jointed legs) is a **group of bilaterally symmetrical, triploblastic, tube-within-tube plan, organ system level of organisation, metamerically segmented** (with appendages on each segment) **animals**.
- Arthropods are the **largest phylum of animals** and **include the insects, arachnids, crustaceans**, and others.
- Arthropods are **common throughout marine, freshwater, terrestrial**, and **even aerial environments**, as well as including various symbiotic and parasitic forms.
- Body is often divided into **head, thorax** and **abdomen.**
- Head and thorax may be united to form **cephalothroax**.
- **Possess jointed appendages** which were **used for locomotion**, **feeding**, **defence** and **sensory purposes**.
- Appendages may be **uniramous** (have one single branch or ramus) or **biramous** (has two primary

rami) and may be secondarily lost or highly modified.

- Most **distinctive characteristic** of arthropod is their **exoskeleton** containing chitin, mucopolysaccharides and proteins, often strengthened by $CaCO_3$ (eg. many crustacea and millipedes).
- Exoskeleton is made up of a **non-living cuticle** (secreted by epidermis) which does not grow and must be shed at intervals (called **molting or ecdysis**) periodically and grows larger.
- Molting occurs 4-7 times before becoming an adult.
- Exoskeleton serves the purpose of forming an **armour against enemies**; a **protection against dessication** and a **framework for support** of the softer parts and for **muscular attachment**.

Cuticle

Formed of three layers

Innermost layer	Intermediate layer	External layer
Endocuticle	**Exocuticle**	**Epicuticle**
Flexible and composed of chitin.	Rigid and high in protein.	Thin, contains a waxy material and serves to prevent transmission of water and other substance; antibacterial.

$\underbrace{\text{Endocuticle} + \text{Exocuticle}}_{\textbf{Procuticle}}$

- Muscles are **striated or striped** which are attached to special anchorages on the cuticle and are capable of rapid action (*i.e*. allows for faster contraction times). Muscles insert into the procuticle and are generally paired antagonistically as flexors and extensors.
- The **success of arthropods is related to their** hard exoskeleton, segmentation, and jointed appendages.
- **Respiratory system** is **well developed** and respiration **occurs through body surface, gills, trachea** or **book lungs**.
- **Aquatic arthropods use gills to exchange gases**. These gills have an extensive surface area in contact with the surrounding water.
- **Terrestrial arthropods** have **internal surfaces that are specialised for gas exchange**.
- Insects and most other terrestrial species have tracheal systems: air sacs leading into the body from pores called spiracles in the epidermis cuticle.
- Arthropods have **complete digestive system with mouth parts** modified and adapted for different methods of feeding.
- Arthropods have an **open or lacunar circulatory system**.

Arthropoda — 4 subphyla

Onychophora
- Worm like
- Primitive arthropoda
- Excretory organ nephridia.
- Eg. *Peripatus* (**connecting link** between annelida and arthropoda)

Trilobitomorpha
- Comprises a wholly extinct group of primitive marine arthropods
- Represent fossil arthropod
- Eg. *Triathrus*.

Chelicercata

Body is divided into cephalothorax and abdomen.

divided into 2 classes

Merostomata
- Aquatic, extinct
- Eg. *Eurypterus* and *Limulus* (**living fossil**)

Arachnida
- No antennae, lacking compound eye
- Most with a cephalothorax and abdomen. Some with a single body region.
- Most are terrestrial or aquatic.
- Most are predacious
- Air breather
- Eg. Spiders, ticks, mites, scorpions, horseshoe crabs.

Mandibulata

divided into 3 classes

Crustacea
- Dominant arthropoda of sea
- Two pairs of antennae
- Two body regions (head and thorax combined into the cephalothorax)
- One pair of appendages per body segment. Appendages terminate in pinchers.
- Primarily an aquatic group, respiration is by gills even in terrestrial species.
- Excretion through green glands
- Some very unusual groups, for example, barnacles (*Sacculina*) and water fleas (*Daphnia*)
- Egs. Shrimp, lobsters, crabs and cyclops etc.

Myriapoda

divided into 2 classes

Diplopoda
- Does not have poisonous claw.
- Single pair of antennae.
- Two body regions, head and body.
- Body segments fused in pairs, each apparent segment composed of two embryonic segments.
- Two pairs of appendages per apparent body segment, extending out from sides of body
- Usually herbivores or detritivore and slow moving.
- Eg. Millipedes (*Julus*)

Chilopoda
- Single pair of antennae
- Two body regions, head and body
- One pair of legs per body segment
- Appendages of first body segment modified into poisonous claws.
- Almost all predaceous and fast moving.
- Eg. Centipedes (*Scolopendra*)

Insecta (Largest class)
- Single pair of antenna
- Three body regions (head, thorax, and abdomen)
- Three pairs of legs (adult insect), one on each segment of thorax (hence called hexapoda)
- Most adult insects with wings.
- Respiration by trachae.
- Excretion by malpighian tubules.
- Development either hemimetabolous (incomplete metamorphosis, no pupal stage) or holometabolous (complete metamorphosis, pupal stage)
- Egs. Cockroach, *Apis, Bombyx* etc.

- The perivisceral body cavity is called **haemocoel** as it is full of **haemolymph** (blood). The **true coelom is restricted to the gonads**.
- Haemolymph containing **haemocyanin**, a copper-based oxygen-carrying protein, is propelled by a series of hearts into the body cavity where it comes in contact with the tissues.
- The heart is dorsal in position and bears, laterally paired openings called **ostia**. Blood capillaries are absent, blood flows through ill defined spaces (sinuses).
- The **blood is colourless** in insects.
- In crustacea the **blood is coloured blue** due to the presence of a respiratory pigment haemocyanin.
- Unlike vertebrates and some annelids, the **blood of an arthropod does not usually carry oxygen**.
- **Excretion** is brought about usually by **green glands in aquatic forms** and **malpighian tubules in terrestrial animals**. (Nephridia occur in onychophores).
- Excretory product is **ammonia/urea in aquatic forms** and **uric acid in terrestrial species**.
- **Nervous system** has **paired pre-oral ganglia** (cerebral and suboesophageal), **connectives, commissures** and a **double nerve cord** having segmented ganglia and nerves.
- **Various sense organs** found in arthropods include **antennae** (jointed feelers, perception of odour), **sensory hair** for touch, **chemoreceptors** (taste receptors located in feet in insects, labium and maxillary palps), **sound receptors** (chirping crickets and cicadas, anal circi in cockroach), **simple and compound eyes**, **statocysts** (for balancing), etc.
- **Antennae are absent in arachnids**.
- The animals are **unisexual/dioecious** and **exhibit the phenomenon of sexual dimorphism**.
- **Fertilization** is **internal in terrestrial forms** and **external in aquatic forms**. The animals are **oviparous**.
- Ovovivipary is occasional, *e.g.*, scorpion.
- **Eggs** are **macrolecithal, cleidoic** and **centrolecithal**.
- Most of the arthropods possess an **endocrine system** which consists of **neurosecretory cells in the brain, at the base of compound eyes** and **glands in the thorax**.
- Hormones **control reproduction, moulting** and **metamorphosis**.
- **Development** can be **direct (without larval stages) or indirect (with larval stages)**.
- **In direct development**, the **young resembles the adults** and occur in the same habitat. In **indirect development**, **independent larval stages occur** which often show different feeding habits, live in different habitats and **do not resemble the adults**. Metamorphosis occurs in such cases.
- Metamorphosis in insects is promoted by a hormone called **ecdysone hormone**.
- Parthenogenesis is also met in some insects like **honey bees**.
- Arthropoda is **divided into 4 subphyla** - onychophora, trilobitomorpha, chelicercata and mandibulata.

Table : Some important examples

	Examples	Important notes
		Class - Onychophora (Most primitive arthropods)
1.	*Peripatus* (Walking worm)	Connecting link between annelida and arthropoda.
		Class - Arachnida
2.	*Palamnaeus* (Indian scorpion)	• Body is divided into prosoma, mesosoma and metasoma. • **Venomous arthropod** and feeds on insects, worm, spider etc. Male is smaller than female. • Viviparous, respiration through book lungs. Shows courtship.
3.	*Aranea* (Spider)	• Chelicerae are **provided with poison gland and pedipalps in male functions as copulatory organ**. • Spinnerets (spinning organs) produce silken threads for construction of spider web to trap insects etc. • Male spider are commonly smaller. • **Common spiders are :** trapdoor spider (*Pachlomerus*); funnel web spiders (*Agelena*); wolf spider (*Lycosa*); oral web spiders (*Argiope*); black window spider (*Latrodectus*); venomous spider (*Lactodectus meactans*).

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4.	*Limulus* (King crab or Horse shoe crab)	It is a **living fossil** and large sized marine arthropod.
5.	*Ticks*	• Minute creature, but **larger than mites**. • **Ectoparasites** of vertebrates and provided with blood sucking mouth parts. • Common ectoparasite tick is cattle tick (*Boophilus micropus*). • Spread diseases like **Rocky mountain fever** besides causing irritation.
6.	*Sarcoptes scabie* (Human itch mite)	• Minute sac like animal without body division. • Free living as well as parasites on both vertebrates and invertebrates. • **Causes scabies** in human beings. • Dust mites (*Dermatofagodes farinea* and *D. pteronysiunus*) causes 45% of allergies. It feeds on dandruff, skin epidermis, hair etc.
	Class - Crustacea (Dominant arthropods of sea)	
7.	*Cyclops* (Water flea or cyclops)	• Possess **single median eye** (hence one eyed animals) • **Intermediate host of guinea worm and blood tape worm.**
8.	*Daphnia* (Water flea)	• Fresh water, laterally compressed. • Single compound eye and two nuchal (probably olfactory) organs are present. • Formed from fertilized eggs give to 4 - 6 generations of females parthenogenetically. • Cyclomorphosis (seasonal changes) occur.
9.	*Euspagurus* (Hermit crab)	• Lives inside molluscan shells. • Hermit crab and sea anemone often **forms a close association, termed commensalism**. Sea anemone protects the hermit crab by keeping its enemies away by its offensive odour and unpalable taste. In return hermit carb carries the sea anemone from place to place, providing varieties of food.
10.	*Palaemon* (Prawn)	Nocturnal, omnivorous, fresh water but bottom feeder. Abdomen ends in pointed telson. Indian marine or tiger prawn is *Penaeus*.
11.	*Astacus* (Cray fish)	• Resembles prawn. Secretive, noctural and carnivorous. • Greatly priced for their meat.
12.	*Sacculina* (Root headed barnacle)	Parasite on crab causing parasitic castration. Shows retrogressive metamorphosis.
	Class - Myriapoda	
13.	*Scolopendra* [Centipede (or hundred leggers)]	• Fast moving, carnivorous and nocturnal. • **First pair of legs** are **poison claws**.
14.	*Julus* [Millipede (or thousand leggers]	• Sluggish, timid and secretive. • When touched or lifted they curl up in flat spiral like a watch spring. • Mostly herbivorous or saprophytic. • **Stink or odoriferous gland is present**.
	Class - Insecta	
15.	*Periplaneta americana* (Cockroach) (*For more detail refer chapter Morphology of animals*)	Terrestrial arthropod, nocturnal (in activity), omnivorous, and shows cannabalism. Unisexual and shows sexual dimorphism. Undergoes paurometaboly (gradual metamorphosis) by 6-7 months. Indian cockroach- *Blatta orientalis* is small sized and female *Blatta* has vestigial wings.
16.	*Lepisma saccharina* (Silver fish)	• Glistening silvery white, fish like body (wingless). Feeds on starchy substances. Chewing type mouth parts. • Nocturnal, commonly occurs amongst book, clothes, photoframes etc.

contd ...

17.	*Mantis religiosa* (Praying mantis)	• Carnivorous insects. Camouflaged in its green surroundings. • **Female eats up the male after copulation.**
18.	*Carausius* (Stick insect of tropical forest)	• Shows **mimicry**, mimics a twig to escape detection by enemies. • Also called **walking stick**, herbivorous. • Shows regeneration and parthenogenesis.
19.	*Phyllium scythe* (Leaf insect)	• Resembles a leaf. • Shows **mimicry with dicot leaf**.
20.	*Schistocerca gregaria* (Locust)	• Migratory allies of grass hopper. • Nymph are called **hoppers**. • **Swarming** occurs in them due to poor vegetation in their natural habitats.
21.	*Microtermes obesi* (Termites)	• Popularly called **white ants** but they are neither ants nor white in colour. • Cellulose is common food for which *Trichonympha* (a zooflagellate) helps in their digestion. • Built nest called **termitarium**. • Known to secrete special odour substances which serve as guide lines for their back journey into the nest.
22.	*Poecilocerus pictus* (Grass hopper)	• Short horned diurnal insect common on *Calotropis* plant. • Male grasshopper produces sound by rubbing edges of wings etc. • **Largest grass hopper** is *Silicofern grandis* (wings span 2.5).
23.	*Tachardia tacca* (Lac insect)	• **Scale insect with separate sexes. Produces lac**. • Lac, resin like substances, is **secreted by larvae and female lac insect** on a number of forest trees (called **stick lac**). • **India is biggest producer of lac**.
24.	*Bombyx mori* (Silk moth or silk worm moth) **Diseases of silkworm** • **Pebrine or pepper disease** - *Nosema bombycis* (protozoan parasite). • **Muscardine** - Fungal disease caused by *Isari farinosa, Spicaria pracina* etc. • **Flacherie** - *Bacillus bombycis* and *Streptococcus bombycis*. • **Grasserie** - Referred to silkworm jaundice, caused by *Borrelina* virus *bombycis*.	• Also called **mulberry silk moth**. Adult moth do not feed. Females are larger than male. Salivary gland (= labial gland) is **modified to form silk gland of larva**. • Male moth **dies soon after copulation**. • Larva is called **caterpiller or silkworm**. • **Life history** include **egg, larva, pupa and imago**. • **Produce silk** (a natural fibrous substance containing fibroin and sericin proteins) **from coccons** (pupa, chrysalis). • Silk is extracted by killing cocoon (called **sericulture**). Silk thread is formed of two proteins - **fibroin** and **sericin**. • **Different species producing silk** are – Mulberry silkworm – *Bombyx mori* Tasar silkworm – *Antheraea paphia* Muga silkworm – *Antheraea assama* Eli silkworm – *Attacus ricinii*
25.	*Musca domestica* (House fly)	• **Active in warm months** and **inactive during winter**. • Metathorax has **halteres for balancing**. Larva is called **maggot**. • **Transmit number of diseases** like conjunctivitis, trachoma, plague, leprosy, TB etc. • Show **complete metamorphosis** • **Stage in life history** : **Egg - Larva** (maggot) - **Pupa - Imago** (adult). • Maggot moults twice thus housefly has three larval instars. • **Myasis** is a **disease caused by maggots**.
26.	*Sympetrum hypomelas* (Dragon fly)	• Often known as **mosquito hawks** as mosquito form their main diet. • They are prehensile.

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<table>
<tr><td></td><td></td><td>• Copulation occurs in flight.
• Both the aquatic nymph (called naiads) and adult are predaceous.</td></tr>
<tr><td>27.</td><td>Apis dorsata
(Honey bee)</td><td>• Social insect lived in colony which contains workers (sterile diploids females), queen (fertile diploid females) and drones (fertiles haploid males).
• Queen develops from fertilized egg and a larva fed on royal jelly, drone develops parthenogenetically and worker bees develops from fertilized eggs and make and repair hive.
• Queens live for five years, drone have short life span and worker bees live for a few weeks only.
• Honey bee exhibit round and waggle dance to communicate for location of food.
• Queen mates only once in a life time and store sperm in her spermatheca. Drone and virgin queen takes part in nuptial flight.
• Royal jelly, given to queen, is produced from pharyngeal gland of workers.
• Workers have pollen collecting apparatus, honey storing mechanism and wax secreting glands (in abdomen).
• Collects honey, secrete bee-wax. Culturing honey bee is called apiculture.</td></tr>
<tr><td>28.</td><td>Mosquito

Table : Diseases caused by mosquitoes<table><tr><th>Disease</th><th>Mosquito</th></tr><tr><td>Malaria (Plasmodium)</td><td>Anopheles female</td></tr><tr><td>Filariasis (Wuchereria)</td><td>Culex female</td></tr><tr><td>Encephalitis (Virus)</td><td>Culex and Aedes female</td></tr><tr><td>Denuge fever (Virus)</td><td>Aedes female</td></tr><tr><td>Yellow fever (Virus)</td><td>Aedes female.</td></tr></table></td><td>• Small nocturnal two winged insects.
• Mandibles are absent in males, therefore, male mosquitoes, usually feed on flower sap on nectar while female feeds on blood of animals and human.
• Because of their blood sucking adaptation females are medically important as carrier of viral, bacterial and protozoan infections.
• Pedicel of antennae has Johnston's organ for percieving vibrations including those of sounds.
• Larva of mosquito is known as wriggler (3-4 days life span) & pupa is called tumbler (2-7 days life span).
• Sex of mosquitoes can be determined by the form of the antennae and maxillary palps.
• Common mosquitoes are Anopheles, Culex and Aedes. Anopheles and Culex can be easily identified by their sitting position. (Culex - body held parallel to surface while sitting, Aedes - body held parallel to surface while sitting with black and white striped body, Anopheles - body held at an angle to the surface, dark spotted wing.)</td></tr>
<tr><td>29.</td><td>Cimex lectularius
(Bed bug)</td><td>• Nocturnal ectoparasite.
• Hind wings are absent. Piercing and sucking mouth part.</td></tr>
<tr><td>30.</td><td>Pediculus humanus
(Human louse)</td><td>• Wingless flat insect. Ectoparasites. Eggs are called nits.
• Carry germs of typhus fever. Piercing and sucking mouth parts.</td></tr>
<tr><td>31.</td><td>Xenopsylla cheopis
(Rat flea)</td><td>• Ectoparasite of rats and humans.
• Transmit Pasteurella or Yersinia pestis or germs of bubonic plague from rats to humans.</td></tr>
<tr><td>32.</td><td>Aphis brassicae
(Cabbage aphid)</td><td>Plant pests. Secrete honey dew. Called 'ant cows'.</td></tr>
<tr><td>33.</td><td>Beetles</td><td>Occurs in almost all types of habitat. Hard bodies insects with heavy cuticle. Complete metamorphosis. Larva is called grubs. Eg. Lady bird beetle (Cocinella septupunctate) etc.</td></tr>
</table>

MOLLUSCA

- **Mollusca** is the **second largest phylum** after the arthropods & **includes predominantly marine species**.
- The molluscs includes a variety of familiar animals well-known for their decorative shells or as seafood. These range from tiny snails, clams, and abalone to squid, cuttlefish and the octopus (which is considered the most intelligent invertebrate).
- The **giant squid**, which until recently had not been observed alive in its adult form, **is the largest invertebrate**; although it is possible that the colossal squid is even larger.
- The scientific study of molluscs is called **malacology** and the study of shell of mollusca is called **conchology**.
- Molluscs are **triploblastic**, **bilaterally symmetrical, schizocoelic & unsegmented protostomes**.
- Mollusca **refers to the bivalve shell** and the **soft bodied animals within the shell**.
- The body is often divided into a **head** with **eyes or tentacles**, a **muscular foot** and a **visceral mass housing the organs** and **mantle**.
- Most molluscs have a **well-developed head**, containing high concentration of sensory and nervous functions.
- Some molluscs, like the cephalopods, have complex, sensitive eyes. Also located in the head is the **mouth region**, with the **radula** (a rasplike feeding organ present in many molluscs).
- Radulae are diverse within the mollusca, ranging from structures used to scrape algae off rocks, to the harpoon-like structures of cone snails.
- The **radula** is usually toothed, and is **adapted to a wide variety of feeding styles**, including scraping, stabbing, tearing and cutting, depending upon the species.
- Adjacent to the head is the large **muscular foot**, which is formed from the ventral body wall and is **used primarily for locomotion**, and is **often ciliated and covered with mucous glands**. Mucous reduces the friction and creates a surface for gliding and cilia aids in movement. This is **one of the reasons why some believe that molluscs evolved from flatworms** since arthropods completely lack external cilia and so do many annelids.
- The **visceral mass** is housed in the shell in most of the molluscs. It **holds most of the internal organs** and **houses the circulatory** and **digestive systems**.
- The **mantle or pallium** is a sheath of tissue formed from the dorsal body wall. It surrounds the mantle cavity, where the gills or lungs are often housed, and its surface can assist in gas exchange.
- The mantle **also secretes the calcium carbonate shell** in the molluscs that do have a shell. It may be **bivalve** or **univalve, spiral** or **cone like, internal** or **reduced** or **even absent**.
- Mantle **serves a protective function** and often has retractor muscles associated with it that allows the shell to be pulled down over the body.
- The principal body cavity is a blood-filled **haemocoel**.
- They have a **true coelom (eucoelom)**; any coelomic cavities have been reduced to vestiges around the hearts, gonads, and metanephridia (kidney-like organs).
- All species of the phylum mollusca **have a complete digestive tract** that starts from the mouth to the anus.
- **Circulatory system** is mainly of **open type**, but some reduced sinuses are present. Cephalopods **have closed circulatory system**, e.g., squid & octopus.
- **Blood** is **colourless** & **has amoebocytes** & often a respiratory pigment is copper containing **haemocyanin dissolved in plasma**.
- **Respiration** by **gills** (called the **ctenidia**), **lungs or both, sometimes direct**.
- **Excretory organ** is paired **metanephridia** (kidney, organ of bojanus). The excretory matter is **ammonia** or **uric acid**.
- Nervous system consists of **paired cerebral, pleural, pedal and visceral ganglia,** joined by longitudinal and cross connectives and nerves. Ganglia **usually form a circumcentric ring**.
- **Sense organs** include **eyes** and tentacles on head**, statocysts and osphradia** (a chemoreceptor to test chemical nature of water) near the base of gills.
- Osphradium (bipectinate means feather like) **serves as olfactory organ**, arises from the mantle, adjacent to the left nuchal lobe and **situated on the left side of the pulmonary chamber**.
- Osphradium **helps in testing the physical and chemical qualities of entering water** and also helps in the **selection of food material**.

If water is foul, then its (osphradium) entry into the mantle cavity is stopped by the closure of the left nuchal lobe. This sensory structure is **absent in terrestrial pulmonates - the land snails and slugs and nudibranches**. The gills have strong cilia that create the water current into the mantle cavity.

- **Reproduction** sexual, dioecious or monoecious.
- The sex organs of molluscs are housed in the visceral mass.
- The fertilized young develops into a ciliated larva called a **trochophore,** which, in the more advanced molluscs, develops into a **veliger** stage, which then develops into the adult organism.
- **Fertilization** is **generally external**, development is direct or through free larval forms like **trochophore**, **veliger**, **glochidium**, etc.
- **Radula**, **muscular foot**, **mantle & highly developed eye** are **unique features of molluscs** which are not found elsewhere.
- Mollusca is **divided into 6 classes - monoplacophora**, **amphineura** (polyplacophora), **scaphopoda**, **gastropoda**, **pelecypoda** (bivalve) and **cephalopods**.
- Species of **monoplacophora** are small, marine, with internal segmentation, possessing conical or cap-shaped shell, e.g. *Neopilina*. Larva is trochophore.
- **Amphineura** or **polyplacophora** have broad foot and a linear chain of eight serially overlapping dorsal shell plates, e.g. *Chiton* (coat of mail shells, sea mouse), *Chaetopleura*.
- **Scaphopoda** are elongated, cylindrical molluscs almost completely enclosed by the mantle, which secretes a single tubular, **calcareous shell** open at each end, **resembling the tusk of some mammals** (like elephant), e.g. *Dentalium* (tusk shell).
- **Gastropods** (stomach-footed mollusc) are **very large and diverse group** sharing the common feature that during the development the visceral hump is rotated through some 180° in an anticlockwise direction called **torsion** (*i.e.* bilateral symmetry in larval stage and asymmetry in adult form). E.g. *Pila* (apple snail), *Limax* (slug), *Helix* (land snail), *Aplysia* (sea hare) and *Cypraea* (cowrie).
- **Pelecypoda** (= lamellibranchia) are **bivalved molluscs**, most of which are **sedentary filter feeders** that depends on ciliary current produced by the gills to bring in food materials.
- **Examples of bivalves** are *Unio*, *Pinctada*, *Teredo*, *Solen* (rajor clam), *Pectan*, *Ostraea.*
- All bivalves are aquatic, with the majority living in shallow marine waters.
- The bivalve body consists mostly of a **muscular foot** in the anterior and a **series of gills** (ctenidia) and a **pair of siphons** (if present) in the centre and posterior part.
- Bivalves **secrete pearls**.
- Shell has three layers -
  - **Periostracum** - Outermost horny formed of chiton like organic substance, **conchiolin**. This layer is **responsible for exterior colouration of the shell and protects the underlying prismatic layer**.
  - **Ostracum (prismatic layer)** - Formed of prisms of $CaCO_3$.
  - **Nacreous or pearly layer** - Innermost layer, secreted by whole outer surface of mantle and formed of alternate transverse of $CaCO_3$ and conchiolin. Also known as **mother of pearl**.
- **Umbo** represents the **oldest part of shell** while **lines of growth** represent intervals between growth stages means indicate the age of individual.
- Unlike the gastropods, they **have no head, no radula** and **very little cephalization**.
- A pearl is **formed of a number of nacreous layers** secreted by nacre-secreting cells of mantle around a foreign body. Nacre is **pearly irridescent material**.
- The pearl of *Unio* is **not of commercial important**.
- **Most valuable pearl** is of *Pinctada margritifera*, commonly called **pearl oyster**.
- **Kokichi mikimota** is commonly called **"father of pearl industry"**.
- **Cephalopoda** (head foot molluscs) are the **most complex of the mollusca**, e.g. *Sepia* (cuttle fish), *Nautilus, Octopus, Loligo*.
- All cephalopoda or siphonopoda are **marine and all are predators**.
- Cephalopods have a **concentrated nervous system** and are among the **most intelligent of the invertebrates**.
- Locomotion is **either by jet propulsion** or **by swimming movements**.
- **Smallest molluscs** is *Ammonicera rota.*
- **Slowest molluscs** is *Helix aspera/garden slug.*
- **Largest shell** is *Tridaena derasa/giant marine clam.*
- **Largest snail is** *Tethys*.
- **Largest octopus is** *Octopus apollyon*.

In some gastropods and cephalopods, the symmetry is distributed during development and they become asymmetrical. **Asymmetry is there because** these molluscs undergo two processes–

(i) **Coiling -** Coiling in shells occurs in various ways and a portion of the body coils to accommodate within the shell. Often this results in a loss of one or more paired organs such as gills and kidneys. Coiling can be **dextral** (clockwise, towards right) or **sinistral** (anticlockwise toward left). e.g. *Pila*.

(ii) **Torsion** - Torsion or twisting involves a rearrangement of the internal organs from their traditional position by rotation of the digestive system and associated organs up to 180 degrees. **Actual site of torsion is neck tissues and structures within it**. It starts much before coiling.

Table : Some important examples

	Examples	Important notes
	Class - Monoplacophora [Only mollusca having segmentation (internal) or metamerism]	
1.	*Neopilina*	**Living fossil**. Only representative of palaeozoic group of molluscs. Also **connecting link between annelida and molluscs**.
	Class - Amphineura	
2.	*Chiton* (Coat of mail shell/sea mouse)	Nocturnal and herbivorous. Have multiple sense organs - osphradia, tactile receptors, taste receptors, otocysts, pit organs etc. A **trochophore larva is present**.
	Class - Scaphopoda	
3.	*Dentalium* (Elephant tusk shell)	• A marine mollusc, living at moderate depth in the sublittoral. • Filamentous captacula are found instead of true tentacles for assisting feeding function.
	Class - Gastropoda	
4.	*Pila* (Apple snail/pond snail)	• Lead amphibious life, **have pulmonary sac for aerial respiration and gill (ctenidium) for aquatic respiration**. • Osphradium of *Pila* is chemoreceptor • Eyes occur over ommatophores. • **Ammonotelic in water** and **ureotelic on land** • Has conispiral shell (coiled along an erect cone) which are either dextral or sinistral • Have **two type of sperm - eupyrene** (small & functional) and **oligopyrene** (large, non-functional)
5.	*Aplysia* (Sea-hare)	Secretes purple fluid when disturbed, which makes the animal invisible to its enemy.
6.	*Patella* (true limpet)	Marine gastropod. Has an aspidobranch gill (feather like 2 rows of gill lamellae.)
7.	*Doris* (Sea lemon)	Nudibranch and marine gastropod.
8.	*Limex* (Grey slug)	Terrestrial gastropod. It is a plant pest and damages seedlings, tender shoots and leaves.
9.	*Helix* (Sand snail)	Herbivorous, nocturnal terrestrial snail which is commonly found creeping over moist and shady place.
	Class - Pelecypoda or Lamellibranchia or Bivalvia	
10.	*Unio* (Fresh water mussel)	**Edible bivalve**. A **'glochidium larva'** (parasitic on fish) and keber's organ are present. Omnivorous and filter feeder. **Marsupium** is enlarged water tube and **act as brood pouch**.

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11.	*Teredo* (Ship worm)	Destructive to wood in sea-water.
12.	*Pinctada vulgaris* (Pearl oyster)	**Secretes precious pearls**. The pearl is **formed as a result of nacreous secretion from the mantle** around a sand particle. Pearl is **formed in about 7 years**.
13.	*Pectan* (Scallop)	Marine, free swimming and swims by clapping movements of shell valves.
14.	*Mytilus* (Sea mussel)	Marine bivalve. **Fixed to rocks** etc by a group of adhesive byssus threads. Development includes glochidium.
		Class - Cephalopoda
15.	*Sepia* (Cuttle fish)	• Shell internal, edible cephalopod of shallow warm sea, carnivorous. • Ink gland is present for escaping from enemy. Larval stage is absent.
16.	*Loligo* (Squid/sea arrow)	• Resembles *Sepia* in broad structures. Edible and fast swimmer in open waters of the sea. • Abundant in pelagic marine environment where they are voracious predators of many organism, especially fish. • Giant squid (*Architeuthis*) is the largest invertebrate.
17.	*Octopus* (Devil fish)	• Bottom dweller, nocturnal and large sized cephalopod. • Its poisonous saliva paralyse its prey. • One of the arms generally the right arms of male is spoon shaped and is called **hectocotylized arm** which is used to transfer sperms into the female mantle cavity.
18.	*Nautilus*	• A tetrabranch cephalopod, has an external coiled and chambered shell. • It floats by secreting gas in the chamber. Animals lives only in last chamber. Active at night and rest on bottom during day.

ECHINODERMATA

- The name echinodermata was coined by **Jacob Klein** in 1938.
- It **constitutes the only major group of deuterostome** (blastopore becomes anus) invertebrates.
- Echinoderms (**literally means spiny** or **prickly skinned**) are a phylum of marine animals found at all depths.
- This phylum **appeared in the early cambrian period** and contains about 7,000 living species and 13,000 extinct ones.
- Echinodermata is the **largest animal phylum to lack any freshwater or terrestrial representatives**.
- Echinoderm is **closely related to the chordates** because the coelom of the animal is made from the digestive tube, not from cell masses like the phyla mollusca, annelida etc.
- Echinoderms are **exclusively marine** and **largely bottom dwellers**, **enterocoelous**, **triploblastic animals**.
- They are **pentameral**, *i.e*, they have fivefold symmetry, with rays or arms in fives or multiples of five.
- Echinoderms possess an **endoskeleton of calcareous plates or spicules embedded in the skin**.
- Endoskeleton of echinoderms is unique in being a mesodermal structure instead of ectodermal, as in other invertebrates.
- Each skeletal element of an echinoderm is actually a single **crystal of calcium carbonate**, very finely branched and structured.

Echinoderms have been **compared to living, moving castles**. Castles are made of interlocking blocks, with a single main entrance and numerous slit windows for air and for defence. Echinoderm skeletons are made up of interlocking calcium carbonate plates and spines with opening.

- In echinoderms, fine networks of calcium carbonate form a structure, known as **stereom**.
- Between the skeleton plates of echinoderm, a

number of special structure protrude, with which the echinoderm **breaths**, **moves** and **defends itself**. Typically these are **tube feet**, **pedicellaria** and **gills**.

- All echinoderms have a peculiar **hydraulic water-vascular system**, a modified coelom, which **help in locomotion**, **adhesion**, **respiration and food capturing**.
- A set of water filled canals branches from a **ring canal** (a canal encircling the gut).
- The canals lead to **podia**, or **tube feet**, which are sucker like appendages that the echinoderm can **use to move, grip the substrate, or manipulate objects**. **It also acts in capturing of food, respiration etc**.
- These **tube feet** are **external** and **retracted by hydraulic pressure in the water vascular system**.
- **Pedicellaria** are small, snapper-like skeletal elements.
- Pedicellaria **help in the capture and removal of debris and minute organisms** such as larvae. In some starfishes they **also helps in capturing of small prey for feeding purpose**.
- Echinoderms **have a spacious coelom** (an open, fluid - filled body cavity lined with tissues).
- Many starfish have the peculiar ability to feed by **turning the stomach inside out through the mouth**.
- Sea urchins scrape algae from rocks with five large teeth arranged in a structure known as **Aristotle's lantern**.

Aristotle's lantern - It is a characteristic of some members of class Echinoidea (*e.g.*, *Echinus*). In these members, five teeth surrounding the mouth are attached to a masticatory apparatus, called Aristotle's lantern, after its discoverer and because of its resemblance to an ancient Greek ship - lantern. It is situated within the test and projects slightly through the mouth. Sea urchin uses Aristotle's lantern for the **purpose of feeding**.

- Echinoderms (except holothurions) **generally lack respiratory systems**.
- The **circulatory system**, if present **consists of a haemal system** that is **derived from coelomic sinuses**.
- They also **possess an open and reduced circulatory system**, and **have a complete digestive tube (tubular gut)**.
- **Nervous and sensory system** are generally **poorly developed**.
- Poorly developed sense organs **include tactile organs**, **chemoreceptors**, **terminal tentacles**, **photoreceptors** and **statocysts**.
- They have a **simple radial nervous system** that **consists of a modified nerve net** (interconnected neurons with no central organs); **nerve rings with radiating nerves around the mouth extending into each arm**; the branches of these nerves coordinate the movements of the animal.
- No echinoderms has a brain, some however do have ganglia.
- The **sexes are usually separate**. Sexual reproduction typically consists of releasing eggs and sperm into the water, with **fertilization taking place externally**.
- Echinoderms are mostly **dioecious**, gonads large and single or multiple.
- Holothurians possess a **single gonad,** crinoids **lack distinct gonads** while asteroids and echinoids have **multiple gonads.**
- Development is **indirect** through free swimming larval forms.
- Echinoderms **possess remarkable power of autotomy** or **amputation** (breaking off the injured or unduly stimulated body parts) and **regeneration**.
- In class, asteroidea **metamorphosis is extremely rapid**, **taking place in about one hour**.
- Echinoderms can be **divided into five main classes** -
  - **Asteroidea** (e.g., *Asteropecten*, *Asterias* etc.)
  - **Ophiuroidea** (e.g., *Ophiura*, *Ophioderma*)
  - **Echinoidea** (e.g., *Echinus*, *Diadema*)
  - **Holothuroidea** (e.g., *Holothuria*, *Thyone* etc.)
  - **Crinoidea** (e.g., *Antedon*, *Neometra*).
- **Some species of asteroidea** (as for example sea stars) are **unique in their ability to regenerate an entire body from a single arm**.
- All **sea-star are voracious carnivores**, feeding mainly on crustaceans, polychaetes and molluscs and even other small fishes, and injured and dead animal.
- *Platasterias latiradiata* is the **only living species of somasteroidea** belonging to class **asteroidea**.
- **Bipinnaria larva** is the **characteristic of class asteroidea**.
- Bipinnaria larva **transforms into brachiolaria larva** before going to the adult stage.
- The members of class **ophiuroidea** are mostly **detritivores** consuming small bit of organic debris from the ocean floor.

- **Brittle stars** and **basket stars** make up the bulk of the members in the class **ophiuroidea**.
- **Ophiopluteus larva** is the free, swimming larva of brittle stars **belonging to the class ophiuroidea**.
- The members of the class **echinodea lack appendages** and includes **sea urchins** & **sand dollars.**
- **Echinopluteus larva** is the **characteristic of class echinoidea**.
- **Auricularia larva** is the **characteristic of class holothuroidea**.
- **Doliolaria larva** is the **characteristic of class crinoidea as well as holothuroidea**.
- **Sea lilies** (belong to **class crinoidea**) are the **most primitive of echinoderms**.

Table : Some important examples

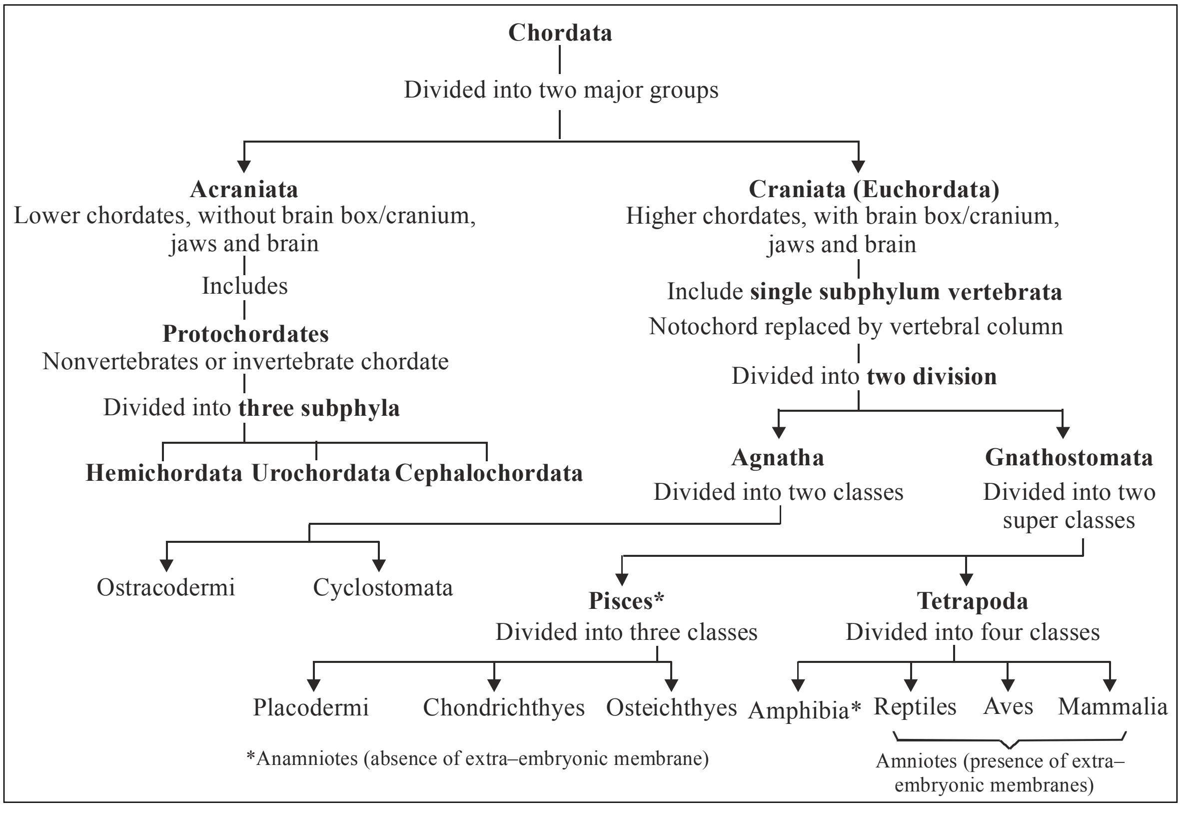
	Examples	Important Notes
1.	*Asterias (Pentaceros)* (Star fish or sea pentagon)	• Has high power of regeneration, unisexual • Digestive glands or pyloric caeca contains four types of cells - **secretory or granular cells** (secrete proteolytic, amylolytic and lipolytic enzymes); **mucous cells** (secretes mucous); **storage cells** (store and reserve food as lipids, glycogen etc) and **current producing cells** (maintains a steady flow of enzymes). • Digestion is extracellular as well as intracellular. • Fertilization is external. • Feeds on molluscs and **destroys pearl oysters**. • Their dried skeletons are crushed and used as fertilizers. • **Largest starfish** is *Pyenopodia hellianthoides* (30 cm in diameter).
2.	*Ophiothrix* (Brittle star or spiny brittle star)	• Mouth is used for both ingestion and egestion. • Jointed parts of arms or ossicles are popularly called vertebrae.
3.	*Echinus* (Sea urchin)	• Live on ocean bottom. • Scrape algae to feed. • Long barbed spines make venom for protection. • **Aristotle's lantern** is present.
4.	*Echinoarachinus* (Sand dollar or sea dollar)	Flattened body. Live in sand along coastlines. Shallow burrowers. Aristotle's lantern is present.
5.	*Cucumaria* (Sea cucumber)	Bottom dweller. Has cloacal respiration and pair of respiratory trees in the coelom.
6.	*Antedon* (Sea lily/feather star)	Superficially resembles a herbaceous plant. Feeds on detritus and plankton.

End of the Chapter

Chapter 15

Chordates

- Phylum chordata was created by **Balfour in 1880**. This refers to the presence of a stiff supporting rod like structures along the back (called **notochord).**
- Chordata is the **most heterogenous group of animals.**
- Chordata i**ncludes humans and other vertebrates**. However, **not all chordates are vertebrates**.
- All chordates have the following features at some point in their life (in case of humans and many other vertebrates, these features may only be present in the embryo). These are the most distinct features of chordates :
  - **Pharyngeal slits** - A series of openings that connect the inside of the throat to the outside of the "neck". These are often, but not always, used as gills.
  - **Dorsal nerve cord** - A bundle of nerve fibres which runs down the "back". It connects the brain with the lateral muscles and other organs.
  - **Notochord** - The first skeleton laid during the embryonic stage. Notochord is a cartilaginous rod running underneath, and supporting the nerve cord.



- **Post-anal tail** - An extension of the body part, the anal opening.

- All chordates are **deuterostomes**, *i.e*, the **anus develops before the mouth in early embryonic stages**.
- In adult vertebrates notochord is **replaced by cranium and vertebral column** and gives viability of movement. In mammals the notochord is represented as vestigial swellings called **nuclei pulposi** in the vertebral column.
- Pharyngeal gill slits is **functional throughout life in protochordates and lower aquatic vertebrates** (fishes) but in higher vertebrates it is modified in the adult with the acquisition of pulmonary respiration.
- **Other characteristics shared by chordates include** the following :
  - Bilateral symmetry
  - Segmented body, including segmented muscles
  - Three germ layers and a well-developed coelom.
  - Single, dorsal, hollow nerve cord, usually with an enlarged anterior end (brain)
  - Tail projecting beyond (posterior to) the anus at some stage of development
  - Pharyngeal pouches present at some stage of development
  - Ventral heart, with dorsal and ventral blood vessels and a closed blood system
  - Complete digestive system
  - Bony or cartilaginous endoskeleton usually present.
- Chordata is **divided into two major groups** – **acraniata** and **craniata**. Acraniata is without brain box and craniata is with brain box. (*See Flow chart on page no. 106*).

PROTOCHORDATES

- Protochordates are chordates **lacking head**, **vertebral column, brain-box** (cranium), **jaws** and **brain**. About 2000 species are known to exit.
- Due to absence of cranium, protochordates are also called **acraniates**.
- Another term of protochordates is **prevertebrates**.
- Protochordata can be **divided into three subphyla** – **hemichordata**, **urochordata** and **cephalochordata**.

Hemichordata

- **Hemichordates** are small groups of marine, solitary or colonial, worm-like **enterocoelous animals**, most of which **live in tubes** (thus, they are also known as **tube dwellers**).

Protochordates

Divided into three subphyla on the basis of location of notochord

Hemichordata
- Exclusively marine, worm like animals
- Notochord (called **stomochord**) found in the roof of buccal cavity
- Due to the absence of true notochord, it is treated as **independent invertebrate phylum** by Hyman (1959) and Van den Horst (1939)
- Considered to be **connecting link between echinoderms and chordates** because of the resemblance between the tornaria larva (of *Balanoglossus*) and bipinnaria and dipleurula larva of echinoderms.
- **Classes**
  - Enteropneusta. Eg. *Balanoglossus*
  - Pterobranchia. Eg. *Rhabdopleura*

Urochordata
- Commonly called **tunicates**
- Notochord (**restricted to tail**) & nerve cord only in larval stage
- Adult sac like, often sessile contained in secreted tunic
- Hermaphrodites, retrogressive metamorphosis
- **Classes**
  - Ascidaceae. Eg. *Herdmania, Ciona*
  - Thaliaceae. Eg. *Salpa, Pyrosoma*
  - Larvaceae. Eg. *Oikopleura*

Cephalochordata
- Notochord & nerve cord **present throughout life along the entire length**
- **Only protochordate with all basic chordate structures**
- **Class :** Leptocardii. Eg.*Branchiostoma* (=*Amphioxus*)

- The body and enterocoelous coelom are divisible into three unequal regions – **proboscis, collar** and **trunk**. Tail is absent.
- In most forms, **one to several pairs of gill clefts** lead from the pharynx to the exterior.
- They **have no bony tissue (true notochord is absent)**, but a buccal diverticulum is present in pre-oral region, which is often regarded as **stomochord**.
- **Development** is **direct** in some (eg *Saccoglossus Kowalevskii*), while in others, it is **indirect** (eg *B. clavigerus*) *via* **tornaria larva**.

The full grown **tornaria larva** is usually ovoid in shape and is excessively transparent. The size of tornaria larva varies from below 1 mm to 9 mm. It is provided with two ciliated bands. At its anterior side, it has apical plate which bears a pair of eye spots.

- *Balanoglossus*, a **unique representative** of the subphylum hemichordata, is a burrowing and exclusively marine animal ranging in size from about **2 cm to 50 cm.**
- *Balanoglossus* is **tubicolous** living in **U shaped burrows** excavated in the sandy bottom.
- The wall of the tube is lined with mucous, secreted by the **mucous gland** of the animal.
- In *Balanoglossus,* there is **no definite exoskeleton** but **there are four stiff structures** of a supporting nature – **buccal diverticulum**, **proboscis skeleton, branchial skeleton** and a **pygochord**.
- The proboscis **forms the anterior part of the body** and is continued posteriorly into a **proboscis stalk.**
- The proboscis sits in the **collar** somewhat like an acorn in its cup, a character that has given the name "**acorn worms**" to the group.
- The collar lies posterior to the proboscis and anterior to the trunk.
- The **functional significance of the cavities and water pores** in the probosics and collar is **related with their burrowing habits**.
- The **trunk** is the **elongated posterior part** of the body.
- **Operculum**, a posterior prolongation of collar is present in some species of hemichordates.
- A pair of **genital ridges or genital wings** are present in the region of **branchial apertures**.
- The coelom is **enterocoelous** having been formed as outgrowths of the enteron.
- The **respiratory organs are in the form of** a large number (upto 700 pairs) of **gill pouches** which open internally in the pharynx by **gill pores**.
- The respiratory organs collectively form **branchial apparatus**.
- The *Balanoglossus* has a **straight digestive tube with mouth and anus at opposite sides**.
- The **blood vascular system** of *Balanoglossus* is of **closed type**.
- **Nervous system** is composed of network of nerve fibrils which is very primitive in nature.
- In *Balanoglossus,* the **sexes are separate** and are indistinguishable externally **except** in case of the colour of the ripe gonads shown through the body wall in the living animal.
- **Sense organs are poorly developed** having numerous **epidermal neurosensory cells**.
- *Balanoglossus* has **great power of regeneration**. One broken piece of the animal can regenerate into new individual.

Urochordata

- **Urochordata** includes a peculiar group of widely distributed marine animals called a **sea squirts or ascidians** and **their allies**.
- Urochordates are also known as **tunicates** as their bodies are covered externally by a leathery translucent test or tunic composed of **tunicin**.
- The **main representative of this subphyla** is *Herdmania.*
- Except in *Herdmania*, urochordates possess cells called **vanadocytes**. They can extract vanadium from sea water.
- The body of *Herdmania pallida* is roughly oblong in outline, narrower at its attached end (with the substratum) than at its free end.
- At its free end, it **is provided with two openings**– the **branchial** and **atrial apertures**.
- *Herdmania* is **called sea squirt** because it can suddenly contract its body to squirt water simultaneously or independently through its branchial and atrial apertures.
- The average size of the adult is about **9.5 cm long, 7 cm broad** and **4 cm thick**.
- There are **two types of spicules** found in the body of *Herdmania*. They are **microscleres** and **megascleres**.
- The body is divided into two parts – **body proper** and **foot.**
- The **foot** is **made entirely of test**.

- The intestine forms a **wide loop within the body**.
- **Ciliary feeding takes place** because of its **sedentary habit**.
- Lying in the midventral floor of the pharynx, is an **endostyle**. It is a groove with four longitudinal rows of gland cells with ciliated cells between them.
- The **blood** of *Herdmania* **contains a green pigment vanadium** which is considered to be a **respiratory pigment**.
- In the adult, there is a brain or nerve ganglion which is about 4 mm long.
- **Peristaltic contraction occurs** in the **heart** of *Herdmania.*
- Different types of receptors are present in its body such as **photoreceptors** (sensitive to light), **tangoreceptors** (sensory to contact), **rheoreceptors** (sensory to water current) and **thermoreceptors** (sensitive to temperature).
- **Nephrocyte cells** in the body of *Herdmania* **have excretory function**.
- The animal is **hermaphrodite** – there are two large gonads.
- *Herdmania* is **protogynous** *i.e.,* the **ovaries mature much before the maturation of testes**.
- **Development is indirect** through **ascidian tadpole larva**.

> The **ascidian tadpole** is tailed larva hatches from the egg and becomes free swimming. It has an oval body and a long laterally compressed tail. It is called a **tadpole larva** because it somewhat resembles a tadpole of a frog.

- The ascidian tadpole **undergoes retrogressive metamorphosis**.
- The developmental process that transforms an advanced larva of ascidians into primitive adult is called **retrogressive metamorphosis**.
- *Pyrosoma* is a pelagic, free swimming colony which probably **emits the strongest light among marine organisms**. Possibly some symbiotic luminiscent bacteria, found in photogenic mesodermal cell masses present on the pharyngeal bands, produce light when the zooids are disturbed even by rough sea waves.

> **Kowalevsky** (1866) discovered that the larvae of the ascidians possess a well-developed dorsal brain and spinal cord, a definite notochord and lateral bands of muscles in the tail (*i.e.,* organs that are typical for the vertebrates). The ascidians, therefore, considered as belonging to the same phylum as the vertebrates, the phylum chordata.

- *Botryllus* is a **colonial ascidian**, widely distributed in the Atlantic and the mediterranean. There is a pair of hermaphrodite gonads.

Cephalochordata

- **Cephalochordata** includes only two genera - *Asymmetron* and *Branchiostoma* (*Amphioxus*).
- *Amphioxus* is now **used as a common name of all cephalochordates**.
- Cephalochordates are **small fish-like animals showing the main chordate characters**.
- Cephalochordata is the **first group to have well developed myotomes** (muscle blocks) as body musculature.
- The **notochord extends the entire length of the body** projecting beyond the nervous system to the tip of the snout.
- They have a **dorsal, tubular neural tube or nerve cord without a defined brain** lying above the notochord.
- Pharynx is large with numerous gill-clefts opening into an **ectoderm-lined atrium**.
- **Wheel organ** or **Muller's organ** is **present in the oral head** of *Amphioxus*.
- Wheel organ present in the vestibule is **used for producing a current of water**.
- **Metamerism** is well marked, even the gonads are segmental.
- There is a **definite coelom**.
- Excretory organs are **segmental nephridia**.
- **Sexes are separate** but males and females are alike except for the gonads (testes or ovaries).
- Development is **indirect with a ciliated larva**.

VERTEBRATA

- Vertebrata are **advanced chordates** and also known as **euchordates** or **higher vertebrates.**
- Vertebrates have **well developed cranium** and **vertebral column.**
- Notochord is embryonic, **in adult it is replaced by vertebral column.**
- Vertebrates **differs from tunicates and lancelets** in two important aspects - **vertebral column** & **head.**
- Vertebrates **originated during** the **ordovician period**.
- Vertebrates are divided into **two superclass** - **agnatha** and **gnathostomata.**

Agnatha

- Agnatha (greek, "no jaws") is a **paraphyletic superclass of jawless fish**.
- In addition to the absence of jaws, agnatha are **characterised by absence of paired fins or limbs; the presence of a notochord both in larvae and adults;** and **seven or more paired gill pouches**. The branchial arches supporting the gill pouches lies close to the body surface.
- The **internal skeleton** of agnathans is **not bony but cartilaginous**.
- There is a **light sensitive pineal eye** (homologous to the pineal gland in mammals).
- There is **no identifiable stomach**.
- **Fertilization** is **external** and both ovaries and testes are present in individual but gonads of only one sex is functional in hagfishes, no larval stage; separate sexes and a long larval stage in lampreys.
- The agnatha are **ectothermic**, and the heart contains 2 chambers.
- The agnathans are the **most primitive and ancient of the vertebrates**. Its fossils have been **found from the late Cambrian (about 500 million years ago)**.
- Agnatha is **divided into extinct type - ostracoderms** with exoskeleton and **living type - cyclostomata** without exoskeleton.
- **Ostracoderms** are oldest known vertebrate fossils in the late cambrian and ordovician rocks dating back to nearly 500 million years. They are the **remote ancestors of all the vertebrates including man**.
- Their **body form was fishlike**, usually flattened dorso-ventrally, with a huge head and gill region, a tapering but muscular trunk and some sort of tail fin, eg. *Cephalapsis.*
- The **cyclostomes** (Gr. *cyklos* = circulation, *stone* = mouth) are marine or freshwater vertebrates. Marine forms ascend rivers for breeding. They **may be parasites or scavengers**. There are only about 45 species in the class.
- Body is **eel like** but tail is compressed.
- **Examples of cyclostomata** are - *Petromyzon* (or lamprey) and *Myxine* (or hagfish).
- **Lampreys** are **parasitic species** that use their suckerlike mouths to attach to a fish host.
- Adult lampreys inhabit a saltwater marine environment but swim up rivers to reach freshwater breeding grounds (**anadromous**).
- Lampreys **breed only once in their lifetime**, in a single tremendous reproductive bout, and die soon after.
- Lampreys pass through an immature larval stage before metamorphosing into adults. The **larval lamprey is always in freshwater**.
- The larva is of particular interest to biologists who study vertebrate evolution because it shares many features with the cephalochordate *Branchiostoma* (formerly called *Amphioxus*), which is the group believed to be most closely related to the vertebrates. The resemblance between *Branchiostoma* and the larval form of a very primitive vertebrate is striking, and supports the closeness of the relationship between the two groups.
- *Petromyzon* is rather unpleasent animals. Its life cycle includes two quite different phases. The **larval phase (called ammonocoete)** is a fresh water sedentary, filter feeding and microphagus creature reminiscent of the lancelet. The **fish like adult** lives in the sea & is parasitic on fishes.
- **Hagfish** (also called **slime eel** because large mucous gland opens along the sides of body and secretes enormous quantity of slime) are **scavenger species** that feed off dead and wounded organisms in the ocean. They are also **well-known for their defence mechanism; when threatened, hagfish ooze out great amounts of foul slime**.
- Evidence from the **fossil record** suggests that agnathans reached their peak of diversity between about 500 million and 340 million years ago. During this period, they were **plentiful both in the seas and in freshwater habitats**.

Gnathostomata

- The gnathostomata **(or gnathostomes)** are the majority of the middle devonian (–380 million years ago) to recent vertebrates.
- They differ from all other craniates or vertebrates in **having a vertically biting device, the jaws**, which consists of an endoskeletal mandibular arch and a variety of exoskeletal grasping, crushing or shearing organs *i.e.*, the teeth and jaw bones.
- The gnathostomata is divided into **one extinct class – placodermi** and **six living classes – chondrichthyes, osteichthyes, amphibia, reptilia, aves** and **mammalia.**
- The **first three classes include the fishes**, and are

often combined together as the superclass **pisces**. They **have paired appendages in the form of fins**. The **remaining four classes are grouped together** as the superclass **tetrapoda.** They **have paired appendages in the form of limbs**.

- The fishes and amphibians **lack embryonic membranes** and are collectively called **anamniota** or **anamnia.**
- The **reptiles, birds and mammals** develop special embryonic membranes (amnion, chorion, allantois, yolk sac) in their embryo for protection, nutrition and gas exchange as an adaptation to terrestrial life. They are combined together as **amnia** or **amniota**.
- **Placodermi** were **freshwater bony fishes** having a protective armour of bony scales and plates around the body.
- The **chondrichthyes** are characterized by a special type of hard tissue lining the cartilages of the endoskeleton, the prismatic calcified cartilage.
- The **osteichthyes** are characterized by endochondral (spongy) bone in the endoskeleton, dermal fin rays made up by lepidotrichiae (modified, tile-shaped scales) and three pairs of tooth-bearing dermal bones lining the jaws (dentary, premaxillary and maxillary).

Table : Differences between pisces and tetrapoda

	Pisces	Tetrapoda
1.	Have an exoskeleton of dermal scales.	Have an exoskeleton of epidermal scales, feathers or hair.
2.	Have paired appendages in the form of pectoral and pelvic fins.	Have paired appendages in the form of pentadactyl (5-digited) limbs.
3.	Have 2-chambered heart (1 auricle, 1 ventricle) except in lung fishes.	Have 3 or 4-chambered heart (2 auricles, 1 or 2 ventricles).
4.	Lack internal nares in most cases.	Have internal nares to help in air breathing.
5.	Breath with gills.	Breath with lungs, except some amphibians.
6.	Have internal ear only.	Have external and middle ear, besides internal ear, in most cases.
7.	They are exclusively aquatic.	They are typically terrestrial, some have secondarily become aquatic.
8.	Lateral line sense organs are well developed.	Lateral line sense organs are absents, except a few larval amphibians.
9.	All are poikilothermic.	Some poikilothermic, others homoeothermic.
10.	Have 10 pairs of cranial nerves.	Have 10 or 12 pairs of cranial nerves.
11.	Tongue is non-muscular and non-protrusible.	Tongue is usually muscular and protrusible.

PISCES

- Pisces is the **first true jawed vertebrate group.**
- The science that deals with fishes is called **ichthyology.**
- **Devonian** is the **golden age of fishes**.
- There are about **30,000 to 40,000 species** of fishes differing widely from each other in shape, size, habit and habitat.
- Members of the superclass pisces are primarily **aquatic in habitat**.
- Skin is **usually provided with scales**. Common types of scales are - **placoid** (present in elasmobranchii fishes), **cycloid** (present in lung fishes, holosteans and teleosteans), **ctenoid** (present in modern higher teleosteans), **cosmoid** (present in extinct lung fish and in living fish *Latimeria*) and **ganoid scale** (characteristics of chondrosteans).
- Endoskeleton is **cartilaginous** or **bony**.
- Muscles are arranged in **myotomes**.
- Pisces are **poikilothermal** or **cold blooded** *i.e.* their body temperature fluctuates considerably with that of their environment.

- Locomotion occurs with the help of **fins**.

Types of Fins

- **Unpaired** – Median fins
  - 1 or 2 dorsal fin
  - Anal fin
  - Caudal fin
    - Diphycercal e.g. *Cyclostomes*
    - Heterocercal e.g. *Acipenser*
    - Homocercal e.g. *Polypterus*
- **Paired** – Lateral fins
  - Pectoral fin
  - Pelvic fin

- Respiration is **branchial** (by **gills**), borne by the gill arches. They open outside by gills slits. Gill slits are 5-7 pairs, naked or covered with an operculum (in teleostomi or bony fishes).
- **Accessory respiratory organ**, called **swim bladder** (or **air bladder**) is usually present. It **arises as a diverticulum from the pharynx** or oesophagus in bony fishes.
- Swim bladder is **absent in cartilaginous fishes**.
- The **primary function of swim bladder** is **respiration** (in ganoid and lung fishes) and **other functions** are **buoyancy & sound protection** (to startle the enemies or to attract mates).
- Heart is **two chambered** (one auricle + one ventricle).
- The heart **pumps only venous blood**, therefore called **venous heart**.
- Kidneys are **mesonephric**, sometimes **opisthonephric** (in cartilaginous).
- Both **renal and hepatic portal systems are present**.
- RBCs are **nucleated**.
- Vertebrae are **amphicoelous** *i.e*. **biconcave on both the sides**.
- They possess **lateral line sense organ** which **detect vibrations** (rheoreceptors) and **electric fields** generated by other organisms.
- Lateral line system is **innervated by VIII, IX & X cranial nerves**.
- **Pit organs** (in all fishes) and **ampullae of lorenzini** (in elasmobranchs, probably thermoreceptors) are other sense organs of lateral line system.
- The **ampulla of lorenzini** are **found in the clusters on the dorsal & ventral surfaces of the head** embedded below the skin.
- These are small vesicles and pores that form a complex and extensive sensory system & **detect weak electrical fields at short ranges**. It may **also detect temperature, salinity, changes in water pressure, mechanical stimuli & magnetic field**.
- Tail is muscular and helps in **propulsion**.
- Eyes are **without lids**.
- **Internal ears** are **present** and it is **used for balancing**.
- Sexes are always **separate**.
- Development **does not involve the formation of extra - embryonic membrane**, thus, they are included in **anamniota**.
- Young ones of fishes are called **hatchlings, fingerlings** and **fries**.
- Pisces is **divided into three classes - placodermi**, **chondrichthyes** (cartilaginous fishes) and **osteichthyes** (bony fishes).

Pisces

Divided into 3 classes

Placodermi
- Earliest gnathostome
- Extinct fishes
- Notochord persist throughout life
- These placoderm fishes first evolved into bony fishes and later elasmobranchs
- **Only class of jawed vertebrates** to become completely extinct (e.g., *Climatius*)

Chondrichthyes (Cartilaginous fishes)
- Mostly marine
- Notochord persists in adult
- Include all members of sharks (scoliodon, *Rhincodon*, *Carcharodon*), skates, rays (*Torpedo*, *Trygon* etc.)
- **Truely chondrichthyes fishes** are **called elasmobranch**
- With operculum called **holocephali** (e.g., *Chimareae*)

Osteichthyes (Bony fish)
- Includes all members of lung fishes, ray finned & lobe finned fishes
- Bony fishes are **also called teleosts**
- Swim bladder present to regulate buoyancy

- The name **placoderm** refers to the heavy armoured bony plates that completely covered the head and the thorax of these curious prehistoric fish.
- Along with acanthodi, placoderm is the only class of jawed vertebrates to become completely extinct that flourish during the devonian period.
- **Chondrichthyes** (**also called cartilaginous fishes**) includes all members of the shark (scoliodon, *Rhincodon* etc.), skates, rays and chimareae.
- **Chimareae** (rabbit fish) is a **connecting link between cartilaginous and bony fishes**. Anatomically it appears as an odd mixture of shark like and bony fish like features. Instead of a toothed mouth, their jaw bear large flat plates. The upper jaw is completely fused to cranium which is very unusual in fish. They eat seawood, molluscs, echinoderms, crustaceans and other small fish. It includes rat fishes, ghost fishes, lungs of herrings etc.
- Chondrichthyes are **ureotelic** (main nitrogenous product is **urea**).
- **Osteichthyes** (**also called bony fishes**) includes all members of lung fishes, the ray finned & lobe finned fish.
- The **exoskeleton of osteichthyes or bony fishes** is formed of **cycloid or ganoid or ctenoid scales**.
- Tail fin is **homocercal** or **diphycercal** in bony fish.
- A **swim bladder** is usually present and **acts as hydrostatic organ**, so these can stay at a particular depth without expending energy in swimming.
- Two accessory heart chambers – **sinus venosus** and **conus arteriosus are present**.
- There are **10 pairs of cranial nerves**.
- Cerebellum and olfactory lobes are relatively **smaller in size than the cartilage fishes**.
- These are **ammonotelic** (main nitrogenous waste is **ammonia**).
- Claspers are **never present in osteichthyes**.
- Bony fishes are also called **teleosts**.
- **Dipnoi** (also **called lung fishes**) belongs to subclass sarcopterygii of class osteichthyes.
- There are **three living genera of lung fishes** - *Neoceratodus* in Australia, *Lepidosiren* in South America and *Protopterus* in Africa.
- **Lobe-finned lung fishes** are believed to be **fore-runners of tetrapods**.
- During unfavourable condition *Protopterus* undergoes **summer sleep (aestivation)** and burrows into the soil to a depth of about 2 feet.
- Lung fishes are **double breathers**. They respire through **gills as well as lungs** (modified structure formed by vascularization of swim bladder).
- Lung fish shows **cannibalism** *i.e.* it eats the flesh of its own kind.
- Lung fishes have **well developed lateral line sense organ** specially on head. Development in lung fish includes metamorphosis.
- Fish as a group **pay little parental care to their eggs and gonads**. This lack of parental behaviour is correlated with production of great numbers of eggs and sperms.
- Fishes which **live within a narrow range of salinity** are called **stenohaline**.
- Fishes that can **tolerate wide variation in salinity** are termed as **euryhaline**.
- **Movement** of fish **from fresh water to salt water** (sea) **for spawning** is called **catadromous migration** (e.g. *Anguilla*).
- The **reverse movement**, *i.e* **from salt water to fresh water** is termed as **anadromous migration** (e.g. salmon, shark etc.)
- **Stone fish** (*Synanceja verrucora*) is a highly **poisonous fish**.
- **Pygmy goby** (*Pandaka pygmaea*) is the **smallest fish**, size – 7.5 to 9.9 mm.
- **Dwarf sea horse** (*Hippocampus zosterae*) is the **slowest fish** having a speed of 0.016 km or 15 mt/hr.
- **Sail fish** (*Istiphorus platypterus*) is the **fastest fish**, having a speed of 109 km/hr.
- **Economics importance of fishes are** –
  - *As food*
    - **Fresh water species :** *Labeo rohita* (rohu), *Labeo calbasu* (calbasu), *Catla* (catla), *Cirrhina mrigala* (mrigal), *Wallagonia attu* (malhi), *Cyprinus carpio* (common carp), *Mystus seenghala* (singhala), *Ophiocephalus* (snake head).
    - **Marine species :** *Harpodon* (bombay duck), *Anguilla* (eel), *Stromateus* (pomphret), *Sardinella* (salmon), *Hilsa* (hilsa), *Exocoetus* (flying fish), *Solea* (flat fish).
    - **Catfishes :** *Mystus seenghala* (singhala), *Clarius batrachus* (magur), *Heteropneustus* (singhi) and *Wallagonia attu* (malhi).
  - *Products of commercial value* : Fish oil, fish meal, liquid glue. Cod liver oil is rich source

Table : Important examples of pisces

	Scientific name	Important notes
	Cartilaginous fishes	
•	**Sharks :** Body is laterally compressed and spindle like. Inhabits open water and swim actively by lateral undulation of body.	
1.	*Scoliodon* (Dog fish)	Fast swimming carnivorous fish. It is edible, its skin is used as an abrasive (shagreen) and its liver yields oil. Exoskeleton is formed of dermal **placoid scales**. Tail fin is mostly **heterocercal (2 unequal lobes).** Teeth are **acrodont** (directly attached to jaw bone). There is a **scroll valve** in the intestine. Males have **claspers** (copulatory organs) **between the pelvic fins**.
2.	*Rhincodon* (Whale shark)	Second largest vertebrate (15-17 mt and weight 39.5 tonnes). Largest fish.
3.	*Carcharodon* (White shark)	Man eater shark.
•	**Rays :** Includes skates, electric rays etc. All are bottom dwellers and sluggish, swim by flapping pectoral fins.	
4.	*Torpedo* (Electric ray)	Carnivorous fish, have a pair of electric organ (formed from metamorphosed (branchial) muscles for defence and predation.
5.	*Trygon* (Sting ray)	Whiplike tail, modified into stinging organ, armed with saw edged spines or stinger with venom glands. There wounds are very painful and heal very slowly.
6.	*Latimeria*	**Living fish**, resemble lung fishes in having internal nares, lobed fins and lung or air sac. **Living fossil**. Connecting **link between fishes and amphibians**.
	Bony fishes	
7.	*Salmo* (Salmon)	Anadromous
8.	*Anguilla* (Eel)	Larva is "**Glass Fish**" or leptocephali, catadromous. The young eel back to fresh water. It is known as **elver**.
9.	*Muraena* (Spotted eel)	**Largest eel**. At times it attacks even human beings also.
10.	*Exocoetus* (Flying fish)	So called because it glides for few metres in air by large pectoral fins.
11.	*Anabas* (Climbing perch)	Can live outside water for several days. Unable to climb trees, birds may pick it up from land and drop on trees.
12.	*Echeneis* (Remora/sucker fish)	Sucker represents modified anterior dorsal fins. Feeds on the left over of shark's prey. The relationship is that of **commensalism** or **ectocommensalism**.
13.	*Hippocampus* (Sea horse)	On the belly of male is a brood pouch for incubating eggs. Sometimes **referred as pregnant males**. Shows parental care. Dried skin used for the preparation of ornaments.
14.	*Labeo rohita* [Rohu (carp)]	Carnivorous when young, but become herbivorous when adult, oviparous.
15.	*Gambusia* (Mosquito fish, Top minnow)	Carnivorous, used as larvicidal (feeds on larvae), Effectively used against malaria as *Anopheles* is the vector of malaria.

1. **Other examples of cartilaginous fishes** are - *Stegostoma* (Zebra shark), *Rhinobatus* (guitar fish), *Pristis* (Saw fishes).
2. **Other examples of bony fishes** are - *Tetradon* (globe fish); *Diodon* (porcupine fish); *Syngnathus* (pipe fish); *Carassius* (gold fish); *Oncorhynchus* (pacific salmon); *Solea* (flat fish); *Clarius* (cat fish or mangri in hindi).

of vitamin A and D (extracted from cod and shark). Fish meal used as fertilizer and poultry feed.

– *Malaria control* : *Gambusia* feeds on mosquito larvae.
– *Leather* : Shark skin provides leather.
– *Pituitary extract* of shark is used for medical purpose.
– *Shagreen* is a rough skin of sharks used for polishing.
– *Isinglass* is a white, transparent, almost pure gelatin obtained from swim bladders of some fresh water fishes for making jellies, glue etc.
– *Fish guano* : After extraction of oil the meat of fishes is dried. It is fish guano and used as poultry feed.

Table : False fishes

Jelly Fish	–	*Aurelia* (coelenterate)
Shell Fish	–	(a) Oyster and other molluscs (b) Lobster and other crustaceans.
Razor Fish	–	Used both for a true fish *Xyrichthyes* species as well as *Solen*, a bivalve.
Silver Fish	–	*Lepisma* (an insect).
Cuttle Fish	–	*Sepia*, a mollusc.
Devil Fish	–	*Octopus* (a mollusc).
Hag Fish	–	*Myxine* (cyclostomata).
Star Fish	–	*Asterias* (echinoderm).
Whale Fish	–	Whale (aquatic mammal).

AMPHIBIA

- The vertebrates to come out of water for the first time are **amphibians**.
- Amphibians are the **first animals to attempt transition from aquatic to terrestrial life**.
- Amphibians are the animals who can **live on land as well as in water**.
- Amphibians **evolved during devonian period** from **osteolepid fishes** and **dominated during carboniferous period**.
- The splitting of one phyletic lineage into two or more lines is termed **cladogenesis**.
- **Primitive amphibians** like *Ichthyostega, Eryops* **closely resemble the lung fishes.**
- **All amphibians** are fresh water except *Rana concrinora* (frog).
- They are **poikilothermic** (cold blooded) *i.e.* **ectothermal animals**.
- These are earliest and the most primitive tetrapods with two pairs of limbs. Each limb is **pentadactyl in nature**.
- Limbs are totally **absent in caecilians**.
- Fore limbs and hind limbs are unequal in size in anura but similar in size in urodeles.
- Skin is **slimy, moist, glandular** as exoskeleton is absent.

Glands in amphibia

Mucous gland	**Poison gland**
• Smaller, flask shaped glands found over the entire surface of the body.	• Larger in size, distributed less evenly.
• Secrete colourless watery fluid, mucous.	• Secrete mild poison
• It keeps the skin moist, glistening and sticky. E.g. frog.	• Protect the animal in some degrees from enemies. E.g toad

- **Scales** are present in some cases of **apoda**, *e.g. Ureotyphlus*.
- Endoskeleton is **bony**. Skull is **dicondylic**.
- Vertebrae are **procoelous** and **amphicoelous**.
- **Ribs are usually absent**. Even, if the ribs are present, they do not reach the sternum.
- **Sternum** makes its **appearance for the first time** in amphibians.
- **Tympanum is found in frogs and toads**. It is **absent in urodeles and caecilians**.
- **Respiration is effected by skin, buccal cavity, lungs and gills** (Gills are found in some adult urodeles).
- **Only respiratory organs during larval stage** are **gills**.
- Both **hepatic** and **renal portal sytems** are **present**.
- **R.B.Cs** are oval, biconvex and nucleated.
- Teeth are present in **both the jaws.**
- **Vomerine teeth** are present.
- Hinds limbs are vestigal in *Siren* (mud eel).
- **Vocal cords** are present. **Anurans** are the **earliest vocal vertebrates**.
- **Radius and ulna** are fused into radio-ulna. **Tibia and fibula** are fused into tibio-fibula in anura.
- **Bidder's organ is attached to the interior part of kidney in toads.** The removal of testis from males leads to the development of ovaries from Bidder's organs.

- **Ductus Botalli** connect systemic and pulmonary arch on each side.
- Heart is **3 chambered**. Accessory chambers are **sinus venosus** and **truncus arterious**.
- Amphibians are **carnivorous**.
- In adult functional kidney is **mesonephric type**. **Nitrogenous end product is urea**.
- In front of each testis are several finger like processes called **fat bodies** or **corpora adiposa**.
- Nervous system includes **central nervous system**, **peripheral nervous system** and **autonomic nervous system**.

External receptors
(Receive impulses from the environment)

- Tangoreceptor (Organ of touch)
- Gustatoreceptor (Organ of taste)
- Statoacoustic receptors (Organ of hearing and balance)
- Olfactoreceptor (Organ of smell)
- Photoreceptor (Organ of sight)

- Eggs are **mesolecithal** and **telolecithal**.
- Cleavage is **holoblastic** and **unequal**.
- Development is **indirect** which includes a larval stage and metamorphosis.
- **Metamorphosis** in amphibians is **controlled by thyroxine**.
- Extra-embryonic membranes are **absent (amniotes)**.
- **Fertilization** is usually **external**, but it is **internal in caecilians and urodela**.
- Some amphibians exhibit **neoteny** or **paedogenesis** e.g. **Axolotl larva** of *Ambystoma.*
- **Tadpole larva** is **connecting link between fishes and amphibians.**
- **Largest frog** is *Rana goliath*.
- **Largest amphibian** is *Cryptobranches alleganiensis*.
- Amphibia having **largest gestation period** is *Salamandra atra* (**36 months**).
- In winter, Salamander goes to **winter sleep** or **hibernation** and in summer, **summer sleep** or **aestivation**.
- Amphibia are **divided into extinct and living types**. **Extinct amphibians** were crocodile and Salamander like with pentadactyly limbs. Eg. *Eryops*, *Branchiosaurs* etc. While **living amphians** are divided into **apoda/gymnophiona, urodela/caudata, anura/salientia**.
- All the **living amphibians** belongs to sub-class, **lissamphibia**.
- **Extinct amphibians** belongs to **stegocephalia**.

Amphibia (Living)

3 subclasses

Apoda/Gymnophiona/Caecilians
(Limbless amphibians)

- Limbs and tail absent.
- Long wormlike (body is eel like), burrowing (snake like because they are burrowers, the eyes are replaced by specialised sensory tentacles on the snout. Very rarely seen due to their burrowing nature).
- Copulatory organs present.
  E.g. *Ichthyophis* (Blind worm), *Ureotyphlus*.

Urodela/Caudata
(Tailed amphibians)

- Body with head, trunk and tail. Limbs of equal size.
- Commonly called **newts and Salamanders**.
- Possess largest RBC.
- Males are **without copulatory organ**

Two orders

Perenibranchiata
e.g. *Necturus, Siren.*

Caducibranchiata
Eg. *Salamandra, Ambystoma, Triton*

Anura/Salientia
(Tailless amphibians)

- Body with head and trunk. Tail absent
- Forelimbs shorter than hindlimbs.
- Respiration by lungs
- Commonly includes **frogs and toads**
- Vocal cords **develops for the first time**
- Order - Phaneroglossa
  Eg. *Rana, Bufo, Hyla* (tree frog). *Rhacophorus* (flying frog) etc.

Table : Important examples of amphibians

	Scientific Name	Important Notes
		Apoda (Limbless amphibians)
1.	*Ichthyophis* (Blind worm)	Male copulates female by protrusible cloaca and fertilization is internal. They hatch into tadpoles.
		Urodela (Tailed amphibians)
2.	*Necturus* (Mud puppy or water dog)	Completely aquatic, represent a permanent neotenic larval stage. (*i.e.* larva is capable to reproduce again). This happens due to lack of iodine in water which causes deficiency of thyroxine hormone.
3.	*Ambystoma* (Tiger salamander)	Shows **both neoteny and paedogenesis**. Larva is called *axolotl* in which metamorphosis is induced by injecting thyroxine (thyroid extract)
4.	*Salamandra maculosa* (Spotted or fire-salamander)	Terrestrial, viviparous
5.	*Siren lacertina* (Mud eel)	Carnivorous, permanent neotenic form showing almost no adult character.
		Anura (Tailless amphibians)
6.	*Amphiuma* (Congo eel)	• Semi-larval form of Salamandra derivation. • Has **largest erythrocyte** of any animals.
7.	*Triton* (European salamandra)	• Exhibit sexual dimorphism. • Male possesses a dorsal median crest. • Fore and hindlimbs are well developed. • Scales are entirely absent.
8.	*Proteus* (Olm or European blind cave Salamandra)	It is a neotenic and a **permanent larva** with three pairs of branching red coloured external gills and two part of open gill clefts.
9.	*Alytes obstetricans* (Mid-wife toad)	Males shows parental care by entangling eggs around their hindlegs.
10.	*Bombinator* or *Discoglossus Igneus* (Fire Bellied toad)	The toxins in its skin induce vomiting so that predators avoids it in future
11.	*Pipa pipa* (Surinam toad)	The male presses fertilized eggs on female's back so that each sinks into a little pocket. Here they develop directly into young toads. Feet possess large webs.
12.	*Hyla* [Arboreal frog (Green tree frog)]	• Green in colour, adapted for life on trees. • Has adhesive pads on the digits for climbing tree. • Shows mimicry.
13.	*Rhacophorus* (Polypedates) (Flying frog)	Webs and flattened body serve as a parachute in gliding from a higher elevation to a lower one.
14.	*Astylosternus* (African hairy frog)	Male has extensive vascular filamentous or hair like cutaneous papillae on flanks and thigh (respiratory).
15.	*Rana tigrina* (Common Indian frog or Indian bull frog) [*For more details refer chapter Morphology & Anatomy of Animals*]	• Undergoes aestivation (summer sleep) and hibernation (winter sleep). • Moulting and colour changes (called **metachromasis**) are well marked. • Larva of frog called **tadpole**, undergoes metamorphosis to become adult. • Males **have vocal sacs and nuptial pad** (used during amplexus which occur in water = **false copulation**).
16.	*Bufo melanostictus* (Indian toad)	• Visits water only for breeding. • Mouth does not contain teeth • Secretions of its skin gland [bufotenin ($C_{12}H_{16}N_2O$), bufotoxin ($C_{34}H_{46}O_{10}$) and bufonin ($C_{34}H_{54}O_2$)] probably have the healing property.

REPTILES

- Reptiles are the **first true land vertebrates.**
- The study of reptiles, lizards and snakes is called **herpatology**, **saurology** and **ophiology** (or **serpentology**) respectively.
- **Reason behind the adaptation of reptiles on land life are - horny scales** which check loss of water, **internal fertilization** as gametes cannot survive on land, **shell around the egg** to check dessication, **fluid filled amnion** around the embryo to provide aquatic environment for development on land.
- Reptiles evolved from **labyrinthodont amphibians.**
- Reptiles were **dominant in mesozoic era** but **not appeared in palaeozoic era.**
- **Mesozoic era** is known as the **golden age of reptiles** or **golden age of dinosaurs.**
- Reptiles are **cold blooded vertebrates** *i.e.*, **poikilothermous.**
- Reptiles are **lung breathing animals.** Respiration by lungs, no gills, cloaca used for respiration in some spp (e.g., turtle), respiration through skin during embryo development.
- Integument covering the body is **dry, horny and scaly**. Skin is **epidermal in origin**.
- In some reptiles the skin is covered with hard plates called **scutes**.
- Reptiles are **tetrapods**. Hind limbs and fore limbs are **pentadactylous** and **provided with claws.**
- The body is **bilateral symmetrical** & divided into **head**, **neck**, **trunk** and **tail**.
- Skull bears **temporal fossae.**
- Skull is **monocondylic,** articulated with the vertebral column by a single occipital condyle.
- Vertebral column is divided into **cervical, thoracic, lumbar, sacral** and **caudal regions**.
- Tongue is **protrusible**. It is **bifid in snakes**.
- Alimentary canal **opens in cloaca.**
- **Vertebrae** in reptiles are **procoelous** and **amphicoelous**.
- Heart is **three chambered** with two auricles and one ventricle (**except**, **crocodile**, **alligator** and **gavialis** where **heart is four chambered**).
- Kidney **metanephric**, excretion **uricotelic**, cranial nerves **12 pairs** (**except snake** as they have **10 pairs** of cranial nerves).
- Sexes are **separate** usually with a muscular copulatory organ.
- Fertilization is **internal**. There is **no metamorphosis**.
- Development is **direct** and cleavage is **meroblastic.**
- **Parental care** usually **absent**.
- **Femoral glands** are secretory glands in the femoral region of reptiles, giving them characteristic smell.
- **Foramen of Panizzae** is an **aperture in the heart of lizards and crocodiles**. It is located at the point where **right and left aorta cross each other** and are in contact.
- Snake has both an **exoskeleton** and **endoskeleton**.
- **Limbs are absent** in snakes**.**
- **Paddle like limbs** are **found in turtles**.
- Tibia and fibula in the hind limbs and radius and ulna in the forelimbs are **separate.**
- R.B.Cs are **oval**, **biconvex and nucleated.**
- **Sternum is well developed**, but **absent in chelonians and snakes**.
- Most of the reptiles are **oviparous.** Few of them like sea snakes and vipers are **viviparous.**
- Eggs are **macrolecithal** covered with **calcarious shell (cleidoic).**
- Reptiles are **classified into two subclasses** - **anapsida** and **diapsida**.
- **Extinct reptiles** are **dominant from the triassic to the cretaceous periods of mesozoic era**. These reptiles were mostly terrestrial with tetrapod locomotion.
- *Seymouria*, **lizard like**, is the most primitive and intermediate **connecting link between amphibia and reptile**.
- *Ichthyosauria* is **fish like** reptile **found in triassic and jurassic period**.
- *Dimnetrodon* is **mammal like** reptile **found in carboniferous and permian period**.
- **Dinosaurs** (means terrible lizard) are large and extinct reptiles.
- Dinosaur originated along with primitive mammals **during triassic period of mesozoic era**.
- It **becomes extinct during cretaceous period** of mesozoic era.
- Dinosaur **belongs to archosauria branch**. Archosauria divided into two orders - **saurischia** (means reptiles hips *i.e.*, possess triradiate pelvis) and **ornithischia** (means birds hips, possess tetraradiate pelvis).

Reptiles

Subclasses

Extinct subclass
- **Parapsida** (eg. *Ichthyosaurus, Protosaurus, Plegiosaurus*
- **Synapsida** (eg. *Dimnetrodon, Cynognathrus*)

Anapsida
(Primitive reptiles)
Order
- **Cotylosauria** e.g. *Seymouria* (extinct)
- **Chelonia** e.g. *Chelone*, *Testudo*

Diapsida
(Extinct as well as living)
Order
- **Rhyncocephalia** Contain extinct reptile except *Sphenodon*
- **Squamata**
  - Living reptiles
  - Procoelous vertebrae
  - Male possess paired copulatory organs (hemipenis)
    - Ophidia (snakes) e.g. *Viper*
    - Lacertilia (lizards) e.g. *Varanus*
- **Crocodilia** e.g. *Crocodilus*, *Gavialis*, *Alligator* etc.

- **Some important dinosaurs** are –
  – *Brontosaurs* (thunder lizard) of jurassic period.
  – *Tyrannosaurs* (tyrent lizard), largest dinosaurs and largest flesh eater.
  – *Diploducus.*
  – *Gigantosaurs* (largest dinosaurs)
  – *Iguanodon* (ornithischian dinosaurs)
  – *Stegosaurs* (plated lizard), found in jurassic period.
  – *Triceratopus* (ornithischian dinosaur)
- **Eyelids**, **lacrimal gland, urinary bladder, sternum, episternum** and **vocal cord** are the parts which are **absent in snakes**.
- Each half of snake's lower jaw is made of **six bones, articular**, **angular**, **sub-angular**, **coronoid**, **dentary** and **splenial**.
- Both the jaws bear teeth. These are **acrodont, pleurodont, homodont.**
- **Jacobson's organs** are the sense organs present on the palate or upper jaws in ophidia.
- Males possess **double penis.**
- Eyes of snake are covered by transparent cuticle.
- **Fangs** are **modified maxillary teeth.**
- **Poison glands** are **modified parotid salivary glands.**
- The poison of snakes is called **venom.**
- The poison contains **proteolysins** (poison of vipers) **cardiotoxins** (poison of cobra & few vipers), **haemotoxins** in which venom react with blood (found in vipers), **neurotoxin** in which poison directly react with nervous system (cobra) and **antibactericidum.**
- **Vipers** are poisonous, possess a **characteristic triangular head** covered with small soles and having a narrow neck.
- **Loreal pit**, a heat sensitive organ, is present between the eye and nostril on either side.
- Loreal pit is the **characteristic difference point with true viper**.
- Vipers are of **two types - pit viper** (Rattle snake) and **pitless viper** (Russel's viper).
- **Antivenom** is used for the treatment of snake bite.
- **Antivenin's** are **prepared by immunising horses and mules** against the various types of snake poison.
- **Haffkin Institute, Bombay and Central Research Institute, Kasauli** are known for Antivenom in India.

Table : Important examples of reptiles

	Scientific Name	Important Notes
		Rhyncocephalia
1.	*Sphenodon punctatum* [Tuatara]	Also called **Hatteria**. 'Living Fossil', abundant during mesozoic times. Resembles with lizard and crocodiles, have functional third eye on the forehead, pentadactylus.
		Squamata
		Lizards
2.	*Hemidactylus* [House Lizard/Wall lizard/ Gecko]	• Unlike most lizards, making clicking and peeping sounds. • Only one of gecko which lay round, hard shelled egg. • Can regenerate the lost tail
3.	*Draco* [Flying dragon/Flying lizard]	• Patagium used for gliding from tree to tree. • **Gular pouch** (below the thorax) is larger in male.
4.	*Phrynosoma* [Horned toad]	• Have two enlarged horns on head give them formidable appearance. Has remarkable protective adaptation. • When irritated it shoots a gel of blood out of its eye which frightens the enemy and provide it the chance of escape.
5.	*Chameleon* [Chamaeleon]	• Famous to change their body colours rapidly to blend with their surroundings (**camouflage**). • Tongue are extremely protrusible spoon shaped sticky and capable for capturing prey even at a distance of 20 cm. • Oviparous lizard.
6.	*Heloderma* (gila monster) [Beaded Lizard]	• **Only poisonous lizard** in the world. Poison is neurotoxic. • Eyes are fixed.
7.	*Varanus* (*V. Komodoensis*) [Monitor Lizard]	• Largest living Lizard (L - 2.5 m, W -100 kg) • Found in Malaya Archipelago. • Savage and carnivorous lizard. • It is capable of killing adult water buffallo, but it normally preys upon wild pigs, goats, deer etc.
8.	*Ophiosaurs* [Glass snakes]	• Limbless Lizard. • The limbless lizards can be differentiated from snakes by their non expansible mouth, movable eyelids and ear openings. • *Anguis Fragilis* (slow/blind worm) is another limbless lizard.
9.	*Calotes versicolor* [Garden Lizard or Girgit]	• Also known as **blood sucker**. • Have ability to change colour which is due to temperature and environment.
10.	*Uromastix hardwickii* [Spiny tailed lizard]	• Non-aggressive lizard. • Herbivorous, oviparous, diurnal. • Tail muscle is eaten by some tribal people.
		Snakes
➢ 11.	**Poisonous** *Naja naja* [Common Indian Cobra]	• 2 mt. long, rake can dilate into hood bear spectacle mark dorsally. • Highly poisonous and have neurotoxic venom, oviparous.
12.	*Ophiophagus hannah* [King Cobra]	• 5 mt. long, one of the **largest deadliest venomous snakes**.
13.	*Bungarus caeruleus* [Krait]	• Highly poisonous land snake. **Its poison is three times as virulent as that of Cobra**. Commonly found in hilly areas.

contd ...

14.	*Crotalus* [Pit viper (Rattle snake)]	• Rattle snake is recognized by a loose, horny rattle at the end of the tail which is shaken vigrously to warn off intruders. • Rattle is formed when the snakes skin is shed, the end section of the rattle and attached ring of the old skin are retained on moulting. • Feeds on small mammals and reptiles.
15.	*Vipera russelli* [Russel's viper (Pitless viper)]	• Usually occurs in pairs. • Terrestrial, nocturnal and carnivorous. • Produces loud hissing sound. • Poison is fatal to man. • Upper surface of the body shows three rows of large black rings appearing like chain so also known as **chain viper** or **Dobia**.
16.	*Echis carinata* [Saw sealed viper]	• A small desert viper (40-25 cm) • It is not fatal to man but can kill small domestic animals. • Found in sandy place throughout the world.
17.	*Hydrophis* [Sea-snake]	• Pass their whole life in sea water and are **highly poisonous** and about 20 times more than cobra. • Have laterally compressed tail (suited for swimming). • All are ovoviparous.
	Sea snakes have no gills and must rise to the surface for air, but they can remain underwater for several hours, obtaining dissolved oxygen from water that they swallow and eject. They feed on elongate fishes, such as eels, which they paralyze with their venom, but do not attack humans unless threatened.	
➢ 18.	**Non-Poisonous** *Dendrophis* [Tree snake]	• It is diurnal. • Feeds on lizard and frogs.
19.	*Eryx johnii* [Double headed snake or Sand boa]	• Tail (small, prehensile) bears a false resemblance to head, hence the common name.
20.	*Python*	• **Largest non poisonous snake**. • Commonly called **ajgar** and grow upto 6 meter. • Indian python - *Python molurus* • *Python reticulatus* of South Asia grow to over 10 meters.
	Anaconda, common name for a large South American snake of the boa family. The anaconda or water boa is one of the largest and most powerful snake in the world, and the largest in the western hemisphere. Average length is 20 ft. Average diameter is 12m. Average weight is 330 lb. (148.5 kg.). It kills its prey by constriction, or squeezing. The reptile is found in the rivers of the Guianas and Brazil.	
21.	*Typhlops braminus* [Blind worm]	• Insectivorous, look like earthworm, hence called **worm snake**.
		Chelonia
•	Turtle and Tortoise	• Ancient reptiles. Former is aquatic and latter is landforms, e.g. *Chelone mydas* (green turtle), *Trionyx* (tortoise or soft river terrapin), *Testudo* (land tortoise).
	Other non poisonous snakes are • *Uropeltus* : Similar to blind snakes. Also called **rough tailed snake**. • *Ptyas* (= Zamenis) : Most common Indian rat snake called **'dhaman'**. • *Tropidonotus* : Common pond or grass snake (most common snake). Grass snake differ from most water snakes in that they lay eggs instead of giving birth to living young. • *Lycodon*: Wolf snake, mimics the poisonous Krait, but it is nonpoisonous. • *Dryophis* : Whip snake.	

- Snakes can receive **sound waves passing through solid terrain only.**
- **Moulting or shedding of skin** in snakes is done by cornified cells.
- Of all the snakes only **33%** of snakes are poisonous.
- The **chief poisonous snakes of India** are cobra, king cobra, krait, vipers, sea snakes and coral snakes.
- **Sea snakes** secrete **mytotoxic venom** and **cause muscular pain**.

AVES

- Study of birds is called **ornithology.**
- Birds are **feathered bipeds**, air breathing, truely flying vertebrates.
- **Oology** is the **study of birds nest**.
- **Phenology** is the **study of birds migration**.
- **Salim Ali**, a famous ornithologist, was known as **bird man of India.**
- Birds **evolved in jurrasic period from ornithischian dinosaurs.**
- Modern birds appeared in **cretaceous period.**
- **Huxley** has called birds to be **glorified reptiles** because *Archaeopteryx* represents a connecting link between the organization of birds & reptiles.
- *Archaeopteryx lithographica* was **discovered in 1861 by Andreas Wanger** from the lithographic state of solenhofen in Bavaria of Germany.
- Birds are the **only amniotes** whose bodies are highly **specialized for aerial mode of life**.
- Skin is **dry and devoid of glands except the oil or preen gland or uropygeal gland at the root of the tail**.
- Oil gland is **absent in ostrich and parrot**.
- They are **warm blooded, oviparous, bipedal, flying vertebrates** with an exoskeleton of feathers.
- **Forelimbs are modified as wings** for flying and variously **adapted for walking**, **running**, **scratching**, **perching** etc.
- **Hindlimbs are adapted for walking, perching** or **swimming** (bipedal locomotion).
- They have **well developed pectoral muscles** for flight.
- **Pectoralis major, pectoralis minor, coracobrachialis longus, tensor patagialis** are the **flight muscles present in birds**.
- Skull is smooth and **monocondylic**.
- Bones are **light** and **pneumatic** and **have no marrow**.
- Both clavicles and single interclavicle fused to a **V shaped bone** called **furcula** or **wishbone**.
- Furcula (also called **merrythought bone**) **helps in flying & keep both the wings well apart**. It is **absent in flightless bird**.
- Fused tail vertebrae form a structure called **pygostyle.**
- Ribs are **double headed with uncinate processes**.
- Eyes are large and possess nictitating membranes, sclerotic plates and a vascular **pecten**. Pecten is **present in flying birds**.

Reptilian characters of *Archaeopteryx*

- The bones were **solid** and not pneumatic.
- Strong jaws with **thecodont dentition**.
- Presence of **long tail** with 18 - 20 free caudal vertebrae.
- Presence of **sclerotic ring**.
- Centra of vertebra were probably amphicoelous or **biconcave** (as in *Sphenodon*).
- Presence of **abdominal ribs**.
- Ribs are without **uncinate process**.
- There is no definite trace of **sternum**.
- Presence of elongated **ilium** and backwardly directed **pubis**.
- Separate **metacarpals**. **Carpometacarpus** is absent.
- Digits are **clawed**.
- **Separate tibia** and **fibula.**
- Hand bears a typical **reptilian** plan, phalanges being 2,3 and 4 respectively in first, second and third digits.

Birds like characters of *Archaeopteryx*.

- Presence of **feathers** as body covering.
- Fore limbs modified into **wings** with only 3 digits.
- Presence of single **occipital condyle**.
- Fusion of **skull bones**.
- Both the jaws protrude to form **beak**.
- Presence of **V shaped furcula**.
- The **scapulae** are slender curved bones.
- The bones of **limbs** and **girdle** are eminently bird like.
- The hind limb possesses a **tarso-metatarsus**, phalanges being 2,3,4, and 5 respectively in each digit which terminates into a **claw** and **hallux** is present directed backwards.

Aves
↓
Subclasses

- **Archaeornithes**
  - Extinct jurassic birds
  - Eg. *Archaeopteryx lithographica*
- **Neornithes**
  (Extinct as well as jurassic birds)
  - Wings usually well developed & adapted
  - Teeth absent except in some fossil birds

  Divided into super orders
  - **Odontognathae**
    - Extinct toothed cretaceous birds, eg. *Hesperornis* (flightless marine bird) and *Ichthyornis* (flying marine birds)
  - **Palaeognathe (Ratitae)**
    - **Flightless birds** (*i.e.*, walking or running birds)
    - Includes the **largest of living birds**
    - Have vestigial or rudimentary wings & poorly developed pectoral muscles
    - Oil gland is absent except in *Tinamous* [Tinamous have a keeled sternum and fly (weakly)] and *Kiwi*
    - Male has large penis
    - Eg. Ostrich, Emu, Kiwi. Extinct ratites (probably as a result of human hunting) are elephant bird of Madagascar and the moas of NewZealand
  - **Impennae**
    - Flightless birds specialized for aquatic life (forelimbs are modified into flippers), eg. Penguins
  - **Neognathae**
    - **Modern flying birds**, feathers with interlocking mechanism
    - Beak and pygostyle is present, wing keeled sternum
    - **Grouped into atleast 6 homogenous ecological groups**
      - Arboreal birds (Eg. Sparrow, pigeon, kingcrow, bulbul etc.)
      - Terrestrial birds (Eg. Quail, cuckoo etc.)
      - Swimming and diving birds (Eg. Swans, kingfishers, duck etc.)
      - Short birds and Wading birds (Eg. Sandpiper, gull, curles etc.)
      - Aerial birds (Eg. Humming birds, goat sucker etc.)
      - Birds of prey (Eg. King vulture, kite, *Tylopus* etc.)

- **Pecten**, a comb like structure, is **well developed in diurnal birds** than nocturnal and **absent in kiwi.**
- Pecten **helps in accomodation and nutrition of eye ball, aids in perception of movements by** falling shadow of its own on retina forming small blind spot & **also regulates the pressure in fluid in the eye**.
- Heart is **4 - chambered**. Only right (systemic) aortic arch **persists in adult**.
- Kidney is **metanephric**, excretory system is without urinary bladder (exception - *Ostrich, Rhea*). **Renal portal system is vestigial**.
- **Bursa fabricus** is a lymphoid tissue attached to cloaca of some young birds which takes part in formation of lymphocytes. It is also called **cloacal thymus.**
- **Syrinx** is the **characteristic feature** of birds which is **responsible for the sound production.**
- Alimentary canal contains **crop** (modified oesophagus) **for storing and softening of food** and **gizzard** as **grinding part of stomach**.
- **Respiration** occurs by compact spongy, non-distensible lungs which is continuous with thin walled sacs.
- Sexes separate and sexual dimorphism is **well marked**.

- Fertilization is **internal.**
- **Only left ovary and oviduct are present** which **provide an adaptation to avian mode of life**. Loss of an ovary and oviduct in pigeon reduce weight which is an advantage in flight. Further, **the retention of a single ovary also helps in the safe manipulation of large eggs with breakable shells**.
- Eggs are **macro** and **megalecithal** with **meroblastic** & **discoidal cleavage.**
- For feeding the young ones, both sexes secrete **pigeon milk from the crop.**
- **Olfactory sense is poorly developed** in birds (*except* kiwi, where it is highly developed).
- **Pseudopenis** is **present in flying bird duck**.
- Parental care is **highly developed** in birds. Nest building is seen.
- Aves is classified into **two subclasses - archaeornithes** and **neornithes.** (*See flow chart*)
- **Perching mechanism** is the characteristic phenomenon of birds **due to which the birds are able to sleep on a twig without falling down**. When the birds settle on the branch of a tree, the legs are bent and puts the **flexor tendons** on the stretch. With the exertion of the pull, the toes are bent spontaneously around the perch.
- **Marine birds** have **salt glands**.
- During migration, **birds determine compass direction** using **celestial bodies**, **sun during day** and **stars at night**.
- The migration in birds is **initated by photoperiod** *i.e.*, the day light affecting the endocrine glands.
- Poor will / Night Jar/Goat sucker, a short billed wide mouthed nocturnal insectivorous birds **undergo hibernation.**
- Arrangement and distribution of feather is called **pterylosis.**
- **Quills** (flight feathers) are large feathers. Feathers of wings are **remiges** and tail are **retrices**.
- Other types of feathers are **coverts** (cover the base of wing quills), **contours** (quill feather on general covering of body having poorly developed barbules), **filoplumes** (distributed among contour feather), **down feathers** (cover body of newly hatched bird or also occur beneath contours) and **bristles, powdery down feathers** etc.
- Filoplume and down feather **help in the insulation of the body**.
- Distinct **types of flight** seen in birds are **- flapping flight** (main type), **gliding** (skimming), **soaring** (sarling) and **hovering** (peculiar variant of flapping).
- **Humming birds** (Cuba), *Mellisuga helenae*, is the **smallest bird** (length 5.5 cm) which can **fly forward and backward in both direction**.
- **Ostrich** is the **largest living bird.**
- **Dodo** is a **flightless bird** (*eg.*, *Raphus solitarius*) of Mauritius which became extinct in 17th century.
- **Tallest Indian bird** is crane/saras (*Crus antigone*).
- **Bird with longest tail** (11m) is *Onagadoris*.
- **Highest bird flier** is *Cygnus cygnus*/Whooper Swan (27000 ft).
- **Deepest diver bird** is Emperor Penguin/ *Aptenodytes foresteri.*
- **Fastest swimming bird** is Gentoo Penguin/ *Pygoscelis papua.*
- **Largest bird nest** is of Bald Eagle/*Heliacetus leucocephalus.*
- **Poisonous bird** is *Pitohui dichrous* (hooded pitohui) of Papau New Guinea. It possesses toxins in its skin and feathers.
- **Hornbill** is **emblem of BNHS** (Bombay Natural History Society).
- **Most abundant bird** is house sparrow/*Passer domesticus*.
- **Slowest flying bird** is American Woocock/*Scolopax minor* (8 km/hr). **Largest flying bird** is *Albatross* (*Diomedea*) which is a marine bird.
- **Fastest bird** is the **swift.**
- **Different types of feet** are present in birds. These are **perching** (sparrow), **raptorial** (owl), **scratching** (fowl), **swimming** (duck), **running or cursorial** (ostrich), **climbing and clinging** (wood pecker), **wading** (jacana and heron).

Table : Types of beaks in birds

	Type	Example
1.	Seed eating	Sparrow
2.	Cutting	Crow
3.	Fruit	Parrot
4.	Insect eating	Hoopoe
5.	Fish eating	Kingfisher
6.	Flower probing	Humming bird
7.	Spatulate	Spoonbill
8.	Water and mud straining	Duck
9.	Tearing and piercing	Eagle and owl

Table : Important examples of birds

	Scientific name	Important notes
		Flying birds
1.	*Passer domesticus* [House sparrow]	Small bird, sexual dimorphism is distinct, breeding occurs almost throughout the year. Omnivorous but chiefly granivorous.
2.	*Corvus splendens* [Crow]	Omnivorous, adapt in stealing, intelligent, cunning and audacious. House crow acts as efficient municipal scavanger.
3.	*Psittacula krameri* [Parrot]	Commonly called rose - ringed parakeet. Can imitate human speech. Spread fatal chlamydial respiratory disease called **psittacosis**.
4.	*Columba livia* [Pigeon]	Gregarious, omnivorous, monogamous.
5.	*Pavo cristatus* [Peacock]	National bird of India. Polygamous, feed on reptiles, birds, insects etc.
6.	*Eudynamys scolopaceous* [Koel of Indian nightingale]	Nest parasite and lays its eggs in a crow's nest Sexual dimorphism is well marked.
7.	*Piocetus species* [Weaver bird]	Constructs retort shaped nests
		Flightless birds
8.	*Struthio camelus* [African ostrich]	• Shows discontinuous distribution. Have well developed powerful legs, small head, rudimentary eyes & wings. • Polygamous, largest living birds (height 2.5 m and weight 150 kg). • Fast runner 60 km/hr • Eggs are the largest • Easily domesticated
9.	*Rhea* [South American ostrich]	• Smaller than true ostrich (1.5m) • Rudimentary wings are better developed • Fond of bathing and able to swim • Used in the manufacture of feather clusters
10.	*Casuarius* [Cassowary]	• Occurs in Australia and New guinea • 3rd largest flightless bird • Nocturnal and frugivorous
11.	*Dromaeus* [Emu]	• Australia • 2nd largest living bird
12.	*Apteryx* [Kiwi]	• Smallest living (50 - 70cm) flightless terrestrial bird, possesses a keen sense of smell. Nocturnal and burrowing in habit. • National bird of NewZealand
13.	*Aptenodytes foresteri* [Penguin]	• Occur in flocks in Antarctica region and some islands of South Africa • Good swimmers and divers • Eggs are incubated by males with the help of loose fold of skin present in between the two legs.

Table : Bird sanctuaries

Name	Bird found
Sultanpur (Lake) Bird Sanctuary, Gurgaon, Haryana	Green pigeon, Saras crane, Spoonbill, Duck
Govind Sagar Bird Sanctuary, Bilaspur, Himachal Pradesh	Teal, Duck, Goose, Crane
Keoladeo Ghana Bird Sanctuary, Bharatpur, Rajasthan	Siberian crane, Storks, Herons, Cormorant, Egret
Chilka Lake Bird Sanctuary, Balagaon, Orissa	Flamingo, Pelican, Egret, Ibis, Sandpiper, Cormorant

MAMMALIA

- Mammals are **homoiothermal hairy quadrupleds with mammary glands** (modified sweat glands) in the female for suckling of young ones.
- Body distinctly divisible into **head, neck, trunk** and **tail.**
- Skin possess **sweat** and **sebaceous glands** (peculiar to mammal only) and sometimes scent glands in both the sexes.
- Skull is **dicondylic.** Vertebrae are **acoelous** or **amphiplatyon**.
- Cervical vertebrae are **seven in number** with variation of **6-9 in sloth (order edentata), sea cow and manatee (order sirenia)**.
- Teeth are **thecodont** (embedded in sockets), **heterodont** (four different types – incisors, canines, premolars and molars) and **diphyodont** (two sets- milk teeth and permanent teeth).
- **Respiratory and digestive tracts are separate** due to development of secondary palate.
- An epiglottis is present over the opening of **trachea or larynx.**
- Pleuric cavity is **coelomic.**
- Respiration is always by **lungs.**
- **Diaphragm is present** which separates the anterior thoracic cavity from the posterior abdominal cavity.
- Kidney is **metanephric** and excretion is **ureotelic.**
- Sinus venosus is **absent**.
- Urinary bladder is **present.**
- Heart is **4 chambered with double circulation**. Renal portal system is **absent**.
- Erythrocyte are **biconcave** and **enucleate**.
- Brain (with 4 optic lobe) is **highly evolved** with 12 pairs of cranial nerves. Senses are **well developed**.
- Optic lobes are converted into **corpora quadrigemina. Corpus callosum** connects the two cerebral hemispheres.
- External ear or pinna is **present.**
- Sexes are **separate**, with well marked **sexual dimorphism.**
- True placenta is **allanto-chorionic**.
- In males the **testes descend outside the body** in scrotal sacs.
- Fertilization is **internal**.
- Mammals are **viviparous** where the foetus is nourished by the mother through placenta.
- The eggs are **small** and **alecithal**.
- Mammals have **evolved from reptiles** like *Dimetrodon* in triassic.
- Class mammalia is **divisible into three subclasses- prototheria, metatheria** and **eutheria**. (*see flow chart*).
- **Metatheria** and **eutheria** are **collectively called theria**.
- **Prototheria** are **primitive mammals which lay eggs**.
- Platypus/*Echidna* is called the **living fossil of chordata or mammals.**
- **Duck Billed Platypus** is the **connecting link between classes reptilia and mammalia.**
- In Spiny Ant Eater, second claw of each hind limb is longer and curved which is used for cleaning spines and fur. Hence called **toilet claw**.
- Milk glands are functional in both sexes. In male the phenomenon is called **gynaecomastism**.
- In **metatheria (marsupials)**, **marsupial pouch is present** where the youngs are developed. They are often called as **pouched mammal**, e.g. Kangaroo.
- Marsupials are **viviparous**.
- Corpus callosum is **absent in marsupials**.
- In **eutheria**, placenta is large and intrauterine development is prolonged. They are known as **placental mammals**.
- Eutherians are also **viviparous.**
- **Corpus callosum** is **present in eutherians**.
- The period between fertilization and delivery is called **gestation period**.
- Gestation period is **shortest in opossums** (12-13 days) and the **longest in elephant** (609 days).

- Kangaroo is the **national animal of Australia**.
- **Flying Lemur** has a hairy fold of skin, called **patagium** which helps in gliding.
- Bats belonging to the order **chiroptera** avoid collision (during flying) by the help of **eco-apparatus** or **radar mechanism** present in them.
- **Tree shrew** is believed to be the **remote ancestor of apes/humans**.
- Female of Armadillo (*Dasypus novemeinctus*) **produces four to eight young ones of one sex** due to breaking of embryo. These are the **only living mammals that have bony plates in their skin**.
- **Indian Pangolin or scaly ant eate**r has small stones in its stomach (like gizzard of birds). It is therefore, also called '**bajra-kit**'.
- Rabbit is **crepuscular** (move out in twilight), **cursorial** (runner with leaps), **fossorial** (in burrows), **coprophagus** (eating its own faecal matter) and **polygamous**.
- Young ones of rabbit are **born naked**, **deaf** and **blind**.
- Mouse is **smaller than rat**.
- **Blue whale** has a **thick insulating layer of fat** or **blubber** occur below the skin.
- Upper jaw of whale bears a **whale bone** consisting of two rows of 600 - 800 plates.
- In the order **carnivora** (seal, bear, panda) large **canines** and **carnassial teeth** (first molars of lower jaw and last premolars of upper jaw) are present for torning flesh.
- **Dolphin** is a **highly intelligent aquatic mammal** which can imitate **human laughter**.
- **Hippopotamus** is the **second bulkiest land animal**, living most of the time in water, hence called **riverine horse**.
- The cells of camel can tolerate dehydration upto 40%. This helps the camel to function as **ship of desert** and remain without water for 10 -15 days.
- **Giraffe** is the **tallest mammal** (5.48 to 6.1 mts).
- **Fastest mammal** is **cheetah** (speed upto 100 km/hr).
- **Slowest terrestrial mammal** is 3-toed sloth/ *Bradypus tridactylous* (speed 100-150 mt/hr).
- **Slowest aquatic mammal** is *Enhydra lutris* (speed upto 10 km/hr).
- Rhino is **hunted for its horn**, the matted hair.
- **Antlers** (found in deer) are solid bony horns which shed and regrown every year.
- Tiger or *Panthera tigris* is **National animal of India.**
- **Primates**, evolved from tree shrew, are intelligent mammals with convoluted cerebral hemispheres, grasping hands, binocular vision etc.
- Two types of primates are **prosomians** (before monkey) and **simians** (monkeys).
- Prosomians included **lemur**, **loris** and **tarsiers** and simians include **monkey, apes** and **humans**.
- *Cebus capucinus*, *Ateles* or spider monkey are the **examples of New World Monkey** and they are found in Asia and Africa.
- **Old World Monkeys** are found in Central and South America. Examples – Rhesus monkey, langur or leaf monkey.
- **Human** with a language is the **most advanced of all animals**.
- **Locomotion in mammal** is– climbing **- scansorial**, flying **- volant**, running **- cursorial**, jumping - **saltatorial**.
- Stripes of no two zebra are **alike**.
- **Smallest mammal** is **Hog Nose Bat** (previously Pigmy water shrew was considered as smallest).
- **Blue whale** is the **largest living animal** with a length of upto 30 -50 mts and a weight of 135 - 209 metric tonnes.
- Dental formula of man is $i\frac{2}{2}, c\frac{1}{1}, pm\frac{2}{2}, m\frac{3}{3}$.
- Dental formula of rabbit is $i\frac{2}{1}, c\frac{0}{0}, pm\frac{3}{2}, m\frac{3}{3}$.
- **Sea lion** is a **large eared seal**.
- **Elephants** belonging to the order proboscidea are the **largest land animals** reaching a height of 3.0 to 3.45 mts and weight of 5 - 7 tonnes.
- **Apes** are man-like primates without tails. The only ape found in India is **Gibbon**.
- Feet of mammals are -
  - **Plantigrade :** Walking or running with whole sole of the foot touching the ground, e.g., bear, human being are plantigrade while walking but become digitigrade while running.
  - **Digitigrade :** Walking or running with only the digits touching the ground, e.g., rabbit, elephant.
  - **Unguligrade :** Running or walking on the tips of the digits. Heels raised above the ground level, e.g., cow, deer, horse etc.

Classification of mammals

Divided into

- **Prototheria** include only one order **Monotremata**
  - Egg laying mammals
  - Mammals with single opening or cloaca
  - Testes abdominal, vagina absent in females
  - E.g., Spiny ant eater (*Echidna* = *Tachyglossus*), Duck billed platypus (*Ornithorynchus*)
- **Theria** (wild animals)
  - Viviparous, both extinct and living
  - Digestive tract and urinogenital ducts open by separate aperture to the exterior
  - Their young develop in the uterus, extra abdominal testes, cloaca is usually absent

Infra classes

- **Metatheria** (Pouched mammals or marsupials)
  - Placenta is simple and small
  - Young ones are born prematurely
  - Corpus callosum is absent
  - The females have a pouch or marsupium for keeping and nourishing the young ones
  - Vagina and uterus are double (didelphic condition)
  - E.g., Kangaroo, Koala, Opossum
- **Eutheria** (Placental mammals with well developed placenta)
  - Cerebrum has corpus callosum
  - Teeth thecodont, diphyodont and heterodont,
  - Cloaca absent but anus is present

Order

- **Insectivora** E.g. Mole (*Talpa micura*) Musk shrew (*Crocidura murina*), shrew (*Sorex*), Hedgehog (*Erinaceus*)
- **Chiroptera** E.g., Small bat (*Scotophilus*), Large bat or flying fox (*Pteropus*), Vampire bat (*Desmodus*)
- **Dermoptera** E.g., Flying lemur (*Galeopithecus volans*)
- **Edentata** E.g., Armadillo (*Dasypus*), sloth (*Bradypus tridoctylus*)
- **Pholidota** E.g., Manis (*Pangolin*)
- **Rodentia** E.g., Rat (*Rattus*) Mouse (*Mus musculus*), *Funambulus* (squirrel), *Beaver* (Castor), Porcupine (*Hystrix indica*)
- **Lagomorpha** E.g., Rabbit (*Oryctolagus*), Hare (*Lepas*)
- **Cetacea** E.g., Whale Dolphin, Porpoise
- **Carnivora** E.g., Lion (*Panthera leo*), Tiger (*Panthera tigris*) etc.
- **Perissodactyla** E.g., Horse (*Equus*), African Zebra (*Equus zebra*), Tapirus (*Tapir*) etc.
- **Artiodactyla** E.g., Hippopotamus Spotted deer (*Cervus axis*), Camel (*Camelus*)
- **Sirenia** E.g., Dugong (*Halicore*), Rhytina Mantus (*Manatae*)
- **Proboscida** E.g., Elephant (*Elephas indicus*)
- **Primates** (Highly developed brain)

Table : Common name of some important mammals

Prototherians	
Echidna aculeata (*Tachyglossus*)	Spiny ant eater (milk gland functional in both sexes)
Ornithorhyncus anatinus	Duck billed Platypus. (only poisonous mammal)
Metatheria	
Macropus major	Kangaroo (National animal of Australia)
Didelphys	American opossum
Notoryctus	Marsupial mole
Phascolarctus	Koala (Arboreal)
Eutheria	
Erinaceus	Hedge hog
Talpa micrura	Mole (short tailed burrowing animal)
Crocidura murina	Shrew (water shrew is the smallest mammal)
Galaeopithecus	Flying lemur
Pteropus	Flying fox (large frugivorous bat)
Scotophilus	Small bat (young ones are born blind)
Desmodus	Vampire bat, blood sucking animals
Dasypus	Armadillo
Bradypus	Sloth (three toed sloth)
Manis crassicaudata	Indian Pangolian (scaly ant eater). Also called *Bajra kit*
Oryctolagus cuniculus	Rabbit (shows coprophagy)
Rattus rattus	Rat (spread plague)
Mus musculus	Mouse (smaller than rat)
Cavia procellus	Guinea pig
Funambulus palmarum	Squirrel
Balaenoptera musculus	Blue whale (largest animal or sulphur bottom whale)
Canis familiaris	Dog
Felis domestica	Cat
Panthera leo	Lion
Panthera tigris	Tiger
Acinonyx jubatus	Cheetah
Lutra	Otter
Herpestes	Mongoose (famous for its fight with the snakes.)
Ursus arctos	Bear
Phocaena	Porpoise (Syahi)
Orcinus	Killer whale
Hysterix indica	Porcupine
Delphinus	Common Dolphin
Platanista	Ganges Dolphin
Physeter	Sperm whale
Rhytina	Sea cow
Trichechus	Manatee
Loxodonta africana	African elephant
Elephas maximus	Indian or Asiatic elephant
Elephas cyclotis	Pigmy African elephant
Ateles paniscus	Spider monkey
Macaca mulatta	Rhesus monkey
Alouta	Howler monkey
Macaca silenus	Lion - tailed macaque
Hylobates hoolock	Gibbon (smallest ape)
Papio	Baboon
Presbytis	Langur
Pongo	Orangutan
Pan	Chimpanazee (most intelligent of the apes, found in Africa, can be tamed and trained)
Gorilla gorilla	Gorilla (largest ape, height 2.0 mts and weight 250 kg)
Equus caballus	Horse
Equus asinus	Ass
Equus zebra	Zebra
Rhinoceros unicornis	Indian rhinoceros
Diceros bicornis	African rhinoceros
Taprius indicus	Malyan Tapir
Hippopotamus amphibius	Hippopotamus
Cervus	Arabian camel
Giraffa cameloparadalis	Giraffe
Odobenus	Walrus

End of the Chapter

Chapter 16

Tools and Techniques in Cytology

- For the advancement of researches in science and to increase our knowledge about minute things, various tools and techniques have been used by the workers.
- **Tools** for cell study are devices and instruments called microscopes.
- **Techniques** are skills required to aid study of cells and their components.
- They are histological preparations, cyto-chemistry, autoradiography, cell fractionation, biochemical techniques and tissue culture.
- Modern techniques and analytical instruments are used to understand the various structural and functional organization of living beings.

MICROSCOPE

- First of all Leeuwenhoek (1683) used hand lenses to study a thin slice of bottle cork.
- Leeuwenhoek is often **called the father of microscopy**.
- **Robert Hooke** in the 18th century **used a compound microscope**.
- Later on various improvements have been done in microscopy.
- The **microscope** is the **first powerful tool** used in the biological studies for magnifying minute objects.
- The **most common microscope**, a basic tool of cell biologists, is the **bright field light microscope** or **compound microscope**.
- A microscope **has both magnification** and **resolution power**.
- **Magnifying power** is the ratio of magnified image of a microscope to that formed in the retina of an unaided eye.
- Magnifying power is represented by the following equation:

$$\text{Magnification} = \frac{\text{Size of retinal image with the instrument}}{\text{Size of retinal image with unaided normal eye}}$$

- Since most **cells are between 1 and 10 μm in diameter**, they can be **observed by light microscopy** and it allows the observation of some of the larger subcellular organelles, such as nuclei, chloroplasts and mitochondria.
- The **resolution or resolving power** is the ability of an optical system to separate details of two closely placed objects.
- The **resolution power** of the unaided **human eye** is **0.1 mm** (100 μm or 1 micron $= \frac{1}{1000}$ mm) and that of the **light microscope** is **200 nm**.
- The **resolving power of microscope depends upon the wavelength of illuminating agent** (λ) and **light gathering capacity of objective lens**, called numerical aperture (NA). It represents width of cone of illumination. The **greater the numerical aperture** the **greater the resolution power**.
- The **limit of resolution** (l) of any optical instrument (*i.e.* eye or microscope) is **given approximately by the Abbe's relationship**.

$$\text{Resolution } (l) = \frac{\text{wavelength } (\lambda)}{\text{numerical aperture } (n \sin\alpha)}$$

where,

- λ (lambda) is the wavelength ("colour") of the illumination or radiation used to form the image,
- n is refractive index (a function of density) of the material (*i.e.*, mostly air or water) between the specimen and the first lens (or objective lens), and
- sin α is sine of the semi-angle of aperture of the first lens as viewed from the specimen.

- The quantity "$n \sin\alpha$" is often called the **numerical aperture (NA).**

Compound or Light microscope

- Compound or light microscope was **invented by Z. Janseen**.
- It is the simplest, widely used microscope having three parts – condenser, objective lens and occular (eye) lens.
- In this microscope an object can be magnified upto 1000 times and the magnification is independent of intensity of light, size of microscope and numerical aperture.
- In this microscope sharp images are produced only if the material is properly fixed and stained.

Phase contrast microscope

- It was **invented by Zermicke** in 1935 and was awarded Nobel Prize in 1953 for this work.
- The microscope has a phase plate and an annular diaphragm.
- They bring about changes in the light rays passing through the specimen producing differences in light intensity.
- Denser parts alters path of light more than the thinner parts.
- This produces varying contrast for different regions.
- **Phase contrast microscopy** enhances the contrast between cells and their environments and between internal organelles and their surroundings.
- Phase contrast microscope is **commonly used** –
  - For observing living or unstained cells.
  - In the observation of cells cultured *in vitro*
  - To study the effect of different chemical and physical agents on the living cells and to examine the artifacts introduced by different methods of fixation and staining.
- Phase contrast microscope **enables one to see mitochondria, mitotic chromosomes, nucleoli and other organelles quite clearly in living cells**.

Differential interference contrast microscope

- It is **also used for study of living structures**.
- Here light is split into beams by prisms, one passing through the object and the other along the object. The first beam of light undergoes phase change or diffraction. The second does not undergo any change. The two beams come together over the object. This gives bright contrast.
- Colour contrast is also produced by light passing through prisms.
- Interference microscope gives better images of living structures.
- The interference microscope, like phase contrast microscope, depends for its functioning on changes in the speed of light as it passes through different materials.
- It also allows deciphering of thickness and determination of several light absorbing chemicals like nucleic acids, proteins, lipids, etc.

Fluorescent microscope

- It is a modification of ultraviolet microscope which was made by **Coons** (1945).
- This instrument **used long wave ultraviolet rays for illumination**.
- It has complementary filters which allow the viewers to observe directly with the eyes.
- The microscope is **useful in detecting those components which show autofluorescence** (e.g., chlorophylls, collagen fibrils, vitamin A).
- Others can be made fluorescent by coating with fluorochrome dyes (like acridine orange and coriphosphine) and minerals, e.g., proteins, lipids, starch, glycogen, etc.
- The light emitted by them is red, orange, yellow or green against dark field.
- It is called secondary fluorescence.
- The technique **is used in diagnosis of viruses, bacteria and protozoa**.
- Immunofluorescent antibody labelling technique is used in diagnosis of specific molecules like antigens and antibodies.
- It involves conjugating specific fluorochromes with specific antibodies.

Darkfield microscope

- Ultramicroscopy (or **dark field microscopy**) is discovered by **Zsigmondy**, 1905.
- Ultramicroscopy is a simple modification of ordinary microscope, where the condenser illuminates the object obliquely so that the object appears bright and background dark. **It helps in detecting objects smaller than those seen with the light microscope**.

Electron microscope

- **M.Knoll and E.Ruska**, two german scientists, invented the electron microscope in 1932.
- It is a large sized instrument which has an internal vacuum, high voltage (50, 000 - 1, 00, 000 volts),

a cooling system, a fast beam of electrons (0.54Å wavelength), a cathode filament of tungsten, electromagnetic lenses (each having a coil of wire enclosed in soft iron casing) for focussing magnification and projection and a fluorescent screen or photographic plate for observation.

- Wavelength of electron beam is 10,000 times shorter than wavelength of visible light. As a result **resolving power of electron microscope is very high**.
- A high vacuum is required because electrons are very small particles as compared to even the smallest atoms (1.06Å for hydrogenation).
- For the same reason the specimen to be studied must be ultra thin, completely dehydrated and treated with chemicals and dyes to enhance contrast.
- Images obtained in electron microscope have usually black grey and white shades. Computer is used to enhance contrast and develop colour.
- Electron microscope **has a very high resolution power and magnification**. It has helped discover a number of small cell organelles (*e.g.*, E.R., ribosomes, centrioles, microtubules, microfilaments, intermediate filaments, plasmodesmata, microbodies).
- **Detailed structure of larger cell organelles** could be known only **with the help of electron microscope**, *e.g.*, chloroplast (thylakoids, grana, DNA, ribosomes), mitochondrion (membranes, elementary particles, DNA, ribosomes), Golgi apparatus (vesicles, cisternae).
- Electron microscope is of **two types** – **transmission** and **scanning electron microscopes**.

Transmission electron microscope

- An ultra thin section is first dehydrated and then impregnated with electron opaque chemicals like lead acetate, phosphotungstate, uranium, palladium or gold.
- The coating is essential for providing contrast and helping the material to withstand electron bombardment.
- The section is now placed over a copper grid in specimen chamber. A beam of electrons is passed through it by means of electromagnetic condenser.
- The electron beam coming out of the section is then spread and projected over a fluorescent screen or photographic plate by electromagnetic lenses.
- Magnification is 1-3 lakh.
- Resolving power is 2 - 10Å.
- TEM is the **most commonly used electron microscope** which **provide two dimensional image**. This is **built by Ruska** and his colleagues.
- Study of viruses, mycoplasma and other small entities could also be made possible with the advent of electron microscope.
- **Advantage** – High resolution (0.5 nm in practice).
- **Disadvantages** are –
  - The specimen must be dead because it is viewed in a vaccum.
  - It is difficult to be sure that the specimen resembles a living cell in all its details because preservation and staining may change or damage the structure.
  - Expensive to buy and run.
  - Preparation of material is time consuming and requires expert training.
  - The specimens gradually deteriorates in the electron beam. Photographs must therefore be taken if further study is required.

Scanning electron microscope

- It is **used for obtaining 3-dimensional and surface images**. The microscope was **invented by Knoll (1935)**.
- The specimen to be studied is first super cooled (in liquid propane at –180°C) and then dehydrated in alcohol (at –70°C).
- It is then coated with gold, platinum or some other metal for creating a reflecting surface for electrons.
- The surface is scanned by a narrow beam of electrons (upto 200Å in diameter).
- The secondary electrons emitted by the surface of specimen are collected by a positively charged grid and then passed over to a fluorescent screen or photographic plate through a television tube.
- Magnification of SEM varies from 15 - 2,00,000. Resolution power is 5 - 20 nm.
- **Advantages** are –
  - Surfaces of structure are shown.
  - Great depth of field, meaning that a large part of the specimen is in focus at the same time. This gives a very striking three dimensional effect.
- **Disadvantage** – Resolution (5-20nm) is not as great as with a TEM (0.5 nm).

Other high powered microscopes

- **Scanning probe microscope :** The microscope is capable of resolving the outer texture of the material to the minutest detail since it has the potential to image even a single atom. Magnification is upto 100 million.
- **Scanning tunnelling microscope :** It has a tiny tungsten probe for moving over the surface of specimen. The microscope is **used to detect defect in electrical conductors and computer chips**.
- **Atomic force microscope :** It has an extremely fine diamond probe for moving over the surface of biochemicals. Oscillations produced in the probe are changed into images by a computer. The microscope is useful in viewing detailed structure of biological molecules, e.g., DNA, proteins.

X-RAY CRYSTALLOGRAPHY

- **X-ray crystallography** (X-ray diffraction; Bragg, 1913) is an important technique in molecular biology to analyze the structure and orientation of molecules, distance between molecules and their atomic organization. It is **based on the diffraction of radiations when they counter small obstacles**.
- The molecular structure of DNA was based on X-ray diffraction study by **Wilkins, Astbury and Franklin** (1953) for which **Wilkins shared Nobel Prize of 1962 with Watson and Crick**.
- **Myoglobin** was the **first protein whose structure was determined by X-ray diffraction**.
- **Polarization microscopy** is **useful mainly for viewing highly ordered objects such as crystals or bundles of parallel filaments**.
- The **mitotic spindle**, made up of microtubules cannot be resolved by light microscope, but **can be studied with polarizing microscope**.
- Ultraviolet microscope **uses the UV-rays of shorter wavelengths** (1500–3500 Å).
- The ultraviolet microscope is **useful in the qualitative** and in some cases **quantitative determination of nucleoproteins**.

CELL FRACTIONATION

- **Cell fractionation** is a technique by which a tissue/ cell is disrupted by mechanical/chemical/ enzymatic methods to release the cell components (organelles and macromolecules) followed by their separation by differential centrifugation according to physical properties like mass, specific gravity, surface tension etc.
- Cell fractionation is a **two stage process– homogenization** and **differential centrifugation**.
- In **homogenization** cells are disrupted/ disintegrated/ broken mechanically by applying pressure in potter homogenizer or by grinding or by insonation (ultrasonic vibrations by sonifier).
- Usually **0.25 M to 0.8 M sucrose solution is used** in which the released cell components do not change their properties as well as preserve the cell organelles and prevent their clumping.
- **Differential centrifugation** is the mechanical separation of individual subcellular components from the homogenate by centrifugation at different speeds.
- **Density gradient centrifugation** is used for the separation of macromolecules like virus particles, nucleic acids.
- **Classical cell fractionation technique may be summarized as follows –**

Homogenate in 0.25 sucrose solution
or cesium chloride solution

1st centrifugation ↓ 700 × g for 10 min

Supernatant-I + Sediment-I
■ Nuclei

2nd centrifugation ↓ 5000 × g for 10 min

Supernatant-II + Sediment-II

↓ ■ Mitochondria

Redispensed

3rd centrifugation ↓ 24, 000 × g for 10 min

Supernatant-IIa + Sediment-IIa
■ Mitochondria and lysosomes

4th centrifugation ↓ 54,000 × g for 10 min

Supernatant-III + Sediment-III
■ Microsome, *i.e.*, broken, ER, ribosomes,Golgi bodies, etc.

5th centrifugation ↓ 1,00,000 × g for 10 hrs

Supernatant-IV + Sediment-IV
■ Soluble enzymes and N. acids
■ Ribosomes

- The cellular extract is **mixed with cesium chloride** on concentrated solution of sucrose and centrifuged at 100000 rpm for 20 hours. The chemicals come to settle in the density gradient according to the density of their molecules.
- **Meselson and Stahl** (1958) proved the semi-conservative nature of DNA replication in prokaryotes by using density gradient centrifugation.
- **Svedberg unit** is a unit of measurement of sedimentation rate or sedimentation coefficient of a particle in an analytical ultracentrifuge.

ELECTROPHORESIS

- Electrophoresis is a technique in which particles of different sizes and charges are separated due to their movement to different distances under the influence of an electric field, e.g., nucleic acids, proteins, amino acids, nucleotides, etc.
- This technique was **developed by Reuss** and **modified by Tiselius** (1937).
- A base material is used for the passage of molecules of the mobile phase. For smaller amount of substances, a supporting media such as polyacrylamide gel, agarose gel or starch gel is used.
- In PAGE (polyacrylamide gel electrophoresis) the base material is polyacrylamide or polymer of acrylamide and methylene bisacrylamide.
- In **agarose gel electrophoresis**, the base material is agarose. The base material dip in solution having cathode at one end and anode at the other end.
- As the electric current is switched on, the chemicals of the mixture separate and pass to different distances. The **gel functions as a sieve**.
- In **two dimensional electrophoresis**, molecules are separated in two directions at right angle to each other with denaturing conditions in one direction and nondenaturing conditions in other direction.
- In **immunoelectrophoresis** antibodies coupled with radioisotopes, specific enzymes or fluorescent dyes are used in detection of particular proteins.
- This **technique is highly sensitive**. It can separate molecules in picogram and nanogram quantities and distinguish proteins which differ from each other in only one amino acid.

AUTORADIOGRAPHY

- Autoradiography is a photographic technique using radioactive isotopes (tracer precursor intermediates) emitting radiations for studying the functions of
  - The cell synthesis of biomolecules,
  - Locating a particular chemical constituent,
  - Tracing the metabolic pathways or events inside the living cells.
  - Tritiated (^3H) and carbon labelled (^{14}C) compounds of thymidine, uridine and aminoacids (leucins) are used to study synthesis of DNA, RNA and proteins respectively.
- The radiation reduces the silver salt of the photographic emulsion to produce metallic silver grains that form the image. The patterns of distribution of silver grains represent the sites where radioisotopes is present in the sample. This technique was used by Calvin and his coworkers for studying the path of labelled carbon in photosynthesis and led to the establishment of Calvin cycle.
- **Radioactive isotopes** are unstable isotopes which emit positively or negatively charged particles. eg ^{14}C (C-14), ^3H (H-3), ^{131}I (I-131), ^{32}p (p-32).
- **Reasons for their importance in biological studies** are –
  - It can be incorporated into any biological molecule.
  - It has very long half life.
- The radioactivity of these isotopes can be recorded by beiger counter or scintillation counter or autoradiography.

CHROMATOGRAPHY

- Chromatography is a technique of separating molecular components of a mixture of a mobile phase by **using the principle of partition coefficient** due to which different molecules move at different rates through a stationary phase and get separated.
- Chromatography is of several types –
  - **Adsorption or column chromatography :** The stationary phase consists of a column of charcoal, silica, alumina, calcium carbonate or magnesium oxide. The solution is made to percolate through this column when different chemicals get absorbed at various levels. The technique is **useful for separation of tissue lipids**.
  - It is the **first type of chromatography** that was **developed** by **Mikhail T. Swett (1906)**.

– **Thin layer chromatography :** The stationary phase consists of a thin plate of cellulose powder or alumina. As a few drops of mixture are poured over it, the different chemicals spread to different distances. The method is **useful in separation of amino acids, nucleotides and other low molecular weight products**.
– **Paper chromatography :** A paste of mixture is applied near one end of a chromatographic paper (or Whatman 1). The lower end below the paste is dipped in a solvent. As the solvent rises in chromatographic paper, the different chemicals of the mixture spread to different distances. The paper can be rotated to obtain two dimensional chromatogram.
– **Ion exchange chromatography :** Beads of cellulose and other materials having negative and positive charges are placed in a column. The mixture (of mobile phase) is poured over the column. As the mixture passes through the column, its constituents separate according to their charges. The technique is **used in purification of insulin, plasma fractionation and separation of proteins**.
– **Gel fractionation chromatography (molecular sieve chromatography) :** Dextran gel sephadex is available with various pore size. A mixture is poured over a column of sephadex. The various chemicals pass through the pores and come out of the column with heavier larger molecules do so first followed by progressively smaller sized molecules provided the pores are larger than the size of largest molecules. The technique is **used in determining the molecular weight of proteins by calibrating the column with proteins of different molecular weights**.
– **Affinity chromatography :** Stationary phase consists of column of ligands (molecules that bind to other specific molecules at particular sites). Mixture is allowed to pass through the column. Chemical linkages are establised between ligands and their specific chemicals. Others pass out of the column. The technique is **used in separation of enzymes, immunoglobulins, mRNA etc**.

SPECTROPHOTOMETRY

- **Spectrophotometry** is the quantitative study of electromagnetic spectra.
- Spectrophotometry involves the use of a **spectophotometer**.
- A **spectrophotometer** is a photometer (a device for measuring light intensity) that can measure intensity as a function of the colour, or more specifically, the wavelength of light.
- There are many kinds of spectrophotometers. Among the most important distinctions used to classify them are the wavelengths they work with, the measurement techniques they use, how they acquire a spectrum, and the sources of intensity variation they are designed to measure.
- Other important features of spectrophotometers include the spectral bandwidth and linear range.
- Perhaps the **most common application of spectrophotometers is the measurement of light absorption**, but **they can be designed to measure diffuse or specular reflectance**.
- Strictly, even the emission half of a luminescence instrument is a kind of spectrophotometer.
- There are **two major classes of spectrophotometers– single beam** and **double beam**.
- A double beam spectrophotometer **measures the ratio of the light intensity on two different light paths**, and a single beam spectrophotometer **measures the absolute light intensity**.

SECTIONING

- For the microscopic studies of biological materials it is essential to cut thin sections of these materials.
- It can be done either by hand sectioning with the help of razor or by section cutting machines called microtomes.
- **Microtome** is an instrument used to cut thin sections (5 to 10 µm *i.e.*, 5,000 to 10,000 nm) of fixed material for microscopic studies.
- **Ultramicrotome** has glass or diamond knife to cut ultra thin sections of 0.01 to 0.05 µm thickness (= 10nm to 50 nm) required in electron microscopy and X-ray microscopy.
- Freezing microtome uses both living and fixed materials.
- Microtome was **invented by W. His**. In electron microscope thin sections of 20 – 100 nm are required. For this ultramicrotome and glass knife of diamond are used.

Table : Dyes used to stain various cell components

	Stain	Used for staining	Final colour
1.	Acetocarmine	Chromosomes	Pink
2.	Acid fuschsine	Cortex, cellulose walls, pith parenchym, mitochondria	Magenta
3.	Aniline blue (Cotton blue)	Fungal hyphae and cellulose cell walls	Blue
4.	Basic fuschsine	Nucleus, mucin and bacteria	Magenta red
5.	Crystal violet	Nuclei and chromosomes	Violet
6.	Eosin	Cytoplasm	Pink
7.	Feulgen's stain	DNA	Purple or red
8.	Hematoxyline	Nuclei, cell wall and cellulose	Violet
9.	Iodine solution	Starch Cellulose proteins, insulin deposits Pectin, cutin, callose	Blue Brown Yellow (in section of fresh material)
10.	Janus green B	Fungi and mitochondria	Green
11.	Methylene blue	Yeast and Golgi complex	Blue
12.	Phloroglucinol + HCl	Lignin	Bright red
13.	Ruthenium red	Pectin	Red
14.	Safranin	Nuclei, lignified tissues	Red
15.	Sudan-III or IV	Suberin, cutin, oil	Scallet red
16.	Sudan black	Fatty sustance	Black
17.	Toludine blue	RNA	Blue
18.	PAS (Periodic acid schiff)	Plants cells for starch cellulose, hemicelluloses and pectins and on animal cells for mucin, mucoproteins etc	Red / Purple Blue
19.	Malachite green	Cell walls, endodermis, cytoplasm, chloroplast, nuclei	Emerald green

CYTOCHEMISTRY

- **Cytochemistry** is a technique used for the localization and identification of different chemicals in the cells.
- Most of the cell components are transparent, so to make these components visible, different dyes are used to stain them.
- The cellular components take up these dyes according to their chemical nature.
- Out of these stains, some stains can be used for staining living materials as they are non-toxic, such stains are called vital stains. e.g., methylene blue, neutral red, janus green, malachite green, etc.

TISSUE CULTURE

- **Tissue culture** (*in vitro* culture) is a technique of culturing mature living somatic nucleated cells in natural or synthetic medium under aseptic conditions.
- Tissue culture was developed by **Harrison** (1970) who successfully cultured small pieces of frog's embryonic spinal cord, but the **concept of tissue culture was conceived** by **Haberlandt** (1902), when he thought of growing isolated mesophyll cells of a leaf in aseptic culture for propagation of the whole plant.
- **White** (1932) was the **first to raise a tissue culture**.
- **White** (USA) and **Gantheret and Nobecourt** of France in 1939 **raised callus** (an undifferentiated unorganized actively dividing mass of cells.

End of the Chapter

Chapter 17

Cell as a Unit of Life

- **Cell** is the **fundamental structural unit** of all living organisms and is sometimes called the 'building block of life'.
- The cell **consists primarily** of an outer **plasma membrane**, which separates it from the environment; the **genetic material** (DNA) which encodes heritable information for the maintenance of life; and the **cytoplasm**, a heterogeneous assemblage of ions, molecules, and fluid.
- Cells are the **smallest structures** capable of basic life processes, such as taking in nutrients, expelling waste, and reproduce new cells that perpetuate life.
- All living things are composed of cells.
- Some microscopic organisms, such as bacteria and protozoa, are **unicellular**, meaning they consist of a single cell. Plants, animals, and fungi are **multicellular**; *that is*, they are composed of a great many cells working in concert.
- Cells require energy for a variety of functions, including moving, building up and breaking down molecules, and transporting substances across the plasma membrane. Nutrients contains energy, but cells must convert the energy locked in nutrients to another form - specifically, the ATP molecule, the cell's energy battery- before it is useful.
- **Word cell is derived from** the Latin word '*cellula*' which means small component.
- The **first observations of cells** were **made in 1665** by English scientist **Robert Hooke** in a thin piece of bottle cork. He **actually observed only cell walls**.
- Noting the rows of tiny boxes that made up the dead wood's tissue, Hooke coined the term **cell** because the boxes reminded him of the small cells occupied by monks in a monastery. While Hooke was the first to observe and describe cells, he did not comprehend their significance.
- **Robert Hooke** wrote his findings in a book titled "**Micrographia**".
- At about the same time, the Dutch maker of microscopes **Anton van Leeuwenhoek** pioneered the invention of one of the best microscopes of the time.
- Cells may have **come from stable bubbles** called **protobionts** which can maintain internal chemical environments that differ from their surroundings.
- In the 1920s, the Russian scientist **Alexander Oparin** formed unique bubbles by mixing a large protein and a polysaccharide in solution and agitating the mixture whose interiors had concentrations of the macromolecules that were higher than those of their surroundings.
- These experiments suggest a **bubble theory for the origin of cells**.
- The **term cytology** was **coined by Hertwig (1893)**.
- **Cell biology** or **cytology** is the study of all aspects of cells and their components including their structure, biochemistry, development and physiology. The study of cell biology is the basis for studying all life, whether single-celled or multicellular.
- The invention of the microscope and its improvement leading to the **electron microscope revealed all the structural details of the cells**.
- The **most common microscope**, a basic tool of cell biologists, is the **bright field light microscope or compound microscope**.
- The **simple microscope** was **invented by Galileo** (1618) and first microscope was made by **Robert Hooke.**
- The microscope has both magnification & resolution power.
- **Magnification** is the power of enlargement, which can be calculated by multiplying the power of eye piece lens by the power of objective lens.

- **Resolution power** is the ability to distinguish neighbouring point/object as distinct and separate entities.
- **Resolving power** of microscope **depends upon the wavelength of illuminating agent** and **light gathering capacity of objective lens**, called **numerical aperture.**
- Resolution power of **unaided human eye**, **compound microscope**, **light microscope** and **electron microscope** is **0.1 mm** (100 μm or 1 micron $= \frac{1}{1000}$ mm), **0.25 - 0.30 μm**, **200 nm** and **10Å** respectively.
- Cell were also **observed prior to Hooke**, **by** –
  1. **Jan Swammerdam (1658)** saw red blood cell of frog.
  2. **Malpighi (1661)** - Examined thin slices of plants and animals tissues and **called them 'utricle' and 'saccule'**.
- **Leeuwenhoek (1672)** was **first to see free cells** as bacteria (in tartar of teeth), protozoa, red blood cells and sperm swimming in semen etc.
- **Dutrochet (1824)** concluded that plants and animals were made up of **globular cells** of extreme smallness and these cells are held together by **cohesion**.
- Working together, German botanist **Matthias Jakob Schleiden** and German zoologist **Theodor Schwann** recognized the fundamental similarities between plant and animal cell.
- In 1939, **Schleiden and Schwann** formulated the **cell theory**.
- Schleiden worked on **plant cell** and Schwann worked on **animal cells.**
- **Cell theory** states that –
  – Living beings are made up of cells and their products. Depending upon the number of cells, a living being is **unicellular, colonial or multicellular**.
  – A cell is a mass of protoplasm having a **nucleus** (some organisms are multinucleated. Multinucleated condition in plants in called **coenocyte,** eg., *Volvox* and in animals is called **syncytium,** eg. epidermis of *Ascaris*.
  – Cells have **similar structure** and **metabolism**.
  – The functions of an organism are due to **activities and interaction of its cells**.
- **Objections to cell theory** are -
  – Viruses **don't have cellular structure**.
  – Monerans and protistans are **acellular**.
  – Certain organisms are multinucleate.
  – A typical nucleus is **absent in prokaryotic cell**.
  – Connective tissue have a lot of non-living material as compared to living matter.
  – Certain cells lose their nuclei in the mature state. (RBC and sieve tube cells)
- Cell theory was further modified by **Virchow (1855, 1858)** that **cells develop from pre-existing cells** - *Omnis cellula - e - cellula*. It is known as **law of cell lineage**.
- Modern cell theory is known as **cell principle** or **cell doctrine**.
- **Cell doctrine** states that –
  – Cells are the morphological and physiological units of all living organisms.
  – The properties of a given organism depend on those of its individual cells.
  – Cells originate only from other cells and continuity is maintained through the genetic material.
  – The **smallest unit of life** is the **cell**.
- **Protoplasmic theory** was proposed by **Max Schultze (1861)**.
- **Protoplasmic theory** states that living matter of an organism is protoplasm and the cell is simply an accumulation of protoplasm limited by an outer membrane and containing a nucleus.
- **Corti (1772)** was the first who observed **protoplasm** in cell which is named as **sarcode** by **Dujardin (1836)**.
- **Hugo Von Mohl (1844)** gave the significance of protoplasm.
- The term **protoplasm** was coined by **Purkinje (1939)**.
- Protoplasm is known as **physical basis of life (Huxley)** and divided into **nucleoplasm** (protoplasm of the nucleus) and **cytoplasm** (extranuclear protoplasm).
- Theories about the **physical structure of protoplasm** are granular theory, fibrillar theory, reticular theory, alveolar theory, crystallo-colloidal theory.
- **Granular theory** was propounded by **Altman**. It states that granules are embedded in a fluid.

- **Reticular theory** was proposed by **Fromann (1885)**. It states that reticulum of fibres are embedded in a fluid.
- **Fibrillar theory** was proposed by **Velton (1873 - 75), Flemming (1882)**. It states that fibrils are dispersed in a liquid.
- **Alveolar theory** was proposed by **Butchili (1878)**. It states that droplets or alveoli are embedded in liquid.
- Crystallo-colloidal theory **was proposed by** Fischer (1894)**. It states that substances dissolved and dispersed in water forming both true solution as well as colloidal solution**. It is the most accepted theory**.**
- **Physical properties of protoplasm** are –
  - Protoplasm is a complex, granular, elastic, viscous and colourless substance.
  - Protoplasm is selectively or differentially permeable.
  - Cyclosis or streaming movements are shown by protoplasm.
  - Protoplasm is considered to be a '**polyphasic colloidal system**'.
  - Fischer (1894) and Hardy (1899) showed its colloidal nature.
  - The **chief component** of protoplasm is **water**. Water, the main inorganic substances, varies from 5% to 90% in different tissues, with an average of 65% to 75%.
  - Various soluble substances such as glucose, minerals etc, remain dissolved in water and form a true solution or crystalloid.
  - In this solution various larger insoluble organic compounds such as fatty acids, proteins and some carbohydrates are suspended in the form of colloidal particles such as protein and lipids etc., constitute dispersed phase.
  - Some emulsions or suspensoids are also present and hence protoplasm is a complex colloidal system of many places.
- The **exact chemical composition of protoplasm cannot be determined** as it undergoes continuous changes and its composition is not, therefore, constant.
- Maximum water content in protoplasm is found in hydrophytes, *ie*., 95%, whereas minimum in seeds, spores (dormant organs), *ie*., 10-15%.
- In animals, water is less (about 65%) and proteins are more (about 15%).
- In plants, pH of protoplasm varies not only in different cells but from time to time in the same cell.
- Although plant protoplasm is less known and generally pH is on acidic side, but different vital activities occur at neutral pH which is considered as 7.
- In animals, nucleus is slightly alkaline (7.5 – 7.6 pH) whereas cytoplasm is slightly acidic (6.7 – 6.9 pH).
- Injury decreases the pH of the cell (*i.e*., 5.2 – 5.5) and if it remains for a long time, the cell dies.
- **Sachs (1874)** proposed **organismal theory**.
- **Organismal theory** states that whole organism functions as a single entity which is made of a continuous mass of protoplasm incompletely divided into cells.
- Cell are **autonomous or self-contained unit** because -
  - they **obtain or manufacture** food.
  - they **require energy** for overcoming entropy, performing body activities and biosynthesis, for this they oxidise food materials in respiration
  - cells convert **non-living material into** components of **living protoplasm**
  - worn out parts are **replaced by new ones**.
  - there is **exchange of gases**
  - cells discard waste materials
  - they are able **to regulate their activities** through flow of energy and information
  - cells maintain their **own internal physio-chemical environment**
  - they may **divide and form daughter** cells with same heredity as that of parent cell
  - there is a **definite life span**.
- **Cells of unicellular organisms** lead independent existence with no dependence on others for any function, material or information.
- **Cells of multicellular organisms** possess autonomy but shows various interactions and specialities for performing different functions.
- Multicellular organisms have 3 types of cells regarding their capacity to divide and differentiate - **undifferentiated, differentiated & dedifferentiated**.
- **Undifferentiated cells** are the meristematic cells which possess the power of division, e.g. apical meristem.

- **Differentiated cells** are post-mitotic specialised cells with a distinct structure and function, e.g. RBC.
- **Dedifferentiated cells** are specialised cells that revert to function of division for wound healing, regeneration, secondary growth etc.
- **Multicellularity is more advantageous than unicellularity** because
  – it **increases survival** and it **induces specialization**,
  – it **ensures uninterrupted activity**,
  – it **provides division of labour**,
  – outer cells **become specialised** to protect the internal cells,
  – internal cells **develop their own environment**,
  – keeps the cells small except where they take part in conduction and support,
  – death of a few cells or reproduction does not kill the organism. Rather some dead cells are functionally important, e.g. tracheids of xylem.
  – differentiated cells may take over the function of division through the process of dedifferentiation, e.g. plant cells.
- **Cellular totipotency** is the ability of a living cell to develop into a complete organism.
- Cellular totipotency was **first suggested by Haberlandt (1902)**, and also **regarded as the Father of tissue culture**.
- **Steward (1957) first provided the evidence** of cellular totipotency.
- Steward and his co-workers demonstrated that in carrots the callus (unorganised group of cells) raised from immature embryos is able to differentiated embryoids identical to the zygotic embryo of this plant.
- **Anita Guha** and **S.C. Maheshwari** (1966) reported that in the anther cultures of *Datura* numerous embryoids developed that had come from haploid pollen grains.
- **Somatic nucleated cells** are totipotent or able to produce a complete organism.
- **Flow of information** in cell is required for performing specific functions at particular times.
- Information is of **two types** - **intrinsic (internal)** (or **genetic**) and **extrinsic (external)** through nerves and hormones.
- DNA is the master molecule which contains **genetic information** for synthesis of proteins.
- The process of RNA formation from DNA template is known as **transcription** and synthesis coded in *m*RNA is called **translation.**
- All physical and chemical changes tend to proceed in such a direction that useful energy undergoes irreversible degradation into random form called **entropy**.
- The energy which can work at constant temperature and pressure is called **free energy.**
- Energy flows through the plant and animal kingdom. Green plants utilize the solar energy and animal feed upon plants to use that energy.
- Living cells capture, store and transport energy in a chemical form which is called **adenosine triphosphate (ATP).**
- Every living cell of an organism keeps its chemical composition steady, such balancing condition is called **homoeostasis.**
- **Bioluminescence** is the production of light by living organisms.
- **Bioenergetics** is the field of biochemistry concerned with the transformation and use of energy by living cells.

COMPARTMENTALIZATION AND TYPES OF CELLS

- Living organisms can be classified into one of two major categories **based on the location within the cell where the most genetic material is stored.**
- Cells are of two types - **prokaryotic and eukaryotic**.
- The term prokaryote comes from Greek words that mean "**before nucleus**" or "prenucleus," while eukaryote means "**true nucleus.**"
- Eukaryotic cells may have evolved from primitive prokaryotes about 2 billion years ago.
- Prokaryotic cells are among the tiniest of all cells, ranging in size from 0.0001 to 0.003 mm (0.000004 to 0.0001 in) in diameter.
- A **prokaryotic cell** has one envelope system with no membrane lined internal organelles except thylakoids if present.
- A **eukaryotic cell** has internal compartments. It has double membrane system, besides cell membrane the cell organelles are also covered by membranes. Eg. plant cell and animal cell.
- Prokaryotes have no nucleus or other membrane-bounded compartments. They lack distinct

Table : Comparison of features of prokaryotic and eukaryotic cells

Characters	Prokaryotes	Eukaryotes
Typical organisms	bacteria, archaea	protists, fungi, plants, animals
Typical size	~ 1-10 µm	~ 10-100 µm (sperm cells, apart from the tail, are smaller)
Type of nucleus	nucleoid region; no real nucleus	real nucleus with double membrane
DNA	circular (usually)	linear molecules (chromosomes) with histone proteins
RNA-/protein-synthesis	coupled in cytoplasm	RNA-synthesis inside the nucleus protein synthesis in cytoplasm
Ribosomes	50S+30S	60S+40S
Cytoplasmatic structure	very few structures	highly structured by endomembranes and a cytoskeleton
Cell movement	flagella made of flagellin	flagella and cilia made of tubulin
Mitochondria	none	one to several dozen (though some lack mitochondria)
Chloroplasts	none	in algae and plants
Organization	usually single cells	single cells, colonies, higher multicellular organisms with specialized cells
Cell division	binary fission (simple division)	mitosis (fission or budding), meiosis

organelles, although some do have invaginated membrane structures.

- In a prokaryotic cell, **found only in bacteria and archaebacteria**, all the components, including the DNA, mingle freely in the cell's interior, a single compartment.
- Prokaryotes **inhabit the widest range of environmental extremes.** They can be found at thermal vents deep in the ocean, living at temperatures above boiling. They also occur in extremely salty environments.
- The cytoplasm (the plasma membrane-enclosed region) of prokaryotes consists of the nucleoid (where the DNA is concentrated), ribosomes (the molecular protein synthesis machines), and a liquid portion called the cytosol.
- Most prokaryotic cells have a cell wall just outside the plasma membrane. [*The cell wall functions to prevent plasma membrane lysis (bursting) when cells are exposed to solutions with lower solute concentrations than the cell interior. It also protects the membrane.*]
- In most bacteria (but not in archaea) the cell wall is made of a polymer of amino sugars called peptidoglycan, which is covalently cross-linked to form one giant molecule around the entire cell.
- **Eukaryotic cells**, which make up plants, animals, fungi, and all other life forms, **contain numerous membrane-bounded nucleus** and **usually have other membrane-bounded compartments or organelles as well**.
- The DNA in eukaryotic cells is enclosed in a special organelle called the nucleus, which serves as the cell's command centre and information library.
- **Compartmentalization is the key to eukaryotic cell function.**
- The subunits, or compartments, within eukaryotic cells are called **organelles.**
- Eukaryotic cells are **typically about ten times larger** than prokaryotic cells. In animal cells, the

Compartmentalization of cell

- **Outside by** Plasma membrane or cell membrane
- **Internally** (within cell) **Comprises**
  - Membrane bound organelles
    - **Eukaryotic cell** (double envelop system)
      - Contain
        - **Protoplasm**
          - **Cytoplasm** Serves for reaction medium, storage, exchange etc.
            - Contain
          - **Nucleus** (Nucleoplasm, a clear non staining fluid material) control centre
            - Contain
              - Nucleolus
              - Chromosomes
  - Without membrane bound organelles - (Except, thylakoids if present) — **Prokaryotic cells** (one envelop system)

Eukaryotic cell and Prokaryotic cells: **Basically differentiated on the basis of**
- organization of biomembranes
- variety of cytoplasmic organelles
- complexity of nuclear membrane

Contain:

Cytoplasmic organelles — **Semi autonomous organelles**: Mitochondria & chloroplast

Organelles
- **With**
  - **Single membrane :** ER, golgi apparatus, vacuoles, lysosomes, sphaerosome, peroxisomes, glyoxysomes, protoplast thylakoid (lamella inside chloroplast)
  - **Double membrane :** Plastids, mitochondria, nucleus
- **Without membrane** — Ribosomes, centrosomes, centriole nucleolus, cytoskeletal structures, cell wall
- **Concerned with moving and movements** — Centrosome (2 centrioles), microtubules and cilia and flagella

Cell inclusions
* Non living granules often called deutoplasmic substances
* Used for food and material storage

Present only in
- **Plant cells**
  - **Cell wall**
  - **Chloroplast** (chemical factores)
  - **Vacuoles** [central vacuole (large) & tonoplast membrane]
  - **Plasmodesmata**
- **Animal cells**
  - **Centrioles** (self replicating organ)
  - **Cell coat**

Common to both cells

Plasma membrane
Endoplasmic reticulum, ER (transport system)
Golgi apparatus (protein packing plant)
Mitochondria (power house)
Lysosome (suicide bag)
Cytoskeletal structures
Microbodies
Sphaerosomes
Flagella and cilia
Ribosomes (protein factories)

plasma membrane, rather than a cell wall, forms the cell's outer boundary. With a design similar to the plasma membrane of prokaryotic cells, it separates the cell from its surroundings and regulates the traffic across the membrane.

- The **eukaryotic cell cytoplasm is similar to that of the prokaryote cell except for one major difference**: eukaryotic cells **house a nucleus and numerous other membrane-enclosed organelles**.
- Eukaryotes have a protein scaffolding called the **cytoskeleton**, which **provides shape and structure to cells, among other functions**.
- Membranes surrounding these organelles keep away inappropriate molecules that might disturb organelle function. They also act as traffic regulators for raw materials into and out of the organelle.
- Compartmentalization in each cell is a distinct compartment due to presence of plasmalemma.
- All cells at their essence have at least three things in common - cell membrane, cytoplasm and DNA (Eukaryotes such as plants and fungi will **have cell walls in addition to the always present cell membrane**).
- All eukaryotic cells are surrounded by a thin, elastic, living covering called **cell membrane**, or **plasma membrane** or **plasmalemma**.
- Certain protists, most of the fungi and all plant cells have a thick, rigid, non-living additional covering outside the cell membrane. It is known as **cell wall**.
- The **cytoplasm** consists of a semifluid, homogenous, translucent, colloidal ground substance, formerly called the **cytoplasmic matrix** or **hyaloplasm**, now termed **cystosol**.
- In free cells, e.g. protozoans, the cystosol has an outer narrow, relatively firm zone, the **ectoplasm** and around the centre relatively fluid mass, the **endoplasm**.
- The cytoplasmic matrix, along with the structures it contains, is often in constant motion, called **streaming movement** or **cyclosis**.
- The cytoplasm contains mainly two types of structures - **organelles** (or **organoids**) **and inclusions**.
- **Organelles** are **living, protoplasmic structures** having specific functions necessary for the metabolism of the cell, e.g. mitochondria, chloroplast, ribosome etc.
- **Inclusions** are **non-living or deutoplasmic cytoplasmic structure**, e.g. reserve food material, pigment granules, crystals etc.
- The **eukaryote cell** are of **two types** - **plant** and **animals cells**.
- Most of the organelles and other structures of cells are common to animals and plants. For example, both animal and plant cells have a plasma membrane, a nucleus, mitochondria, endoplasmic reticulum, a Golgi apparatus, ribosomes and lysosomes.
- **Only plant cells have a cell wall containing cellulose**. Plant cells usually contain a large permanent vacuole contained within a special membrane, the tonoplast. Green plant cells contain chloroplast.
- **Only animal cells contain two centrioles** (making up the centrosome), and often also **temporary vacuoles or vesicles**.

CELL SIZE

- **PPLO** (pleuro pneumonia like organism) is the **smallest cell**.
- In human beings **cells of kidney are smallest** and **of nerve fibre are largest**.
- **Cell coat** (glycocalyx or extraneous coat) is made up of oligosaccharides which acts as recognition centre during organ transplantation.
- **Longest plant** cell is the fibre of *Ramie Boehameria nivea* (55 cm in size).
- Photosynthetic cells are called **energy transducers** because they possess chloroplasts for absorbing light energy, convert the same into chemical energy and store as food energy.
- Cells vary considerably in size. **The smallest cell**, a type of bacterium known as a **mycoplasma**, measures 0.0001 mm (0.000004 in) in diameter; 10,000 mycoplasmas in a row are only as wide as the diameter of a human hair. Among the **largest cells** are the **nerve cells** that run down a giraffe's neck; these cells can exceed 3 m (9.7 ft) in length.
- Human cells also display a variety of sizes, from small red blood cells that measure 0.00076 mm (0.00003 in) to liver cells that may be ten times larger. About 10,000 average-sized human cells can fit on the head of a pin.
- **Nucleo-cytoplasmic** (NP) or **karyoplasmic ratio** is the ratio between volume of nucleus and volume of cytoplasm of a cell.

- A **reduced karyoplasmic ratio** either induces the cell to divide or undergo maturation and senescence.
- **Metabolically active cells are small** as **small cells have higher NP ratio** for better control and **higher surface-volume ratio** for quicker exchange of materials.
- Cell size is **limited by the surface area-to-volume ratio.**
- **Surface area-to-volume ratio** is defined as the surface area divided by the volume. For any given shape surface to volume ratio **decreases with the increase in cell size or volume.**
- Shape also **influences surface area-to-volume ratios**.
  - A sphere has the least surface area-to-volume ratio of any shape.
  - Imagine you have a lump of clay. Fashioning it into a sphere minimizes the surface area.
  - If you flatten the ball of clay to make a pancake shape, the surface area increases, while the volume remains the same. Cells such as red blood cells flatten into a pancake shape to increase surface area.
  - Fashioning the clay into a thin string also increases the surface area without increasing the volume.
  - Nerve cells have this shape, which allows some of them to be a meter long or more.
  - If the clay is spherical but the surface is irregular with many fine projections coming off the surface, surface area is greatly increased. In epithelial cells, such projections are called microvilli.
- Most cells are tiny, with diameters in the range of 1 to 100 μm.
- The **surface of a cell** is the area that interfaces with the cell's environment. The **larger the surface area of a cell**, **the faster a cell can take in substances and remove waste products**.
- The **volume of a cell** is a measure of the space inside a cell. The **larger the volume of a cell**, the **more chemical activity it can have**.
- The small size of cells makes the use of microscopes necessary to view them.
- If two objects are too close together, they start to look like one object. With normal human vision the smallest objects that can be resolved (*i.e.*, distinguished from one another) are about 200 μm (0.2 mm) in size.
- Light microscopes use glass lenses and visible light and typically have a resolving power of 0.2 μm (0.2 . 10 – 6m). Resolution depends on the wavelength of the illuminating light, but in general, resolution is about 1000 times better than that of an unaided human eye. Living or killed and fixed cells may be viewed with light microscopes.

Fossil studies indicate that cyanobacteria, bacteria capable of photosynthesis, were among the earliest bacteria to evolve, an estimated 3.4 billion to 3.5 billion years ago. In the environment of the early Earth, there was no oxygen, and cyanobacteria probably used fermentation to produce ATP. Over the eons, cyanobacteria performed photosynthesis, which produces oxygen as a byproduct; the result was the gradual accumulation of oxygen in the atmosphere. The presence of oxygen set the stage for the evolution of bacteria that used oxygen in aerobic respiration, a more efficient ATP-producing process than fermentation. Some molecular studies of the evolution of genes in archaebacteria suggest that these organisms may have evolved in the hot waters of hydrothermal vents or hot springs slightly earlier than cyanobacteria, around 3.5 billion years ago. Like cyanobacteria, archaebacteria probably relied on fermentation to synthesize ATP.

End of the Chapter

Chapter 18

Biomembrane

- All cells are enclosed by a thin, film-like plasma membrane or plasmalemma.
- The term **"plasmalemma"** was introduced by **Seifriz** in 1928 later followed by **J.Q. Plower** (1931).
- This is also known as **cell membrane (Nageli** and **Cramer** 1855) which is a component of the cell surface and form the cell boundary.
- The **other cell membranes** includes the
  - **nuclear envelope** (encloses the nucleus)
  - **tonoplast** (encloses the vacuole of plant cells), and
  - the membranes of the various cell organelles such as ER, Golgi apparatus, mitochondria, chloroplasts and lysosomes.
- In prokaryotic cells, the membranes forms the boundary of the cytoplasm being guarded from outside by extracellular matrix and the cell walls.
- The plasma membrane and other intracellular membranes surrounding the organelles and vacuoles are collectively known as **biological membranes**.
- Historically, **E. Overton** (1895) was **first to study the structure or composition of plasma membrane**.
- Overton postulated that cell membrane is composed of a continuous layer of lipid material.
- **E. Gorter** and **F. Gredel** (1925) studied **RBCs** of a variety of mammals and proposed that the cell membrane is formed of a **bimolecular layer of lipid sheet**.
- Cells communicate with their environment by cell membrane.
- **Permeability** is **fundamental to the functioning of the living cell** and **to the maintenance of satisfactory intracellular physiological conditions**. This function determines which substances can enter the cell, many of which may be necessary to maintain its vital processes and the synthesis of living substances. It also regulates the outflow of excretory material and water from the cell.
- The **presence of a membrane establishes a net difference** between the *intracellular* fluid and the *extracellular* fluid in which the cell is bathed. This may be fresh or salt water in unicellular organisms grown in ponds or the sea, but in multicellular organisms the internal fluid, *i.e.*, the blood, the lymph, and especially the *interstitial* fluid, is in contact with the outer surface of the cell membrane.
- One of the functions of the cell membrane is to **maintain a balance between the osmotic pressure of the intracellular fluid and that of the interstitial fluid**.
- The plasma membrane is a **semi-permeable** (not every thing can pass through) boundary between the cell and its external environment.
- Plasma membrane act as semi-permeable because it **has the character of selective permeability** means that the cell membrane has some control over what can cross it, so that only certain molecules either enter or leave the cell while keeping other constituents from escaping from the cell; and detects and responds to the changes in the surrounding.
- The cell membrane is a **fluid mosaic of lipids, proteins and carbohydrates**.
- Chemically a biomembrane consists of **lipids** (20-40%), **proteins** (50-75%) and **carbohydrates** (1-5%).
- The **main lipid components** of the plasma membrane are phospholipids, cholesterol and galactolipids.
- The **major proportion of membrane phospholipids** is represented by phosphatidylcholine, phosphatidylethanolamine,

and sphingolipids (eg. sphingomyelin and cerebrosides), all of which have no net charge at neutral pH (i.e., *neutral phospholipids*) and tend to pack tightly in the bilayer (This property is also shared by cholesterol).

- The lipid molecules are **amphiatic** or **amphipathic**, *i.e*, they **possess both polar hydrophilic** (water loving) and **nonpolar hydrophobic** (water repelling) **ends**. The hydrophilic region is in the form of a head while the hydrophobic part contains two tails of fatty acids.
- Membrane proteins have been classified as **integral** (**intrinsic**) or **peripheral** (**extrinsic**) according to the degree of their association with the membrane and the methods by which they can be solubilized.
- **Integral proteins** are generally transmembrane proteins, with hydrophobic regions that completely span the hydrophobic interior of the membrane.
- Proteins are much larger than lipids and move more slowly, but some do drift.
- **Peripheral proteins** are not embedded in the lipid bilayer at all; they are loosely bound to the surface of the membrane, often to the exposed parts of integral proteins.
- Proteins can be fibrous or globular, structural, carrier, receptor or enzymatic. About 30 kinds of enzymes have been recorded in different biomembranes, e.g., phosphatases, ATP-ase, esterases, nucleases, etc.
- **Carbohydrates** present in the membrane are **branched or unbranched oligosaccharides**, e.g., hexose, fructose, hexoamine, sialic acid, etc.
- Some of these oligosaccharides are covalently bonded to lipids, forming molecules called **glycolipids**. Most are covalently bonded to proteins, which are thereby **glycoproteins**.
- The biomembranes are **asymmetric** *i.e* the two surfaces of biomembrane are not similar because –
  – Lipids present in both the layer are different, eg, lecithin on outer side and cephalin on inner side of erythrocyte membrane.
  – Extrinsic proteins are more abundant on inner side than on the outer surface.
  – Oligosaccharides, attached to external surface of lipids and proteins, are absent on the inner side.

ULTRASTRUCTURE OF PLASMAMEMBRANE

- Under electron microscope the plasma membrane appears three layered, *ie*., trilaminar. One optically light layer is of lipids and on both sides of it two optically dense layers of proteins are present.
- **Three important models** explaining the ultrastructure of plasma or cell membrane are–
  – Danielli - Davson model : Bilayer model.
  – Robertsonian : Unit membrane concept
  – Singer and Nicolson : Fluid mosaic model.

Bilayer model by Davson & Danielli

- Danielli and Davson proposed that the plasma membrane is made up of three layers : a **biomolecular layer of lipid sandwiched between two layers of proteins**.
- Danielli and Davson model is the **oldest model on the structure of plasma membrane**.
- The inner ends and lipid molecules are hydrophobic and non-polar while the outer ends are hydrophilic and polar.
- Proteins are attached at the outer ends of lipid layer (hydrophillic ends) by ionic exchanges and hydrostatic forces.

Unit membrane model by Robertson

- Based upon electron microscopy on myelin, **Robertson** in 1959 proposed his famous **'unit membrane concept'**.
- Robertson called it as a 'unit membrane' because the pattern of molecular organization was same for all membranes.
- According to Robertson the thickness of lipid biomolecular layer is 3.5 nm, each protein layer 2.0 nm, making up a total thickness of 7.5 nm (75Å).
- One of the **major weaknesses of Robertson's model** was its **failure to explain permeability and transport properties of the membrane**.
- It has been well established that in plasma-membrane proteins are of two types –
  – Extrinsic proteins are peripheral proteins, associated with the surface.
  – These can be easily removed, eg., spectrin in red blood cells and ATPase in mitochondria.
  – Intrinsic proteins or Integral proteins – enter the lipid bilayer and extend all the way through it, eg., rhodopsin in retinal rod cells.

– The portions of the polypeptide chains that extend through the lipid bilayer typically occur as α-helices composed of hydrophobic amino acids.

Fluid mosaic model by Singer & Nicolson

- The most universally accepted **"fluid mosaic model"** of structure of plasma membrane was proposed in 1972 by **S. Jonathan Singer** of University of California and **Garth Nicolson** of the Salk Institute.
- Singer and Nicolson took the help of **freeze-fracture techniques in electron microscopy**.
- According to fluid mosaic model, the membrane contains a biomolecular lipid (2 dimensional, liquid) layer, the surface of which is interrupted by proteins.
- Some proteins are attached at polar surface of lipids called the **peripheral** or **extrinsic proteins** and the other proteins, which penetrate the bilayer or span membrane entirely are called the **integral transmembrane** or **intrinsic proteins**.
- The integral proteins **form about 70% of the total membrane protein**.
- The extrinsic proteins may be **covalently attached to fatty acids chains** or **non-covalently attached to other transmembrane proteins**.
- The transmembrane proteins extends through the bilipid layer as a single helix (eg, glycophorins).
- The proteins on the outer side may bear chains of sugar forming **glycoproteins.**
- The three major types of membrane lipids are **phospholipids, cholesterol** and **glycolipids**. These lipids are **amphiphatic**.
- Cholesterol **becomes intercataled between phospholipids in membranes** and **increases the stability of the bilayers** and **prevents the loss of membrane liquidity at low temperature.**
- The proteins **may float freely like icebergs**.
- The **lipids act as a barrier to the entry or exit** of charged polar substances.
- Some proteins in the plasma membrane act as "gatekeepers" that regulate the traffic of molecules and ions into and out of the cell.
- **Selective permeability** of plasma membrane can be **explained with the help of fluid mosaic model**.
- Plasma membrane is **composed mainly of protein, lipid** and a **small percentage (1–5) of carbohydrates**.
- The carbohydrates of plasma membrane are **hexose, hexosamine, fructose** and **sialic acid.**
- Carbohydrates present in plasma membrane are in the form of **glycoproteins** and **glycolipids**.
- Lipids and intrinsic proteins form a mosaic pattern.
- The membrane is semifluid in nature and hence the lipid molecules and intrinsic proteins move freely.
- Such membranes are also present around different cell organelles, eg. mitochondria, Golgi bodies, endoplasmic reticulum, etc.

SPECIALISATION OF PLASMA MEMBRANE

- The term **'coenocyte'** is used to describe the multinucleate condition in which cell membrane is lacking between cells.
- The **concept of membrane fluidity** refers to the fact that both lipids and proteins may have considerable freedom of lateral movement within the bilayer.
- The fluidity of the membrane can be studied with a series of techniques that can be classified as physical or biological.
- The **physical techniques** are of **two main types** : (1) those that involve a minimal perturbation of the membrane, such as X-ray diffraction and nuclear magnetic resonance (NMR) spectroscopy; and (2) those that use certain added molecules to monitor specific sites of the membrane. Into this second class fall fluorescence microscopy, which uses fluorescent probes, and electron spin resonance (ESR) spectroscopy, which uses paramagnetic probes (e.g., nitroxide-containing amphipathic molecules) that are introduced into the lipid bilayer.
- The **biological techniques** involves light and fluorescence microscopy and electron microscopy, including freeze fracturing and radioisotope labelling methods.
- Several **factors that influence membrane fluidity** are: temperature; percentage of unsaturated tails; and the presence of cholesterol.
- Fluidity **increases with rise in temperature** and **decreases with lowering of temperature**. Membrane fluidity is essentially a property of the lipids.
- Normally these are fluid at body temperature and the main consideration is the degree of saturation of the hydrocarbon chains.

- As temperature decreases, a critical temperature is reached at which the membrane solidifies. At this temperature, the tails of the phospholipids are packed tightly together and movement is inhibited.
- One **factor that tends to increase rigidity is the concentration of cholesterol**. The steroid cholesterol, which is wedged between phospholipid molecules in the plasma membranes of animals, helps stabilize the membrane. At relatively warm temperatures, *for example*, 37°C, the body temperature of humans, cholesterol makes the membrane less fluid by restraining the movement of phospholipids. However, because cholesterol hinders the close packing of phospholipids, it also lowers the temperature required for the membrane to solidify.
- **Rapid changes in fluidity** can be **produced by methylation of phosphatidylethenalomine by methyltransferases present in the membrane**. These inturn are regulated by receptors. This has been confirmed by a simple but ingenious experiment devised by **Frye and Edidin (1970)**.
- **L.D. Frye** and **M. Edidin** (1970) **provided evidence for the mobility of membrane proteins** obtained by fusing mouse and human cells to form **heterokaryons.**
- Before fusion, they labelled mouse cells with green fluorescent antibody dye **fluoroscein** and human cells with red fluoroscent antibody dye **rhodamine**.
- The frequency of cell fusion could be greatly increased by adding **Sendai virus.**
- Cell membrane modified into **foldings**, **intercellular junctions** and **extracellular coats**.
- **Infolds** (invagination) **facilitate pinocytosis** (cell drinking) and **phagocytosis** (cell eating) which together constitute **endocytosis**.
- **Invagination** results in the formation of pores, mesosomes, lomasomes and transfer cells.
- Cell-cell junctions play an important role in cell-cell adhesion and in intercellular transport.
- The **most common types of junctions** are –
  - **Tight junctions (zonula occludens)**
  - **Intermediate junctions (belt desmosomes)**
  - **Spot desomosomes (macula adherens)**
  - **Gap junctions (connexons or nexuses)**
  - **Plasmodesmata**
- **Extracellular coats** formed in animal cells are of following types – **chitin**, **glycocalyx**, **basement membrane**, **cell wall** etc.

TRANSPORT ACROSS BIOMEMBRANE

- Membranes are **selectively permeable.** The different methods of transport across the cell membrane consists of: **passive transport**, **active transport**, **bulk transport**.

Passive transport

- **Passive transport** is a mode of membrane transport where the **cell does not spend any metabolic energy**.
- This transport is **according to the concentration gradient**.
- Passive transport is of following types – **diffusion** (**simple diffusion**), **facilitated diffusion and osmosis**.
- **Simple diffusion** can occur either through lipid matrix of the membrane or with the help of channels.
- In **faciliated diffusion** some specific solutes diffuse down electrochemical gradients across membrane more rapidly than might be expected from size or charge.
- Facilitated diffusion **occurs through the agency of special membrane proteins** (called carrier proteins which is also known as **permeases**), but like simple diffusion, it **requires no metabolic energy**.
- **Osmosis** (discovered by Albe Nollet, 1748) is the **net movement of a solvent through a selectively permeable membrane**.
- In living systems, the **solvent is water**, which moves by osmosis across plasma membranes from an area of higher water concentration to an area of lower water concentration.
- In osmosis, water moves through a selectively permeable membrane from an area of lower solute concentration to an area of higher solute concentration.
- The **water potential** of a solution is the term given to the tendency for water molecules to enter or leave that solution by osmosis.
- Water potential is a term derived from thermodynamics, and is a **measure of the free kinetic energy of the water molecules in the solutions**.
- **Two important factors** which **determine the water potential of solutions in and around living cells** are– the presence of dissolved solutes (giving rise to a solute potential) and the mechanical pressure acting on water (pressure potential).

- **Osmotic pressure** is the maximum pressure which can develop in an osmotically active solution when it is separated from its pure solvent by a semipermeable membrane under ideal conditions.
- The solute potential of a concentrated solution can be demonstrated dramatically in an apparatus known as an **osmometer**.
- **Tonicity** is the amount of tension developed in a system on account of the occurrence of solute particles in it. It is usually determined in comparison to other systems or solutions.
- When two solutions are compared for their osmotic pressure or concentration, one may have higher concentration than the other or the two may have the same concentration.
- **On the basis of tonicity**, solution are of **three types** – **hypertonic, hypotonic** and **isotonic**.
- **Tonicity determines exosmosis and endosmosis**.
- **Hyperosmotic** (hypertonic) **solutions** will cause water to leave cells by osmosis, and **cells may shrink** (**in animal cells, membrane collapses or becomes crenated and in plant cell**, **shows plasmolysis**).
- Hypertonic solution **has higher proportion** (**concentration**) **of solutes**.
- **Hypo-osmotic** (hypotonic) **solutions** will cause water to enter cells by osmosis, **causing the cells to swell** and **burst in animal cell** and **becomes turgid in plant cells**.
- In hypotonic, the external solutions has a lower solute concentration (more water) than the internal solution of the cells.
- **Isotonic solutions** will **have equal proportions of solutes to water on both sides of the membrane**.
- Iso-osmotic solutions are osmotically balanced and there is **no net movement of water**. Water will move through the membrane, but equal amounts of water will be moving in both directions.
- **Types of osmosis** are– endosmosis and exosmosis.
- **Endosmosis** is the process of osmotic entry of solvent or water into a cell or system when it is in contact with hypotonic solution or pure solvent. Endosmosis is best seen by placing raisins in water.
- **Exosmosis** is the outflow or exit of solvent or water from a cell or system when the same is kept in contact with hypertonic solution. Exosmosis is best seen when sliced cucumber is sprinkled with salt.
- **Exosmosis** causes **plasmolysis in plant cells**.

Active transport

- The **active transport** is the transport of ions or molecules against their concentration gradient or electrochemical gradient.
- Active transport **differs from diffusion** in that molecules are transported away from thermodynamic equilibrium, hence **energy is required**.
- This energy can come from the hydrolysis of **ATP,** from **electron movement** or from **light**.
- **Two main types of active transport** are : **primary active transport** and **secondary active transport**.
- In **primary active transport**, energy is provided by another coupled reaction such as the **hydrolysis of ATP**.
- **Sodium-potassium exchange pump is an example** of primary active transport.
- For each molecule of ATP used, **three Na^+ ions are pumped** out and **two K^+ ions are pumped in**.
- The Na^+ gradient established by the $Na^+ – K^+$ pump provides a source of energy that is frequently used to power the active transport of sugars, amino acids and ions in mammalian cells.
- A **secondary active transport** takes place with the help of ion gradient from the coupled transport of a second molecule.

Bulk transport

- **Bulk transport** is the transport of large quantities of macromolecules, micromolecules and food particles through the membrane.
- Bulk transport occurs by two main methods, **endocytosis** and **exocytosis.**
- Bulk transport involves the enclosure of the material under transport in **carrier vesicles** of the membrane.
- The inward transport of carrier vesicles is called **endocytosis** and outward transport of carrier vesicles is called **exocytosis**.
- The bulk transport is **common in excretory and secretory cells**.
- When cells engulf extracellular substances and bring them to the cytoplasm in membrane bound vesicles it is called **endocytosis**.
- Endocytosis **occur by pinocytosis, phagocytosis** and **receptor mediated endocytosis**.
- **Phagocytosis** (Gr. *phagein,* to eat, *kytos,* cell) is a process whereby certain cells and unicellular organisms are capable of ingesting and digesting solid material.

Biomembranes

- **Covers**
  - Cell – called plasma membrane
  - Cell organelles – called subcellular membranes
  - Allows certain inorganic salts nutrients, water and other metabolites to pass into the cell and permit the release of cellular waste products and other specific molecules.
- **Modification**
  - **Foldings**
    - **Invagination**
      - – Facilitates cell drinking and cell eating
      - – Occurs by forming pores, endocytotic vesicles, mesosome, lomasomes etc
    - **Evagination**
      - – Occurs by microvilli, stereocilia, interdigitations
  - **Intracellular junctions**
    - – interdigitation
    - – tight junctions
    - – gap junctions
    - – plasmodesmata
    - – desmosomes etc
  - **Extracellular coats**
    Chitin, glycocalyx, basement membrane, cell wall.
- **Models**
  - **Lipid model** by Overton (1900) and Gorter and Grendal (1926)
  - **Bilayer model** by Danielli and Davson (1930's)
  - **Unit membrane concept** by Robertson (1959)
  - **Fluid mosaic model** by Singer and Nicolson (1972)
- **Transport across cell membrane**
  - **Active transport** *(see on next page)*
  - **Passive transport** (Do not need energy)
    - **Diffusion**
      - • Fat soluble substances pass through biomembranes
      - • Operates in any medium
    - **Facilitative Diffusion**
      Passage of substances along the concentration gradient without expenditure of energy with the help of membrane transport protein
    - **Osmosis**
      - • Diffusion across a semi-permeable membrane
      - • Operates only in liquid medium
      - Types
        - **Exosmosis**
          - Causes
            - **Plasmolysis**
              shrinkage of protoplast of cell from its cell wall under the influence of hypertonic solution
              - Occur in three stages
                - **Ist Incipient** (just starting to happen) **plasmolysis**
                - **IInd Evident plasmolysis**
                - **IIIrd Limiting** (the ultimate extent) **plasmolysis**
              - **When shrinkage stops** at particular stage then there is no further decrease in size
                - Called
                  - **Limiting plasmolysis**
        - **Endosmosis**
          - Causes
            - **Deplasmolysis**
              Swelling of plasmolysed protoplast under the influence of hypotonic (low salt concentration) solution or water
  - **Bulk transport** *(see on next page)*

Flowchart : Biomembrane at a glance

Transport across cell membrane

Active transport
Required energy and takes place against concentration gradient

Takes place through

Carrier proteins
Integral protein particles which have affinity for specific solutes

Form

Carrier solute complex
Undergoes
Conformational changes
To transport the solute

Gated channels
Opens by either change in electrical potential or specific substance
Eg. (1) K^+–H^+ exchange pump (in guard cells)
(2) Na^+–K^+ exchange pump (in animal membranes)

Operate with the help of ATP

Bulk transport
Transport of large quantities of micromolecules, macromolecules and food particles through the membrane

Occur by

Exocytosis
Transport of material out of cells

Reverse pinocytosis

Used to throw solids, undigested waste and other materials
Eg, excretion in *Amoeba*, secretion of hormones by cells.

Endocytosis
Transport of material into the cell

Occur by

Phagocytosis (cell eating)
- Eg, lysosomes, phagocytes, *Amoeba* for engulfing food. Leucocytes to remove dead bacteria and germs
- Material taken up in the solid form
- Generally a large vacuole
- Used to engulf germs, bacteria or other large particles.

Pinocytosis (cell drinking)
- Eg, *Amoeba*, liver cells, amoeboid cells.
- Materials taken up in liquid form
- Generally small vesicles.
- Used to take secretions like lipo-proteins or food like macromolecules in liquid form. (generally the macromolecules that cannot enter through the plasma membrane are taken in this way).

Receptor mediated endocytosis
- Process by which cell internalize molecules or viruses. It depends on the interaction of that molecule with a specific binding protein in the cell membrane called a receptor.

- The term phagocytosis has been coined by a Russian scientist **Ilie Metchnikoff** in 1893.
- For the description of phagocytosis Metchnikoff got **Nobel prize** of **Physiology** and **Medicine** in 1908.
- Phagocytosis is done by the cell extending pseudopodia which encircle and engulf it into membrane delimited vesicles called **phagosomes**.
- The term **pinocytosis** (Gr. *pinein,* to drink) was coined by **Lewis** in 1931.
- **Lewis was the first to observe pinocytosis** in living cells in culture.
- Pinocytosis (also called **cell drinking**) is quite common in the cell lining the blood capillaries.
- Lewis described the uptake of fluid matter and substances dissolved in it (eg ions, sugars, amino acids) by an active movement of undulating membrane formed at the periphery of the cell.
- **Mast** and **Doyle** using fluorescence microscopy indicated that pinocytosis may be important for the cellular uptake of proteins.
- A receptor mediated selective process is known as **absorptive pinocytosis**.
- The vesicles formed during absorptive pinocytosis are derived from invaginations (pits) that are coated on the cytoplasmic side with filamentous material like **clathrin.**
- The signal for exocytosis is often a hormone which, when it binds to a cell surface receptor, induces a local and transient change in Ca^{2+} concentration. **Ca^{2+} triggers exocytosis**.
- **Exocytosis** (the reverse of endocytosis) causes expulsion of materials from the cells.
- In plant cells, exocytosis is an important means of exporting the materials needed to construct the cell wall through the plasma membrane.
- Among protists, contractile vacuole discharge is a form of exocytosis. In animal cells, exocytosis provides a mechanism for secreting many hormones, neurotransmitters, digestive enzymes, and other substances.

FUNCTIONS OF BIOMEMBRANES

- The most important function of plasma membrane is to provide passage for various substance, into and out of the cell.
- Plasma membrane is selectively permeable, *ie*., allows some solute particles (1–15 Å) to pass through it readily along with all solvents.
- It not only provides mechanical strength but also acts as a protective layer.
- Plasma membrane is responsible for the transportation of materials, molecules or ions, etc., through it.
- Anchoring of the cytoskeleton to provide shape to the cell.
- Attaching to the extracellular matrix to help group cells together in the formation of tissues.
- The plasma membrane takes part in cellular locomotion in two ways : pseudopodia and undulation.
  - In **pseudopodia** *Amoeba*, macrophages and WBCs move with the help of temporary locomotary organelles like pseudopodia.
  - In **undulation** some mammalian cells such as fibroblasts can move over a solid surface by wave like undulations of the plasma membrane.

End of the Chapter

Chapter 19

Structural Organization of Cell

- Cell are the **smallest structural and functional units** of life (and of diseases processes) in all tissues, organs and organ system.
- A cell has a variety of molecules, often called biomolecules, in it.
- A biomolecules may occur in solution, or in colloidal state in the cell, or may be assembled into subcellular components of the cell.
- The subcellular components are often called as cell organelles, that is small organs.
- **Organelles** are membrane bound, enzyme containing subcellular compartments (eg mitochondria). Each type of organelles has a distincting structure and performs unique functions.
- Cell include plasma membrane, endoplasmic reticulum, ribosomes, Golgi apparatus, lysosomes, microbodies, mitochondria, plastids, microtubules, microfilaments, intermediate fibres, centrioles, basal bodies, cilia, flagella, vacuoles and nucleus.
- The **entire protoplasm of a cell** is known as **protoplast**.
- Protoplast has **four components – plasmalemma** (or plasma membrane), **cytoplasm, nucleus** & **vacuole**.

Cell
- Cell wall & Plasma membrane (in plant)
- Vacuole (in plant cell only)
- Protoplasm
  - Cytoplasm
    - **Metabolically active organelles** (or cytoplasmic organelles)
      1) Mitochondria
      2) Plastids
      3) Endoplasmic reticulum
      4) Golgi bodies
      5) Ribosomes
      6) Centrosomes
      7) Microbodies (*i e.* Lysosomes, Perioxisomes, etc.)
    - **Metabolically inactive substances** (or Cytoplasmic inclusions or Ergastic substances or Deutoplasmic substances or Deutoplasm)
      - **Storage substances** eg., carbohydrates, fats, proteins etc
      - **Secretory substances** eg., colouring matter, enzymes, nectar etc
      - **Excretory substances** eg., glucosides, tannins, gums, resins, etc.
  - Nucleus

Flow chart – Organization of cell

PLASMA MEMBRANE

- The cell membranes separate a cell from its environment and form distinct functional compartments (nucleus, organelles) in the cell. The outer cell membrane is called the **plasma membrane** or **plasmalemma**.

(*For more details on plasma membrane refer chapter Biomembrane*)

- In the cells of bacteria, cyanobacteria, protists, fungi and plants, a thick, rigid, protective but porous coat, the **cell wall**, outside the plasma membrane **is found**.
- The composition of cell wall varies in different groups.

- **Composition of cell wall**
  - In **plants**, cell wall is made up of **cellulose** (β-D-glucose units), **hemicellulose** (arabinose, mannose, xylose, galactose, etc.) and **pectin** (galactose, galacturonic acid and arabinose)
  - In **bacteria**, cell wall is composed of protein-lipid-polysaccharides having two important chemical components: **N-acetyl glucosamine (NAG) and N-acetyl muramic acid (NAM)**.
  - In **fungi**, cell wall is made up of **chitin** (polymer of N-acetyl glucosamine).
  - **Algal cell** wall contains cellulose and a variety of glycoproteins.
- One of the **most important differences between plant and animal cells** is the **presence of a cell wall** (non-living protective layer) in **plant cells**.
- Cell wall was first discovered in the cell by **Robert Hooke in 1665**.
- Cell wall is **absent in animal** because cell wall is incompatible with the way in which an animal moves and grows.
- In an animal cell and many protists, cell membrane are covered by filamentous layer (also called **cell coat**) of an oligosaccharide sialic acid (called **glycocalyx**), which protects the underlying membrane and **helps in recognition of the cells** (by **Wilson**, 1907).
- Recognition ability is mainly **due to Ca^{2+} and Mg^{2+} absorbed over glycocalyx**.
- The cell coat of glycocalyx may be supported and strengthened by deposition of calcium salts, silicon or other substance.
- A typical cell wall is **made up of 4 layers** – **middle lamella**, **primary**, **secondary** and **tertiary wall**.
- **Middle lamella** is the **cementing layer** between the cells. It is made up of Ca & Mg pectates.

The **ripened fruits becomes softened** due to dissolution of middle lamella. It can be done artificially by spraying strong acids.

- **Primary cell wall**
  - It is **formed in a growing cell**.
  - It is laid down on both sides of middle lamella.
  - It is **present in all plant cells**.
  - It is **elastic** and **capable of expansion** in a growing cell.
  - It **grows in thickness by intussusception**.
  - It consists of a single layer of wall material.
  - It is **1–3 mm thick**.
  - Its cellulose macrofibrils are short, wavy and loosely arranged.
  - It **lacks pits and additional materials**.
  - Its water content is about 60%.
  - It **has relatively low cellulose content**.
  - It **has high hemicellulose, protein and lipid contents**.
- **Secondary cell wall**
  - It is **formed in a mature cell**.
  - It is laid down on the inner side of primary wall after the growth of cell stops (at maturity).
  - It is **present in certain plant cells only,** for eg. gymnosperms.
  - It is **rigid** and **non-elastic** and **incapable of expansion**.
  - It **grows in thickness by accretion**.
  - It consists of 3 or more layers of wall material.
  - It is **5–10 mm thick**.
  - Its cellulose macrofibrils are long, straight, compactly arranged.
  - Its water content is about 30–40%.
  - It has **relatively high cellulose content**.
  - It has **relatively low hemicellulose**, **protein**, **and lipid contents**.
- Sometimes **tertiary wall** is laid down on secondary wall, *e.g.*, **tracheids of gymnosperms**. It is **purely cellulosic in nature**.
- The cell wall is not uniform in thickness throughout; at certain places secondary wall or both primary and secondary walls are not laid down. Such places are called **pits**.
- Pits are of **two types** – **simple pit** in which pit chamber is uniform in diameter, and **bordered pit** in which pit chamber is flask-shaped in tracheids of gymnosperms and vessels of angiosperms.
- A number of **plasmodesmata or cytoplasmic strands** are present in pit through which the cytoplasm of one cell is in contact with another.
- Endoplasmic reticulum **plays a role in origin of plasmodesmata**.
- **Origin of cell wall** takes place from cell plate during cytokinesis. Many cell wall vesicles provided by Golgi bodies and endoplasmic reticulum combine to form a cell plate. After some chemical and physical changes, the cell plate grows on both sides to form a middle lamella. Primary and secondary walls are laid down on middle lamella to form cell wall. Beside these, different materials are deposited as – lignin, suberin, cutin, silica and mucilage.

- **Lignin** is special type of polysaccharide which deposits mainly in xylem cells and makes them hard and lignified. Due to its deposition xylem tracheids take up different forms, *e.g.*, annular thickening, spiral thickening, scalariform thickening.
- **Suberin** is a complicated mixture of fatty acids deposited on cork cells. Suberin is impermeable to water.
- **Cutin** is a wax-like fatty substance. It is deposited on the epidermal cells in the form of cuticle which reduces loss of water. Cuticle is very thick in xerophytes, thin in mesophytes and absent in hydrophytes.
- **Silica** In some cases sand or silica particles are deposited which give a rough touch, *e.g.*, *Equisetum* and *Saccharum munja*.

  In family Moraceae, Urticaceae, Cucurbitaceae and Acanthaceae, Ca oxalate and Ca carbonate crystals are deposited.
- **Mucilage:** Some cells are slippery to touch due to secretion of mucilage, e.g., blue-green algae. The cells can withstand extremes of temperature, *i.e.*, very low or very high.
- After maceration it has been found that cell wall consists of fibrils and gel like matrix.
- The macrofibrils consists of bundle of microfibrils which in turn consists of bundle of micelles.
- The matrix consists largely of polysaccharides. It also contains polygalacturonic acid and xylans.
- **Functions of cell wall** are –
  - It maintains shape of the cells.
  - It protects the cell from mechanical injury.
  - It wards off the attack of pathogens (viruses, bacteria, fungi, protozoans).
  - It provides mechanical support against gravity.
  - The cell wall prevents undue expansion of the cell when water enters by osmosis to compensate for the lack of contractile vacuole. This prevents bursting of cells.
  - It allows the materials to pass in and out of the cell.
  - Though permeable, the cell wall plays some regulatory role on the passage of materials into and out of the cell.
  - Growth of the cell wall enables the cells to enlarge in size.
  - The wall in some cases has a role in defence and offense by means of spines.

CYTOPLASM

- The **cytoplasm** surrounds the nucleus and is enclosed by the plasma membrane.
- Cytoplasm, a jelly like substance (**called cytosol** or **hyaloplasm or cytoplasmic matrix**) and composed of mainly water is **found between the cell membrane and nucleus**.
- Cytoplasm contains the structures and substances needed to decode the instruction of DNA and carry on the activities of the cell.
- Autonomic movement of matrix in the cytoplasm in a cell is called **cytoplasmic streaming** or **cyclosis**.
- Cytoplasm exists in two states – **sol** (plasmasol) and **gel** (**plasmagel**).
- **Sol** or **hydrol** is a liquid colloidal solution where the colloidal particles are well dispersed in water.
- **Gel** is a thick semi – solid colloidal system in which the colloidal particles come in contact and form a sort of network with water dispersed in the meshes.
- **Only the sol part of the cytoplasm** shows cyclosis.
- Cytoplasmic structures comprises 3 groups – **cell-organelles**, **cytoplasmic inclusions**, and **cytoskeleton**.

Cell organelles

- These are regarded as **living structure of a cell**.
- They are **capable of growth**, some may divide also and form metabolic machinery of a cell.
- These are **formed in the cell itself**.
- Eukaryotic cells are far more complex than prokaryotic cells.
- Both animal and plant cells share the same features but plant cells usually have the following feature in addition – cell wall (*described earlier*), vacuole and chloroplast.
- While centrioles, basal bodies and flagella are present in animal cells and are lacking in plant cells.
- The **type of organelles** are – ER, golgi complex, lysosome, mitochondria, ribosomes, microbodies, cytoskeletal structures, flagella and cilia etc.

Endoplasmic reticulum (ER)

- The ER was **first noted by Porter**, **Claude and Fullman** in 1945 as a network. It was **named ER by Porter** in 1953.
- It is **absent in prokaryotes** but **present in all the eukaryotes** except germinal cells and mature mammalian erythrocytes.

Structures formed by ER

- **Sphaerosomes.** Sphaerosomes (= spherosomes) are small cell organelles bounded by single membrane which take part in storage and synthesis of fats. They were discovered by **Perner** in 1953. Sphaerosomes are small spherical and refractile vesicles which are 0.5-1.0 mm in diameter. 98% of a sphaerosome is fat. Proteins constitute the remaining 2%. Some proteins are probably enzymatic and take part in the synthesis of fats. Because of the presence of fat, sphaerosomes can be seen under light microscope after staining the cells with Sudan dyes and osmium tetraoxide. Sphaerosomes **occur abundantly in the endosperm cells of oil seeds**. Sphaerosomes of some tissues (e.g., tobacco endosperm, maize root tip) contain hydrolytic enzymes. Therefore, they are considered to have lysosomic activity.
- **Ergastoplasm.** The term ergastoplasm used for the specialised ER with ribosomes. Furthermore they show special staining and cytochemical properties and may be connected with the ER.
- **Myeloid bodies.** Another kind of specialized endoplasmic reticulum (SER) which are found in the pigmented epithelial cells of retina. Ribosomes are not found attached to them. It consists of vesicles and tubules near the basement membrane of the cell so they acts as photoreceptors of the cells.
- **Microsomes.** Microsomes are the fragments of RER. It may **also derived from the plasma membrane**. They are formed as a result of fragmentation of cells. Microsomes derived from RER have ribosomes attached to outside. It should be noted that they are not found in the intact cell, *i.e.* they are not the natural cell structures.

- **Development of ER depends upon the metabolic state** and **stage of differentiation of the cells**, *e.g.*, **absent** from embryonic cells, **less developed** in spermatocytes (only a few vesicles) and **well-developed** in fully differentiated and metabolically active cells (*e.g.*, pancreas, liver, etc.) and **simple** in storage cells (in the form of tubules in adipose cells).
- The striated muscle fibres have a special type of ER called **sarcoplasmic reticulum (SR)**.
- ER is a **well-developed electron microscopic network of interconnected cisternae, tubules** and **vesicles** present throughout the cytoplasm, especially in the endoplasm.
- **Cisternae** are **flattened**, **unbranched**, **sac-like elements**. The sacs in the stack are interconnected with one another. They **bear ribosomes on the surface** that makes the cisternae appears rough.
- The cisternae **contain glycoproteins** named **ribophorin-I** and **ribophorin-II** that bind the ribosomes.
- **Tubules** are **tube-like extensions** which may be connected with cisternae or vesicles to **form a reticular system**. The tubules can be irregular or regular, branched or unbranched with a diameter of 50-100 nm **often free of ribosomes**.
- **Vesicles** are **oval or rounded**, **vacuole-like elements** 25-500 nm in diameter. They often occur isolated in the cytoplasmic matrix. They are also **free of ribosomes**. They are often called **microsomes**.
- The endoplasmic reticulum (ER) is a complex organelle, **involved in the synthesis, packaging and processing of various cell substances**.
- The ER membranes **actually attach to the cell membrane** and **the nuclear membrane as well as golgi bodies in the cytoplasm**.
- In mature cells, **ER occurs** in **2 forms** – **rough (RER)** and **smooth (SER)**.
- The fine **structure of RER** (membranes and individual ribosomes) is **visible only with the electron microscope.**
- RER (**consists mainly of cisternae**) is mainly **concerned with the synthesis of proteins** for sequestration from the rest of the cytoplasm, *i.e.*, secretory proteins such as collagen, proteins for incorporation into cell membrane, and lysosomal enzymes (separated from the rest of the cytoplasm to prevent autolysis).
- The **smooth endoplasmic reticulum** (SER) **lacks ribosomes** and thus appears smooth in electron micrographs.
- SER cisternae are **more tubular or vesicular** than those of the RER.
- SER **has many enzymes, important in lipid metabolism**, **steroid hormone synthesis**, **glycogen breakdown** (glucose-6-phosphatase) and **detoxification**. The last occurs *via* enzymatic conjugation, oxidation and methylation of potentially toxic substances.

- SER is also **abundant in liver cells (hepatocytes)**, where it is **involved in glycogen metabolism and drug detoxification**.
- **Functions of ER** are –
  - Facilitates transport of materials from one part of the cell to another, thus forming the cell's circulatory system.
  - Detoxification of drugs
  - associated with muscle contraction by release and uptake of Ca^{2+} ions
  - Help in formation of primary lysosome with hydrolytic enzymes.
  - Helps in the synthesis of nuclear envelope during telophase of cell division.
  - Provides space for temporary storage of synthetic products such as glycogen.

Golgi complex

- Golgi complex **(Golgi apparatus or dictyosome)** participates in many activities, particularly those associated with secretion.
- In **animal cells** Golgi complex or apparatus is either single or consists of a single connected complex. The two conditions are respectively called **localized** (most vertebrate cells) and **diffused** (most invertebrate cells, liver and nerve cells of vertebrates). The localized organelle is compact. It generally occurs at one end between the nucleus and the periphery. The diffused organelle is found to form a network, e.g., around the nucleus in nerve cells.
- In **plant cells** Golgi apparatus is formed of a number of unconnected units called **dictyosomes**. Their number is highly variable—from one in certain simple algae to 25000 in rhizoidal cell of *Chara*.
- A liver cell may possess upto 50 units of Golgi apparatus called **Golgisomes**.
- This membranous organelle comprises **3 major compartments** : (1) a stack of 3-10 discrete, slightly curved, flattened **cisternae**; (2) numerous small **vesicles** peripheral to the stack; and (3) a few large condensing **vacuoles** at the concave surface of the stack.
- Products synthesized by the ER are packaged in vesicles by the Golgi complex. These secretory vesicles, or secretory granules, are transported to the plasma membrane for **exocytosis**.
- Golgi complexes are **best developed in neurons and glandular cells**, which are specialized for secretion.
- Golgi apparatus is named from **Camillo Golgi** who discovered it in 1898 in the nerve cells of barn owl and cat by means of metallic impregnation method (*i.e* osmium chloride + silver salts).
- The golgi apparatus is the **processing, packaging** and **secreting organelle of the cell**.
- **Functions of Golgi apparatus** are –
  - A variety of enzymes are localized in the Golgi complex to help in the cell's biochemical reaction.
  - Absorbs materials from the environment.
  - Lipids and proteins coming from the ER are complexed into lipoproteins in the Golgi apparatus. This process is **liposylation**.
  - Golgi apparatus links carbohydrates with protein coming from ER to form glycoproteins. This process is **glycosylation**.
  - Formation of nematocytes (in *Hydra*) and trichocysts (in *Paramecium*).
  - Formation of acrosome, an important constituents of the tip of animal sperms.

Table : Functions of golgi complex in different types of cells

	Cell type	Golgi functions
1.	Exocrine cells of pancreas	Secretion of zymogen (digestive enzymes – protease, lipase carbohydrates and nucleases).
2.	Goblet cells of intestinal mucosa	Secretion of mucus and zymogens.
3.	Paneth cells of intestine	Secretion of proteins.
4.	Brunner's gland cell or duodenum and ileum	Secretion of mucopolysaccharides.
5.	Hepatic cells of liver	Transformation and secretion of lipids.
6.	Follicle cells of thyroid gland	Prothyroglobulins (hormone).
7.	Plasma cells of blood	Immunoglobulins (hormone).
8.	Cells of alveolar epithelium of mammary glands	Secretion of milk proteins.
9.	Plant cells	Secretion of protein and cellulose.

- In plant cells, synthesizes pectin and some other carbohydrates, necessary for the formation of cell walls etc.

Lysosomes

- The lysosomes are **noticeable with electron microscope only**.
- The lysosomes were **first reported** by a Belgian cytologist and biochemist **Christian de Duve** in 1955.
- In 1956, **Novikoff** observed lysosomes in the cell with electron microscope and coined the term lysosome.
- Lysosomes are **common** in the cell of animals, fungi and protista, but **rare in plant cells**.
- In **animals**, lysosomes are **abundant in leucocytes, macrophages**, **Kupffer's cells** and similar cells with phagocytic activity, **prokaryotes lack lysosomes**.
- Lysosomes are spheric, single membrane-limited vesicles (produced by golgi apparatus) that may contain more than 50 enzymes each and function as the cellular digestive system.
- Lysosome is also known as **suicidal sac/bag** as they contain hydrolytic enzymes.
- At **pH 4.8** the **interior of the lysosomes is more acidic than the cytosol pH 7**.
- The **important enzymes** are – acid phosphatases, sulphatases, proteases, nucleases, lipases and glycosidases. They are also called **acid hydrolases** because these digestive enzymes (usually occur as glycoproteins) usually function in acidic medium or pH less than 7.
- The covering membrane of lysosomes keeps the hydrolytic enzymes out of contact from the cellular contents. The covering membrane becomes fragile in the absence of the oxygen, or the presence of excess of vitamins A and E, male and female hormones, bile salts, X-rays and ultra-violet rays. These are called **membrane labilizers**.
- These labilizer **cause instability of the lysosomal membrane**, **leading to release of enzymes from the lysosomes**.
- The membrane is **protected from these agencies by cortisone**, **cortisol**, **chloroquine** and **a type of cholesterol**. These substances are called **membrane stabilizers**.
- Lysosomes are of **two types** – **primary** and **secondary**.
- **Primary lysosomes** are small (5-8 nm in diameter), with electron-dense contents.
- Primary lysosomes are the **storage form of lysosomes** and **their enzymes are mostly inactive**.
- The primary lysosomes disperse through the cytoplasm. They are found in most cells but are **most abundant in phagocytic cells**, eg. macrophages, neutrophils.
- **Secondary lysosomes** are larger and less electron dense.
- They are **formed by the fusion of one or more primary lysosomes with a phagosome**.
- Their **primary function** is **digesting products of heterophagy** and **autophagy**.
- Secondary lysosomes **occur throughout the cytoplasm** in many cells, in numbers that reflect the cell's lysosomal and phagocytic activity.
- **Residual bodies** (or **tertiary lysosomes**) are membrane limited inclusions of various sizes and electron densities associated with the terminal phases of lysosome function.
- They **contain undigestible materials** such as pigments, crystals and certain lipids. Some cells (eg, macrophages) expel residual bodies as waste, but **long-lived cells** (eg, nerve, muscle) **tend to accumulate them**.
- **Autodigestion** occurs when lysosome digests parts of the cells.
- **Missing or inactive lysosomal enzymes** causes serious childhood diseases (like Tay sach's disease or Pompe's disease).
- **Functions of lysosomes** are – digestion of useful unwanted and harmful materials; renewal of cells and organelles; by releasing nucleases, it may cause mutations and breakage of chromosomes which may lead to blood cancer.

Ribosomes

- Ribosome are **small dense cytoplasmic particles** which are found individually in the cytoplasm and also line the membranes of the rough endoplasmic reticulum.
- Ribosomes were **discovered by Robinson and Brown (1953) in plant cell** and **Palade (1955) in animal cell**.
- Palade **also coined the term ribosome**.
- The ribosomes are especially **numerous in actively synthesizing cells**, such as liver cells, pancreatic cells, endocrine cells, lymphocytes, yeast cells, and meristematic cells.
- They are **fewer in less active and starved cells**. As expected the cancer cells have numerous ribosomes.

They are **absent in mammalian RBC**.

- Ribosome is an organelle **composed of RNA** and **ribosomal proteins.**
- Ribosomes are the **site of protein synthesis** (production or construction) **in a cell** hence called **protein factory**.
- There are **2 basic types of ribosome** – **mitochondrial** (like prokaryotic, eg PPLO, bacteria, blue green algae) **ribosomes** which are smaller (20 nm) than the **cytoplasmic ribosomes** of eukaryotes (25 nm).
- **Mitochondrial ribosomes** (**70S overall**) have a 50S and a 30S subunit; **cytoplasmic ribosomes** (**80S overall**) have 60S and a 40S subunit Or the ribosomes are also of two types: **80S** and **70S**.
- 80S ribosomes or cytoplasmic ribosome are **synthesized inside the nucleolus**.
- The **two subunits of 80S** ribosome are – **60S** (large subunit) and **40S** (small subunit). 5S RNA is synthesised separately while others are formed by the nucleolus. 80S ribosomes **do not become functional inside the nucleolus**. Their subunits come out of the nucleus and become operational in cytoplasm.
- Cytoplasmic ribosomes occur in 2 forms– **free** (found in cytosol) or **bounded** (membrane bound, found exterior of the ER constituting rough ER).
- **70S** ribosome have **50S** and **30S subunits**. **Magnesium** ions **play an important role in holding the two subunits together** and also in **maintaining the structure of the two subunits**.
- **Svedberg unit** (S) is a measure of rate of sedimentation of a particle in a centrifuge, where the sedimentation rate is associated with the size of the particle.
- **Polyribosomes or polysomes** are groups of ribosomes distributed along a single strand of messenger RNA (*m*RNA) in an arrangement that permits synthesis of multiple copies of a protein from the same message.
- Polysomes **occur free in the cytoplasm** (free polysomes) and are attached to membranes of the rough endoplasmic reticulum.
- **Ribosomes read (translate) the *m*RNA code** and thus play a critical role in assembling amino acids into specific proteins.
- **Functions of ribosomes** are –
  - Furnish enzymes and factors needed for the formation of polypeptides.
  - Provide sites for the attachment of tRNAs and mRNA which participate in protein synthesis.
  - Newly formed polypeptide is protected from degradation by cytoplasmic enzymes in a tunnel of the large ribosomal subunit before releasing it into RER lumen.
  - Groove between the two subunits furnishes the site for the synthesis of polypeptide.

Microbodies

- The microbodies were **first seen by Rhodin in 1954** in the electron micrographs of mouse kidney tubule cells.
- The microbodies occur in nearly all eukaryotic cells. They **usually lie near the endoplasmic reticulum**, sometimes near the mitochondria or plastids or both.
- The **microbodies** are minute, simple, roughly spherical sacs bounded by a single unit membrane.
- They contain a densely granular matrix which has a regular **core** or **nucleoid** of crystalline material. The latter represents a variety of enzymes. These **enzymes catalyse oxidation reactions not involved in respiration**.
- The microbodies bud off from the rough endoplasmic reticulum after receiving the enzymes synthesized on the latter.
- The **microbodies** are of **three main types: peroxisomes** (**animal** and **plant peroxisomes**) and **glyoxysomes**.
- The **peroxisomes were so called** because of their potential peroxidase activity. Peroxisomes in contrast to lysosome are **produced only on the smooth ER**. The rare total genetic disease Zellweger's syndrome is the result of malformed peroxisomes. All types share peroxisomes catalase activity.
- **Animal peroxisomes** are **abundant in the liver and kidney cells of vertebrates**. They are also found in other organs, such as brain, small intestine, testis, and adrenal cortex. They also occur in the invertebrates and protozoans, such as *Paramecium*.
- The peroxisomes **contain one or more peroxide producing enzymes** like urate oxidase, D-amino acid oxidase, α-hydroxy acid oxidase and β-hydroxy acid oxidase. Molecular oxygen is required for producing hydrogen peroxide (H_2O_2).
- Peroxisomes also contain another enzyme, **catalase**, for metabolising hydrogen peroxide.
- Peroxisomes **help in detoxifying the alcohol in the liver cells**. In animal cells, peroxisomes **take**

part in oxidation of a number of biochemicals including extra amino acids, alcohol and toxins. *For example*, about 50% of the alcohol consumed by a person is detoxified by peroxisomes inside liver cells. The microbodies may also take part in **lipid metabolism.**

- **Plant peroxisomes** are **found in the leaf cells** capable of photosynthesis.
- They **contain enzymes present in both animal peroxisomes and glyoxysomes**. In addition, they have enzyme **glycolic acid oxidase** that oxidises glycolic acid (glycolate), a product of photosynthesis, to glyoxylic acid, a process called **photorespiration.**
- Photorespiration is **so called** because light induces the synthesis of glycolic acid in chloroplast. The entire process involves intervention of two basic organelles – chloroplast and peroxisomes.
- The **plant peroxisomes have enzymes for all these reactions** also. Thus, **they are the most complex microbodies**.
- **Glyoxysomes** are microbodies which **contain enzymes for β-oxidation of fatty acids** and **glyoxylate pathway**.
- These microbodies have been recorded only in plant cells. They are quite common in germinating oil seeds such as castor, watermelon, cucumber, peanut and others.
- Like other microbodies, glyoxysomes have a single covering membrane and an enzyme rich matrix with a crystalloid core. β-oxidation of fatty acids produces acetyl CoA. The latter is metabolised in glyoxylate cycle to produce carbohydrates. Glyoxylate cycle converts two acetyl CoA units into C_4 acids for gluconeogenesis.

Plastids

- Plastids are organelles enclosed by a **double membrane found in all plants** and **some unicellular organisms** (*Euglena*) of uncertain affinity.
- Plastids are of **different types** varying in shapes, size, colour and function.
- **E. Haeckel** (1865) gave the term plastid.
- Plastid are the **largest cell organelle**, and **involved in the formation** and **storage of soluble and insoluble carbohydrates**.
- Plastids are **broadly classified into two groups** – **leucoplast** *i.e* colourless plastids incapable of performing photosynthesis and **chromoplast** *ie* coloured plastids which are photosynthetically active.
- These organelles are bound by two membranes. As these organelles contain their own genetic material, and protein synthesizing machinery *i.e* DNA, RNA and ribosomes, they are **capable of multiplication by a fission like process**.
- **Leucoplasts** are **colourless plastids**. Oval, spherical rod like or filamentous leucoplasts **occur in large number in cells of fruits**, **seeds**, **tubes** and rhizomes. Leucoplasts **act as storage organelles**.
- Leucoplasts are **classified into three types** on the basis of the material stored -
  - **Amyloplast** (of potato) stores starch.
  - **Elaioplast** stores droplets of oil or fats.
  - **Proteinoplast** store protein grains (**aleuroplast**)
- **Chromoplasts** are **coloured plastids** with yellow, orange and red carotenoids and other pigments.
- Chromoplasts are **responsible for colours** in flowers, ripening fruits, autumn leaves and some root like carrot.
- Chromoplast arises from proplastid or chloroplast.
- **Proplastids** are found in embryonic tissue, composed only of an inner membrane, outer membrane, a small amount of stromal space with **DNA**.
- The term **chloroplast** was **coined** by **A.J.W. Schimper** in 1883.
- Besides leucoplast (aleuroplast), starch grains can develop in **chloroplast**.
- Chloroplast are the **photosynthetic organelles** (able to capture light energy using H_2O and CO_2) **of green plants and contain the pigment chlorophyll**.
- Chloroplast is the organelle which **acts as factory for the synthesis of sugars in autotrophic eukaryotes.**
- Each chloroplast is covered with a **double membrane** containing a proteinaceous matrix (or ground substance) called **stroma**.
- Stroma contains a small circular **double-helical DNA**, **ribosomes** and **several enzymes**.
- **Ribosomes of chloroplasts** are **70S type containing 23S and 16S RNA**.
- Many sheet-like lamellae (called **thylakoids**) occur in stroma.
- The term thylakoid was given by **Menke (1961).** About **20-50 thylakoids** are placed one above the other like a stack of coins to form a **granum**.
- Many membranous tubules called **stroma lamellae** interconnect thylakoids of different grana.

Table : Plastids, their occurrence and functions.

	Kind of plastids	Occurrence	Functions	Pigment
		Chromoplasts		
A.	**Photosynthetically active chromoplasts**			
1.	Chloroplast	Higher plants and green algae	Photosynthesis	Chlorophyll-*a* and chlorophyll-*b*
2.	Pheoplasts	Brown algae, diatoms dinoflagellates	Light absorption	Fucoxanthin along with chl *a* and chl *c*
3.	Rhodoplasts	Red algae (rhodophyceae)	Light absorption	Chl *a* along with phycoerythnin and phycocyanin
4.	Blue-green chromoplasts	Blue-green algae	Photosynthesis	phycocyanin, phycoerythrin, chlorophyll-*a*, and carotenoids
5.	Chromoplasts of photosynthetic bacteria	Purple and nonpurple sulphur bacteria	Absorption of infra-red portion of light	Bacteriochlorophyll
B.	**Chromoplasts devoid of photosynthetic activity**			
6.	Carotenoids	Tomato, redpepper, flower parts, fungi, bacteria and fruits	—	Lycopene and capsanthin
		Leucoplasts		
7.	Amyloplasts	Storage tubers, cotyledons and endosperm	Starch storage	None
8.	Elaioplasts	Epidermal cells of Orchidaceae and Liliaceae	Oil storage	None
9.	Aleuroplasts	Epidermal cells of Helleborus and seeds of *Ricinus* and Brazil nut	Protein storage	None

- **Quantasomes** are **photosynthetic units** present on the surface of grana.
- Each quantasome contains **230 chlorophyll molecules**.
- Chlorophyll molecule has a complex **porphyrin ring** with a long **phytol chain**.
- The metal **magnesium** is located at the **centre of chlorophyll molecule**.
- The blood pigment **haem** is almost identical to chlorophyll but it contains **iron** instead of magnesium.
- Chlorophyll has **four pyrrole rings**, so called a **tetrapyrrole**.
- **Pigments of chlorophyll** are – chl *a*, *b*, *c*, *d*, *e*, and carotenoids.
- **Anthocyanin** does not occur in chloroplast.
- **Absence of chlorophyll** in plants is known as **albinism**.

Mitochondria

- Mitochondria is the **third largest organelle in plant cell** and **second largest organelle in animal cells**.
- Mitochondria are the **site of chemical reactions** that transfer energy from organic compounds to ATP.
- ATP is called the **energy currency of the cell**.
- ATP production is called **cellular respiration**.

- The mitochondria were **first seen in 1880 by Kolliker**, who isolated them from insect muscle cells. They were **named mitochondria by Benda** in 1898.
- Mitochondria can be **stained differentially with Janus Green** and are **easily distinguishable under light microscope** though ultrastructure can be studied only under electron microscope.
- The mitochondria are often **concentrated in the more active regions of cells**, like – in the muscle cells, in the sperm, in the gland cells, in the intestinal epithelial cells near the absorptive surface, in dividing cells, and in cilia bearing cells, because these location of mitochondria quickly deliver ATP for cell activities.
- Each mitochondrion is bounded by **2 unit membranes**.
- The **outer mitochondrial membrane** has a smooth contour and **forms a continuous but relatively porous covering**. It is **freely permeable to various small molecules**.
- The **inner mitochondrial membrane** is less porous and thus is semipermeable. It **has many infoldings or cristae** that project into the mitochondrion's interior.
- The cristae **greatly increases the surface area of the inner membrane** by providing more space for the chemical reaction to occur.
- The **intermembrane space** is located between the inner and outer membranes and is continuous with the intracristal space which extends into the cristae.
- The wide space between the cristae is called the **inner chamber**. It is **filled with a dense fluid termed the mitochondrial matrix.**
- The matrix **contains proteins and enzymes, lipids, some ribosomes, RNA, one or two DNA molecules and certain ions, fibres, crystals and granules**. The ribosomes are 70S in size like those of the prokaryotic cells. They are called **mitoribosomes** in contrast to the 80S **cytoribosomes** that occur in the cytoplasm. The DNA molecules are circular, short and without proteins as in the prokaryotic cells. All the three types of RNAs (rRNA, tRNA and mRNA) are present in the mitochondrial matrix. The ions include Ca^{++} and Mg^{++}. These are necessary for the functioning of mitochondrial enzymes.
- The numerous soluble enzymes, present in matrix, involved in **specialized mitochondrial functions** such as the Krebs cycle (tricarboxylic acid cycle), β-oxidation of lipids and mitochondrial DNA synthesis.
- The inner surface is covered by inner membrane subunits, also called **F_1 subunits/mitochondrial particles/oxysomes etc**.
- These particles were **first seen by fernandez Moran in 1961**.
- In recent works only **the stalked particles of the inner membrane are involved in various oxidation reaction and are supposed to supply electrons to the interior of the organ**. Therefore they are **termed as electron transport particle or functional unit of mitochondria**. These particles are spaced about 100 Å interval.
- An oxysome **consists of 3 parts** – a rounded **head piece**, or **F_1 subunit**, joined by a short **stalk** to a **base piece**, or **F_0 subunit**, located in the inner membrane. There may be 100,000 to 1,000,000 oxysomes in a single mitochondrion.
- The oxysome, also called **F_0-F_1 complex**, represents **adenosine triphosphatase,** or **ATPase**, or **ATP synthetase,** enzyme and is thus **concerned with ATP formation**.
- The rest of the inner mitochondrial membrane contains the electron carrier molecules (coenzymes) of the electron transport chain (flavoprotein, FeS, CoQ, cyt. b, cyt c_1, cyt. c, cyt. a, cyt. a_3), succinate dehydrogenase and enzymes of fatty acid synthesis.
- Mitochondria **provide energy for chemical and mechanical work** by storing energy, generated from cellular metabolites, in the high energy bonds of ATP.
- Mitochondria **grow and reproduce by fission or budding** and can undergo rapid movement and shape changes.
- Mitochondria are also called **semi-autonomous organelle** as they synthesize their own DNA and some proteins.
- **Cardiac muscle cells are notable for their abundant mitochondria**. Epithelial cells lining the kidney tubules have abundant mitochondria interdigitated between basal plasma membrane infoldings where active transport of ions and water occurs.
- Mitochondria are also **called the powerhouse of the cells** because their primary purpose is to manufacture adenosine triphosphate (ATP), which is used as a source of energy.

Enzymes of Mitochondria

Outer membrane
- Monoamine oxidase
- Rotenone-insensitive NADH-cytochrome c reductase
- Kynurenine hydroxylase
- Fatty acid CoA ligase

Space between outer and inner membranes
- Adenylate kinase
- Nucleoside diphosphokinase

Inner membrane
- Respiratory chain enzymes
- ATP synthetase
- Succinate dehydrogenase
- β-hydroxybutyrate dehydrogenase
- Carnitine fatty acid acyl transferase

Matrix (contain enzymes of Krebs cycle)
- Malate and isocitrate dehydrogenases
- Fumarase and aconitase
- Citrate synthetase
- α-keto acid dehydrogenases
- β-oxidation enzymes

(Inner membrane and Matrix enzymes:) **Constitute respiratory unit**

Cilia & Flagella

- **Cilia** are **short, more numerous** hair like structures made of **bundle of microtubules** to help cells move.
- Cilia **occur in group ciliata of protista, flame cells of worms, larval bodies of many invertebrates, epithelium of respiratory tract, renal tubules, oviducal funnel**, etc.
- A **flagellum** is like a cilium, but it is **longer** and there is usually only one or 2 flagella on a cell.
- There are **three main varieties of flagellum** – the **bacterial flagellum** (a helical filament that rotates like a screw), **archaeal flagellum** (similar but nonhomologous to the bacterial flagellum), and the **eukaryotic flagellum** (a whip-like structure that lashes back and forth).
- Flagella of bacteria **do not show 9 + 2 arrangement**.
- The **principal protein** of cilia and flagella is **tubulin**.
- Both cilia and flagella have following parts – **basal body**, **rootlets**, **basal plate** and **shaft**.
- **Basal body or kinetosome** is also called **basal granule** or **blepharoplast**.
- The basal bodies of cilia are found embedded in the refractile, gelatinous ectoplasm immediately beneath the cell surface and are uniformly spaced in straight parallel rows. The **basal bodies are said to be homologous to the centriole**.
- **Rootlets** are striated fibrillar outgrowths which develop from the outer lower part of the basal body and are **meant for providing support to the basal body**.
- The rootlets are **made of bundles of microfilaments**. They are **commonly present** in the ciliated epithelium of lower animals but are **absent** in the ciliated epithelium of mammals and in the ciliated protozoa.
- **Basal plate** is an area of high density which **lies above the basal body** at the level of plasma membrane. In the region of basal plate, one sub-fibre of each peripheral fibril disappears. The central fibrils develop in this area.
- **Shaft** is the **hair-like projecting part** of flagellum or cilium.
- The shaft is covered on the outside by a sheath which is the extension of plasma membrane. Internally, it contains a semifluid matrix having an **axoneme** (an essential motile element) of 9 peripheral doublet fibrils and 2 central singlet fibrils. This arrangement is called **9 + 2 or 11-stranded in comparison to 9 + 0 arrangement of the centriole or basal body**.
- Each axoneme is organized by and anchored in a **basal body**.
- The function of cilia and flagella includes **locomotion** for one celled organism and **to move substances over cell surface** in multicelled organism.
- The movements of cilia and flagella are brought about by sliding of doublets past each other rather than by their contraction.
- The cilia may beat in **metachronous** or **synchronous (isochronous) rhythm.** In metachronous rhythm, the cilia of a row beat one after the other, whereas in synchronous rhythm all the cilia of a row beat simultaneously.
- Movements of cilia and flagella are of **four types** – **pendulus movement**, **undulant movement**, **unciform movement**, and **infundibuliform movement.**

Table : Major protein structures of the axoneme of the cilia and flagella.

	Axoneme component	Functions
1.	Tubulin (8 nm)	Principal component of microtubule.
2.	Dynein (24 nm)	Project from microtubule doublets and interacts with adjacent doublets to produce bending.
3.	Nexin link (86 nm)	Hold adjacent microtubule doublets together.
4.	Radial spokes (29 nm)	Extend from each of the nine outer doublets inward to the central pair.
5.	Sheath projection (14 nm)	Projects as a series of side arms from the central pair of microtubules; together with radial spokes these regulates the form of ciliary beat.

- **Functions of cilia and flagella** are –
  - They help in locomotion in flagellate and ciliated organisms.
  - They create current for obtaining food from aquatic medium. It is also called food current.
  - In some protists and animals, the organelles take part in capturing food.
  - The canal system of porifers operates with the help of flagella present in their collar cells or choanocytes.
  - In coelenterates, they circulate food in the gastrovascular cavity. In tunicates and lancelets, the cilia help in movement of food and its egestion.
  - In land animals the cilia of the respiratory tract help in eliminating dust particles in the incoming air.
  - Internal transport of several organs is performed by cilia, e.g., passage of eggs in oviduct, passage of excretory substances in the kidneys, etc.
  - Ciliated larvae take part in dispersal of the species.

Centriole (Centrosomes)

- Centrioles are **submicroscopic**, **microtubular**, **subcylindrical structures** which **usually occur in the form of two granules** oriented at right angles to each other. These are also called **diplosomes** (= pair of centrioles).
- Two centrioles are always found inside a specialized distinctly staining cytoplasm that lacks other cell organelles and is called **centrosphere** or **cytocentrum**.
- The **complex formed of centriole and centrosphere** was termed **centrosome**.
- The term '**centrosome**' was given by **Theodar Boveri** 1888.
- A centriole is 150 nm in overall diameter and 350-500 nm long, **containing 9 microtubule triplets in a pinwheel array**. Fibrils are **absent in the centre**. The arrangement is therefore called **9 + 0**.
- Each microtubule in a triplet, shares a portion of the wall of the neighbouring microtubule.
- Centrioles are the **structural organizers of the cell**.
- **Centriole duplication is a pre-requisite** for cell division and during mitosis the centrioles organize the microtubules of the mitotic spindle.
- The centriole and associated golgi complexes constitute the cell **cytocentre**, which appears as a clear zone near the nucleus.
- During the S phase of interphase, each centriole duplicates by giving rise to a **procentriole** that grows at right angles to the original. During mitosis, the new **centriole pairs migrate to opposite cell poles** to organize the spindle.
- **Centriole and basal bodies have common structure** and **power of duplication**.
- Basal bodies are structurally similar to centrioles with 9 microtubule triplets.
- Basal bodies occur in the **cytoplasm**, one at the base of each cilium or flagellum, and serve as the **anchoring points** and **microtubule organizers** for these structures.
- Some spindle microtubules (**continuous fibres**) extend from centriole to centriole. Others (**chromosomal fibres**) extend from one centriole to the centromere of a chromosome.
- The centrioles **occur in nearly all animal cells** and **in motile plant cells** such as zoospores of algae, sperm cells of ferns and motile algae. They are **absent** in amoebae, prokaryotic cells, higher gymnosperms and all angiosperms.
- **Functions of centriole** are –

– **Serves as basal bodies** for cilia and flagella.
– Concerned with **spindle formation** during cell division, therefore called microtubule organising centre (MTOCs).
– Though centriole does not contain DNA yet they are capable of forming new centrioles with the helps of **massules or pericentriolar satellites** which function as nucleating centres.

Cell inclusions

- The cell inclusions are **non-living materials** present in the cytoplasm.
- They are often called **deutoplasmic substances**.
- They may be **organic or inorganic compounds**, or both.
- The **common cells inclusions** are– **stored organic food materials**, **secretions** and **excretions** and **inorganic crystals** (*See table given below*).
- **Reserve food materials** are of **four major types**: starch grains, glycogen granules, aleurone grains, fat droplets.
- **Starch grains** are **found in plant cells only**, particularly in storage organs such as seeds, fruits, rhizomes, and tubers. They are spherical, oval, elliptical or polyhedral bodies. Each starch grain contains a shining body called **hilum** made of protein.
- **Fat droplets** are **found in adipocytes** (fat-storing cells) of animals, the **endosperm of castor** and **coconut** and **cotyledons of groundnut** and **mustard seeds**.
- **Glycogen granules** are small, spherical or large rosette-shaped particles occurring near SER in liver and muscle cells. Glycogen granules are also found in blue-green algae, slime moulds, fungi and bacteria.
- **Aleurone grains** contain stored proteins. They are present in all cereal grains such as wheat, maize and barley below seed coat.
- **Excretory and secretory products** are of several types like mucus in several animal cells; essential oils, alkaloids (eg atropine, colchicine, nicotine etc), resins, gums, tannins, latex, nectar, gum, resins in plant cells, etc.

Cytoskeleton

- The cytoskeleton is a cellular scaffolding or skeleton contained within the cytoplasm.
- Cytoskeleton consists of a network of **long protein tubes and strands** in the cytoplasm to give **cells shape** and **helps move organelles**.
- The cytoskeleton is a mesh of filamentous elements called **microtubules**, **microfilaments** and **intermediate filaments** and provide structural stability for the maintainence of cell shape.
- It is important in cell movement and in the rearrangement of cytoplasmic components.
- **Microtubules** are larger, **hollow** tubules of the protein called **tubulin** that maintain **cell shape,** serve a **tracks for organelle movement** & help cells divide by **forming spindle fibres that separate chromosome pairs.**
- Microtubules are thickest cytoskeleton components with diameters of 24 nm. They are fine tubular structures of variable length, with dense wall (5 nm thick) and a clear internal space (14 nm across).
- The walls are composed of subunits called **tubulin heterodimers**, each of which consists of one α-tubulin and one β-tubulin protein molecule.
- The tubulin heterodimers are arranged in thread like polymers called **protofilaments.**
- Microtubules increase in length by adding new heterodimers to one end, called the **nucleation site**. This polymerization can be controlled experimentally by regulating calcium ion concentration or by treating cells with antimitotic alkaloids.
- **Colchicine** blocks the process by binding to the nucleation site. Vinblastine disrupts microtubules by binding to free tubulin.
- Microtubules **have roles** in the maintenance of cell

Table : Types of inorganic crystals

(a) *Cystolith*	It consists of calcium carbonate crystals deposited around a cellulose framework, as in epidermal cells of *Momordica*, hypodermal leaf cells of *Ficus benghalensis*.
(b) *Crystal sand*	It is a powdery mass of calcium oxalate as in *Atropa*.
(c) *Raphides*	These are needle-like crystals of calcium oxalate in *Lemna*, *Eichhornia*.
(d) *Sphaeraphides*	These are star-shaped groups of calcium oxalate crystals in *Colocasia, Chenopodium* and *Begonia*.
(e) *Prismatic crystals*	Crystals of calcium oxalate occur in the dry scales of *Allium cepa*.

shape, axoplasmic transport in neurons, melanin dispersion in pigment cells, chromosome movements during mitosis, organization of the Golgi complex, and the shuttling of vesicles within the cell.

- Unlike microfilaments, microtubules are unable to contract. Shortening occurs *via* **depolymerization.**
- Microtubules are found throughout the cytoplasm of most cells and in highly groupings in centrioles, cilia, flagella, basal bodies and the mitotic spindle apparatus.
- **Microfilaments** are **rope like** structures made of 2 twisted strands of the **protein actin** capable of contracting to cause cellular movement (muscle cells have many microfilaments).
- Microfilaments, the thinnest cytoskeletal components (5-7 nm wide) are usually composed of one of several types of actin protein.
- Microfilaments are contractile, but to contract they usually must interact with myosin.
- Microfilaments **occur in eukaryotic plant and animal cells**.
- Microfilaments often associate to form **hexagonal bundles**. They may also occur in parallel bundles or loose network. Microfilaments generally lie at sol-gel interphase as well as below plasma membrane. Microfilaments are also connected with spindle fibres, endoplasmic reticulum, chloroplast, etc.
- During mitosis of animal cells, they have been found associated with cleavage furrows.
- Microfilaments **form the contractile machinery of the cell**, like formation and retraction of pseudopodia, plasma membrane undulations, microvilli, endocytosis, cytoplasmic streaming and movement of other cell organelles.
- The **microfilaments serve a number of functions** – support, intracellular movement, streaming movement, cleavage, locomotion, change in form, contraction, movement of villi, movement of plasma membrane, membrane undulations, and formation of spindle.
- **Intermediate filaments** are intermediate in thickness (10-12 nm) between microtubules and microfilaments. They are **supportive elements in the cytoplasm of the eukaryotic cells** except the plant cells.
- They occur in the cell junctions and in the form of basket around nucleus of animal cells.
- **Examples of intermediate filaments** are – **cytokeratins** in epithelial cells, **vimentin** in mesenchymally derived cells (eg, fibroblasts. chondrocytes), **desmin** in muscle cells, **glial fibrillary acidic protein** in glial cells, **neurofilaments** (intermediate filament bundles) in neurons.
- The **IFs serve a variety of functions** –
  - They form a part of cytoskeleton that supports the fluid cytosol and maintains the shape of the cell.
  - They stabilize the epithelia by binding to the spot desmosomes.
  - They form major structural proteins of skin and hair.
  - They integrate the muscle cell components into a functional unit.
  - They provide strength to the axons.
  - They keep nucleus and other organelles in place.
  - Cardiac muscle cells are interconnected by spot desmosomes. Desmin filaments interconnect these desmosomes, allowing the stress and strain of the contractile force of one muscle to be transmitted to the other.

NUCLEUS

- The nucleus is often the **most prominent structure** within an eukaryotic cells and it controls **all functional activities of the cell**.
- The nucleus is the **control centre of the cell for cell metabolism and reproduction**.
- The nucleus is a specialised **double membrane bound organelle** which **contains genetic information (DNA) on special strands called chromosomes**.
- A nucleus **in the non-dividing or metabolic phase** is called **interphase nucleus** as it controls metabolic activites of the cell.
- The nucleus is also known as **karyon** and its study is known as **karyology**.
- The cell nucleus was **discovered** by an English botanist **Robert Brown** in 1831.
- The nucleus is the **primary carrier of hereditary material in the cell**.
- The nucleus contains a **linear code (DNA) for the synthesis of cell components and products** conferring upon the cell a range of adaptability to changing environmental conditions and to extrinsic signals such as hormones.

- The **nucleus serves many functions** –
  - Cell maintenance and growth
  - Cell metabolism
  - Genetic information
  - Cell replication
  - Ribosome formation
  - Variation
  - Cell differentiation.
- The nucleus can be divided into **five parts**: **nuclear membrane**, **nucleoplasm**, **nuclear matrix**, **chromatin** and **nucleolus** (or **nucleoli**).
- Nuclear envelope is **double membrane** that separate nucleoplasm from cytoplasm.
- The nuclear contents are set apart from the cytoplasm by a **double membrane** called the **nuclear envelope** (**karyotheca**) and a narrow (40-70 nm) intermembrane space called the **perinuclear cisternae**, or perinuclear space.
- The **outer membrane** is connected with endoplasmic reticulum and its outer surface may contain ribosomes while **inner surface is smooth**.
- In most cells, the **barr body** is attached to the **inner surface** of the nuclear envelope. In a neutrophilic leucocyte, it may appear as a drumstick shaped appendage of the lobulated nucleus.
- The nuclear envelope is **perforated by many nuclear pores**, each of which has a diameter of about 70 nm and is bounded by 8 globular subunits called **annular proteins** which presents an octagonal appearance in some preparations.
- The **pores and annuli together** are called **pore complex**.
- Nucleus communicates with cytoplasm through **nuclear pores**.
- Structure of nuclear envelope facilitates **nucleocytoplasmic exchange of materials**.
- The pores **provide a channel for the movement of important molecules between the nucleus and cytoplasm** including nucleic acids synthesized in the nucleus and used in cytoplasm (mRNA, rRNA, tRNA) and proteins synthesized in the cytoplasm and used in the nucleus (histones, polymerases).
- The nuclear envelope is **formed during telophase** by coming together and fusion of small vesicles into which the nuclear envelope breaks up during prophase.
- Nuclear envelope **serves four functions**–
  - It maintains the shape of the nucleus.
  - It keeps the nuclear contents in place and distinct from cytoplasm.
  - It regulates the flow of materials into and out of the nucleus.
  - Its pores allow the exit of ribosomal subunits and tRNAs and mRNAs.
- The nucleus contains a viscous fluid, the **nucleoplasm** (**nuclear sap** or **karyolymph**) which keeps nucleus turgid and has a different pH from cytosol.
- The **nucleoplasm** contains raw materials (nucleotides), enzymes (DNA and RNA polymerases) and metal ions (Mn^{++}, Mg^{++}) for the synthesis of DNA and RNAs. It also contains histone and nonhistone proteins for combination with DNA, and other proteins for combination with DNA, and the formation of ribosomal subunits.
- The **nucleoplasm has the following functions** –
  - It is the seat of synthesis of DNA, RNAs and ribosomal subunits.
  - It supports the chromatin material and nucleoli.
  - It provides turgidity to the nucleus.
  - Some of the proteins present in nucleoplasm are essential for spindle formation.
- The **nuclear matrix** is a network of fine, criss-crossing, acid protein-containing fibrils which are joined to the nuclear envelope by their ends. It **forms a sort of nuclear skeleton**. It remains intact after the chromatin and DNA have been removed. Terminal ends of chromatin fibres or telomeres are embedded in nuclear or fibrous lamina.

Enzymes of the nucleus

- Many enzymes associated with DNA and RNA synthesis are present in the nucleus. These enzymes include nucleoside phosphorylase and ribonuclease. The synthesis of DNA takes place inside the nucleus. Bulk of the RNA is synthesized in the nucleus and nucleolus and later these RNAs move into cytoplasm. Enzymes involved in protein synthesis are also present in the nucleus.
- Glycolytic enzymes like aldolase, enolase, 3-phosphoglyceraldehyde dehydrogenase are present in the nucleus.
- Inorganic materials like salts of calcium, magnesium, zinc, iron are present in the nucleus. These are very essential for enzyme activities.

- The **nuclear matrix has the following functions** –
  – It maintains the shape of the nucleus.
  – Chromatin fibres are anchored to nuclear matrix.
  – The machinery for various nuclear activities, such as replication and transcription, is associated with the matrix.
- **Nuclear chromatin** is **intensely basophilic** and consists of DNA and associated basic histone and acidic or neutral nonhistone proteins.
- Histones are structural protein and non-histones are functional proteins.
- Chromatin is the **interphase chromosomal material**, a complex between eukaryotic DNA and protein.
- The **major proteins of chromatin** are the **histones**, small proteins containing high proportion of basic amino acids (arginine and lysine) that facilitate binding with **negatively charged DNA molecule**.
- Chromosomes, the most highly condensed form of chromatin, are **visible during mitosis**,.
- The chromatin **forms chromosomes during cell division by condensing and tight coiling of chromatin fibres**.
- The **whole chromatin is not functional**, **only a portion of euchromatin** which is associated with acid proteins, **takes part in transcription or formation of RNA's**.
- After cell division, the chromosomes change back into chromatin fibres. Most of the fibres become uncoiled, extended and scattered. They form the **euchromatin** (**true chromatin**) of the interphase nucleus. It stains lightly. Some chromatin fibres remain coiled and compacted in the interphase also. They constitute the **heterochromatin** (**the other chromatin**). It stains deeply. It lies close to the nuclear lamina.
- **Nucleolus** (or **nucleoli**) was **discovered by Fontana in 1781**, **described by Wagner in 1840** and the term 'nucleolus' was **coined by Bowman in 1840**.
- Nucleolus is **characterized by the absence of limiting membrane**, **presence of chromatin** and **granules** and **fibrils of RNA and protein**.
- There is **one nucleolus** for **each haploid set** of chromosomes.
- Nucleolus is largely **composed of RNA and it stains more darkly than the nucleus**.
- **Nucleolus** consists of **DNA + RNA + protein**.
- The nucleolus **disappears during prophase** of mitosis and reappears after mitosis is completed. Distinct nucleolar components can be seen with the **electron microscope**.
- Nucleolus disorganises itself during **late prophase** and reappears during **telophase**.
- **Nucleoli** are the **synthesis sites for most ribosomal RNA (rRNA)**. They are **largest** and **most numerous in embryonic cells**, **in cells actively synthesizing proteins and in rapidly growing malignant tumor cells**.
- Nuclei **display wide variation** in –
  – Size both absolute and relative to the amount of cytoplasm (**nucleo-cytoplasmic ratio**);
  – Number per cell, allowing classification of cells as **enucleate**, **mononucleate**, **binucleate or multinucleate**;
  – Chromatin pattern *i.e.*, the amount and distribution of **heterochromatin**; and
  – Location, e.g., basal, central, ecentric.
- Nucleoli were divided into **2 main groups**– **plasmasomes** (or true nuclei), which stain with acidic dyes and disappear during mitosis, and **karyosomes** (or false nuclei), which stains with basic dyes and are of flakes of chromatin.
- Nucleolus has **four components** – **amorphous matrix**, **granular part**, **fibrillar portion** and **chromatin**.
- **Amorphous matrix** is the homogeneous ground substance of the nucleolus. Matrix is formed of protein.
- **Granular part** consists of granules of the size of 150—200 Å which lie scattered in the amorphous matrix. The granules are formed of protein and RNA in the ratio of 2 : 1. They are **believed to be precursors of ribosomes**.
- **Fibrillar portion** (nucleolonema) is formed of a large number of small fibrils that are 50 – 80 Å long. The fibrils are made up of both protein and RNA and are believed to be precursors of granules.
- **Chromatin portion** is that part of chromatin which is associated with nucleolus. Depending upon its position nucleolar chromatin is of two types– **perinucleolar** and **intranucleolar**.
- The **perinucleolar chromatin** lies around the periphery of the nucleolus. It gives rise to in growths or trabeculae which produce the intranucleolar chromatin.
- **Functions of nucleolus** are –
  – Principal or active site for the development of

ribosomal RNAs. It produces 70–90% of cellular RNA in many cells. The chromatin in the nucleolus contains genes or ribosomal DNA (rDNA) for coding ribosomal RNA.
  - Centre for the formation of ribosomes.
  - Stores nucleoproteins. The same is synthesized in the cytoplasm (over the ribosomes) and transferred to nucleolus.
  - Essential for spindle formation during nuclear division.
- The configuration of nucleolus is maintained by **calcium**.
- The messenger RNA is formed **inside the nucleus** but **outside nucleolus**.

VACUOLE

- Vacuole may be defined as a **non-living reservoir**, bounded by a differentially or selectively permeable membrane, the **tonoplast**.
- The structure of tonoplast is similar to that of single unit membrane, *i.e.*, tripartite structure.
- In a young cell, vacuoles are extremely small in size or may be absent. As the cell enlarges, these smaller vacuoles fuse and form a large central vacuole at maturity. So in a mature cell the protoplasm is present as thin layer, pushed towards the wall of the cell. This thin layer of protoplasm is called as **primordial utricle**.
- Vacuole is not an air-filled cavity, rather it is filled with a highly concentrated solution called **vacuolar sap or cell sap**.
- This cell sap is **generally neutral but at maturity it becomes acidic**.
- Cell sap contains many dissolved solutes such as organic acids, soluble carbohydrates, soluble nitrogenous compounds as nitrates, enzymes, tannins, chlorides, phosphates, amino acids, alkaloids and anthocyanin pigments.
- Vacuoles and their contents are considered to be distinct from the cytoplasm and are classified as ergastic.
- In general, **vacuole functions** include
  - Removing unwanted structural debris
  - Isolating materials that might be harmful or a threat to the cell
  - Containing waste products
  - Maintaining internal hydrostatic pressure or turgor within the cell
  - Maintaining an acidic internal pH
  - Containing small molecules
  - Exporting unwanted substances from the cell.
  - Enabling the cell to change shape.
  - Proteins found in the tonoplast control the flow of water into and out of the vacuole through active transport, pumping potassium (K^+) ions into and out of the vacuolar interior.
- Vacuoles **also play a major role in autophagy**, **maintaining a balance between biogenesis** (production) and **degradation** (or turnover), of many substances and cell structures. They also aid in destruction of invading bacteria or of misfolded proteins that have begun to buildup within the cell.

Vacuoles

Depending upon contents vacuoles are of 4 types

Sap vacuoles
- Bubble like sac
- Contain cell sap
- Store and concentrate mineral salts
- Contain water soluble vacuoles pigments —anthocyanin and anthoxanthine
- Present in plant cell

Contractile vacuoles
Helps in osmoregulation and present in freshwater protozoans

Food vacuole
- Occur in protozoan protists, lower animals etc.
- Contain digestive enzymes

Air vacuole or Pseudovacuole
- Occur in prokaryotes
- Store gases, regulate buoyancy of cell, provide mechanical support etc.

Flow chart : Types of vacuoles.

End of the Chapter

Chapter 20

Biomolecules

- All molecules or chemicals functional in living organisms are known as **biomolecules**.
- Biomolecules show **optical activity** *i.e.* they rotate the place of polarisation of independent light. Organic molecules produced **abiologically** lack this phenomenon because products of biological origin prefer the **odd number** of carbon atom per molecule.
- The organic molecules are found both in **aqueous** and **non-aqueous** phase.
- The collection of different types of chemicals present in cell is called **cellular pool.**
- **Cellular pool is mainly constituted** by
  – Inorganic compounds like salt, minerals etc.
  – Organic compounds like carbohydrates, lipids, amino acid etc.
- Organic and inorganic compounds in a cell occur in **9 : 1** ratio.
- The constituents of cellular pool is also divided as **micro–** and **macro–molecules**.
- **Micromolecules include water**, **minerals**, **carbohydrates**, **amino acid**, **lipids**, **nucleotides enzymes**, **vitamins and hormones**.
- Small molecules of cellular pool are characterised by **low molecular weight**, **simple molecular conformation** and **higher solubility**.
- **Polymerisation** of a large number of small molecules gives rise to **macromolecules** such as **proteins**, **nucleic acid** and **certain carbohydrates** (**polysaccharides**).

WATER

- Water is the **most abundant substance of living beings**.
- In adult human body 20 - 22 litres (50% of the total) is present inside the cells as intracellular water.
- The remaining water occurs in the extracellular fluids like blood, lymph and tissue fluid.
- The water content of actively living cells varies between 60 - 95%.
- In human beings maximum water content is found in the embryo 90 - 95%.
- Water is a double hydride of oxygen, *i.e.*, a molecule of water is made of one atom of oxygen and two atoms of hydrogen. The hydrogen atoms are connected with oxygen atom by covalent bonds.
- Water has a **maximum solvent power as compared** to other liquids. This is **because of its ability to develop hydrogen bonds in association with most of the polar substances**, both **electrolytes and non-electrolytes**.
- Water is habitat for a large number of organisms called aquatic organisms.
- Water **allows the light to pass through it** because of its transparent nature. This helps the chloroplasts to receive light while lying inside the living cells deep inside the leaves.
- Presence of low hydration is essential for dormancy of seeds. Availability of water helps a seed to germinate through **imbibition**, **swelling**, **bursting of seed coat**, **activation and growth of embryo**.
- Many movements (e.g., opening and closing of stomata, **seismonasty in *Mimosa***, **locomotion in starfish**) **occur due to loss or gain of water** (*i.e.* turgidity).
- A small amount of water is in the ionic state. $H_2O \rightleftharpoons H^+ + OH^-$.Water can, therefore, **act both as an acid and a base**.
- Water is reagent is many chemical reactions. Because of its **solvent action**, water is an **ideal medium for chemical reactions**.
- Water **remains fluid** due to rapid formation and dissociation of hydrogen bonds amongst its molecules.

- **Lipid bilayer which is basic component of cell membrane** is formed from phospholipids only in contact with water.
- Water molecules form shells around dissolved particles with the help of their H or O regions.
- Water **has a high specific heat as well as hight hermal conductivity**. It, therfore, acts as a **temperature buffer as well as distribute heat uniformly**.
- Water **has high latent heat of vaporisation**. Evaporation of sweat causes elimination of excess heat from the body.
- A number of waste products are eliminated in solution form as urine.
- High cohesion force accounts for high tensile strength of water while high adhesive force allows it to be held inside transport channels.

MINERALS

- Minerals occur in living organisms as components of organic and inorganic molecules and ions.
- Minerals are formed as part of the cellular structure, biologically active substances, enzymes activators and several other functions.
- An organism may have upto 40 elements.
- They are divisible into two categories **essential** and **non-essential**.
- An **essential element** is the one which takes part in nutrition, growth, development and functioning of the organisms.
- The organisms are unable to complete vegetative or reproductive growth in the absence of the essential element.
- A **non-essential element** is the one that is not involved in metabolism, structure or functioning of the organism.
- Deficiency of the element produces disorders which can be rectified only by the supply of the element, e.g., carbon, hydrogen, oxygen, nitrogen, calcium, magnesium, manganese, etc.
- Depending upon their concentration required, **essential minerals** are **differentiated into two categories** – **major** and **minor** (in case of animals) or **macronutrients** and **micronutrients** (in case of plants).
- **Major minerals** are xalcium, phosphorus, sodium, chlorine, magnesium and sulphur.
- **Minor minerals** are iron, copper, cobalt, manganese, molybdenum, zinc, fluorine, iodine and selenium.
- Minerals required in extremely low concentration are known as **ultra-trace minerals**, *e.g.*, silicon, banadium, aluminium, boron, chromium, tin.
- **Macronutrients** are phosphorus, potassium, calcium, magnesium, sulphur and iron. Framework elements C, H and O are also macronutrients but are not generally derived from minerals. Modern day workers place iron in the category of micronutrients on the basis of its concentration in plants.
- **Micronutrients** are manganese, cobalt, zinc, boron, copper, molybdenum and chlorine. Nickel, required for enzyme urease, has recently been added to this list.

  [*For more on minerals refer Chapters "Mineral and Nutrition in Plants" and "Nutrition and Digestive System"*]

CARBOHYDRATES

- Carbohydrates are nature's **most abundant** organic substance and **principal source of energy** for body.
- Carbohydrates contain **carbon** combined with **hydrogen** and **oxygen** often in the same ratio as in water **(1C : 2 H : 1O)**.
- Carbohydrates are usually **divided into** the following **three classes** –
  - **Monosaccharides** or simplest sugars
  - **Oligosaccharides** (contain upto 10 monosaccharides unit)
  - **Polysaccharides** (a polymer of more than 10 monosaccharide units).
- Most sugars (monosaccharides) have the general formula **CH_2O**.
- **Sugars** containing three carbons are known as **trioses**, those with four carbons as **tetroses**, those with five carbons as **pentoses** and those with six carbons as **hexoses.**
- Two **trioses** namely **glyceraldehyde** and **dihydroxyacetone** are crucial intermediates in the metabolism of **glucose in glycolytic cycle**.
- **Erythrose** is a **tetrose** which **forms the raw material for synthesis of anthocyanin and lignin**.
- Pentose sugar, **ribose** is found in every animal and plant cell. It **occurs in a number of compounds which play crucial roles in metabolism**, *e.g.*, ATP,

ADP, riboflavin and RNA. Its reduced form **deoxyribose** is found in DNA.

- The hexoses are divided into **aldoses** or **ketoses** according to whether they contain an **aldehyde or keto group**.
- All hexoses are aldoses (**glucose, galactose** and **mannose**), except **fructose** which is a ketose.
- The **most important carbohydrate** occurring in animals is **glucose** and in plants is **starch**.
- Simple sugar of the **blood is glucose**. Blood sugar level is a measure of glucose.
- Glucose is **stored as glycogen** in **liver** and **muscles.**
- **Fructose (levulose)** is the fruit sugar; it is the **sweetest** among naturally occurring sugars.
- Sugars having a free aldehyde or ketone group can reduce Cu^{2+} to Cu^{+}. These are called **reducing sugars.**
- **Galactose** occurs in milk as a component of the milk sugar, **lactose.**
- Certain compounds of galactose, the **galactosides, occur in the brain and nervous tissue**.
- Galactose is a constituent of **agar-agar** and **galactolipids found in plant leaves**.
- **Mannose** is an **aldohexose,** found in the polysaccharides of plants. Mannose is also found in blood serum, globulins and certain egg proteins.
- **Mannitol** is an alcohol of mannose commonly found in brown algae.
- **Oligosaccharides** are formed by **condensation** of 2–10 monosaccharides.
- **Disaccharides** are oligosaccharides with a combination of **two molecules of monosaccharides**.
- The common disaccharides are **sucrose, maltose, lactose** and **cellobiose.**
- **Sucrose** is made up of **glucose + fructose.**
- Sucrose **occurs in sugar cane and sugar beets, which are the two most important sources of commercial sugar**.
- Sucrose has no free aldehyde or ketone groups; sucrose is not a **reducing sugar**.
- **Maltose** or malt sugar is found during germination of starchy seeds.
- Maltose is produced commercially from starch by a starch hydrolyzing **enzyme diastase**.
- **Lactose** (glucose + galactose) is **present in milk**.
- Compared to the milk of cow, buffalo and goat, **lactose is highest in human milk**.

Human milk has a very high lactose content, 7 grams per decilitre or about 200 mM and lactose provides about 40% of the calories available to the infant. The adaptive significance of this high lactose content (the highest of any species currently known) is probably two-fold – (i) The infant brain is large and requires glucose as a metabolic substrate; lactose is broken down into glucose and galactose prior to intestinal absorption. (ii) From an osmotic standpoint, the secretion of lactose obligates the concomitant secretion of large amount of water. This water is sufficient to meet the infant's needs for sweating and transpirational water loss, high in a warm climate, as well as for urine formation. Because lactose can be synthesized only from glucose, maternal glucose utilization is increased by about 30% in the fully lactating woman.

- Lactose does not occur in nature **except** as a product of the **mammary gland**.
- Cellobiose consists of two molecules of **β-D-glucose**; it cannot be split by mammalian enzymes.
- **Raffinose** is a **trisaccharide** (Galactose + Glucose + Fructose).
- **Saccharine** has a sweet taste,but it is not a sugar.
- Polysaccharides are **polymers of monosaccharides**.
- **Glycogen** and **starch** are both polymers of α-glucose.
- **Starch** in plants and **glycogen** in animals are two **food storage polysaccharides**.
- Glycogen is known as **'animal starch'**.
- Glycogen is related to starch as **both are polysaccharides**.
- A starving man first consumes reserve **glycogen**.
- Glycogen found in liver and muscles **store energy** in mammals.
- Glycogen is broken down by the hormone **glucagon** secreted by **islets of Langerhans**.
- Unlike starch, **glycogen** is **water-soluble** and **gives a red colour with iodine**. Starch gives **blue black colour with iodine**.
- Most plants store their chemical energy in the form of **starch**. Starch grains are found in all parts of the plants although in storage organs, eg. seeds, fruits, rhizome etc, it is found in larger amount.
- Starch is of **two types** – **temporary starch** (formed in the process of photosynthesis during day and is

converted to sugar during night) and **permanent starch** (sugar above a certain level is converted to permanent starch and found mostly in rhizome, seeds and fruits).

- Starch can be separated into two fractions - **amylose** and **amylopectin**. Natural starches are **mixtures of amylose (10-20%)** and **amylopectin (80-90%).**
- **Amylose** is an unbranched, helical molecule whose sugars are joined by α(1-4) linkages.

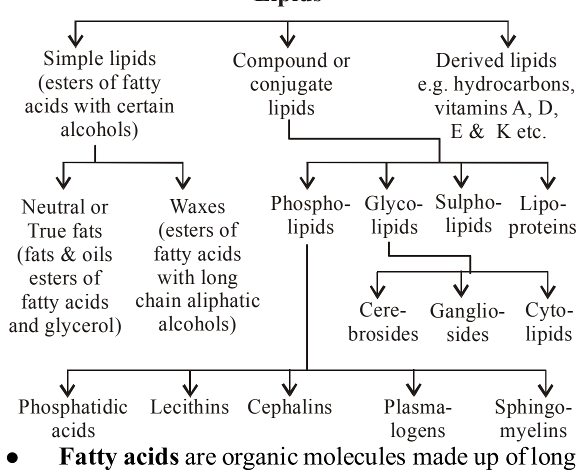
Amylose forms a colloidal dispersion in hot water whereas amylopectin is completely insoluble. Amylose in starch is responsible for the formation of a deep blue colour in the presence of iodine. Iodine is not very soluble in water, therefore the iodine reagent is made by dissolving iodine in water in the presence of potassium iodide. This makes a linear triiodide ion complex which is soluble. The triiodide ion slips into the coil of the starch causing an intense **blue-black colour**.

- **Amylopectin** differs from glycogen in being much less branched and having much smaller molecular weight.
- The **basic unit of starch is glucose**.
- **Cellulose** and **chitin** are two **structural polysaccharides**.
- Cellulose is an unbranched chain of glucose units joined by β **(1–4) linkages**.
- Cellulose is a **homoglycan hexosan**.
- Cellulose is a constituent of **cell wall of higher plants**, **some algae** and **some fungi**.
- Cellulose is **digested by termites and sheep** by harbouring bacteria and protozoa that synthesize the necessary enzyme, **cellulase**.
- Cellulose eaten by grazing animals is digested by **intestinal bacteria**.
- **Maximum amount** of cellulose occurs in **cotton**.
- **Chitin** is a polysaccharide and is the principal component of the exoskeleton of insects and crustaceans; it is a polymer of **N-acetyl glucosamine.** It is also present in cell wall of **fungi**.
- **Inulin** (Dahlia starch) is a carbohydrate, polymer of **fructose**.
- Trioses, glyceraldehyde and dihydroxy acetone, are important intermediates of both respiratory and photosynthetic pathways.
- Pentose sugars, arabinose and xylose form polymers (arabans and xylans) which are constituents of hemicellulose.
- Ribose is an important sugar which is found in a variety of chemicals like CoA, FAD, NAD, NADP and ATP, RNA, DNA etc.
- Fats and aminoacids are formed from glucose and other sugars.
- Heparin prevents blood clotting inside blood vessels.
- Mucilage present as a protective coating around aquatic plants, bacteria, blue-green algae and some animals is derived from polysaccharides.
- Pectins are commercial jellying agents.

LIPIDS

- Fats and their derivatives are together known as **lipids.**
- They are **heterogenous group** containing **mainly carbon, hydrogen** and **oxygen**.
- Term lipid was coined by **Bloor (1943)**.
- Lipids **form about 35 percent of cell content**.
- Lipids are biological molecules **insoluble in water**, **but readily soluble in nonpolar organic solvents like chloroform and benzene**.
- Lipids include **seven major groups** of substances: **fatty acids**, **triglycerides** (**neutral fats**), **waxes**, **phospholipids**, **glycolipids**, **steroids** and **terpenoids**.
- Broadly lipid can be classified into following types.

Lipids



- **Fatty acids** are organic molecules made up of long hydrocarbon chain which contain a **terminal (–COOH) carboxyl group**.
- **Acetic acid** CH_3COOH is a **simple fatty acid** and **stearic acid** $CH_3(CH_2)_{16}COOH$ is **more complex**.
- Most of the fatty acids found in nature have an **even number of carbon atoms** (usually 14 to 24).
- Fatty acids are either **saturated** (all carbon-carbon

bonds are **single bonds**) or **unsaturated** (with **one or more double bonds** in the hydrocarbon chain).

- The general formula of a saturated fatty acid is $\mathbf{CH_3(CH_2)_nCOOH}$.
- If a fatty acid **has only one double bond** (palmitic acid and oleic acid) it is said to be **monounsaturated fatty acid (MUFA)**.
- The **most common monounsaturated fatty acid is oleic acid**.
- If a fatty acid **has more than one double bond** (2 in linolenic acid, 3 in linoleic acid and 4 in arachidonic acid), it is said to be **polyunsaturated fatty acid (PUFA)**.
- Unsaturated fatty acids are **slightly more abundant in nature** than saturated fatty acids, especially in higher plants.
- Fatty acids become **less and less water soluble as the length of their hydrocarbon increases**.
- Unsaturated fatty acids have **lower melting point** than saturated fatty acids.
- **Fats and oils** are esters derived from **glycerol** (an alcohol) and **fatty acids.**
- Depending upon the number of fatty acids, they are called **mono, di** or **triglycerides**.
- Normally, three fatty acids can join to form a **glycerol molecule**. So the glycerol serves as a binder or carrier for fatty acids.
- Neutral animal fats formed from 16 carbon palmitic acid and 18 carbon stearic acid are called as **tripalmitin** and **tristearin** respectively. These are pure fats.
- **Palmito-oleio-stearin** is a **mixed fat** as it bears a molecule each of **palmitic, oleic and stearic acid**.

Table : Common biological fatty acids

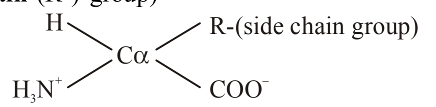
Common Name	Empirical formula	Symbol	Number of bonds
Saturated fatty acids			
Capric acid	$C_{10}H_{20}O_2$	10 : 0	0
Lauric acid	$C_{12}H_{24}O_2$	12 : 0	0
Myristic acid	$C_{14}H_{28}O_2$	14 : 0	0
Palmitic acid	$C_{16}H_{32}O_2$	16 : 0	0
Stearic acid	$C_{18}H_{36}O_2$	18 : 0	0
Arachidic acid	$C_{20}H_{40}O_2$	20 : 0	0
Unsaturated fatty acids			
Palmitoleic acid	$C_{16}H_{30}O_2$	16 : 1	1
Oleic acid	$C_{18}H_{34}O_2$	18 : 1	1
Linoleic acid	$C_{18}H_{32}O_2$	18 : 2	2
Linolenic acid	$C_{18}H_{30}O_2$	18 : 3	3
Arachidonic acid	$C_{20}H_{32}O_2$	20 : 4	4

- **Essential fatty acids** are some polyunsaturated fatty acids which cannot be synthesized in the animal body and must be supplied with food to avoid their deficiency.
- **Maximum number of double bonds present in essential fatty acids** is **four**.
- **Rich source of polyunsaturated fatty acids** in the diet is **vegetable oils**.
- **Sunflower oil** is **rich in linoleic acids** and **minimum fatty acid content is in coconut oil**.
- **Mustard oil** is one of the **most unsaturated** fatty acid.
- Essential fatty acids serve as a precursor for synthesis of **prostaglandins**.
- **Waxes** are complicated mixtures of long chain alkanes with an odd number of carbon atoms ranging from **C_{25} to C_{35} and oxygenated derivatives** such as secondary alcohols and ketones.
- Waxes are chemically **inert**. They bear no double bond in their hydrocarbon chain and **insoluble in water**. Wax present in blood is **cholesterol palmitate**.
- A common example is beeswax, a combination of **palmitic acid** and **myricyl alcohol ($C_{30}H_{61}OH$)**.
- Wool fat or **lanolin** is secreted by **cutaneous glands** and closely **resembles sebum**. It mainly consists of palmitic, oleic or stearic acid and cholesterol.
- **Phospholipid** is **amphipathic molecule** with both hydrophilic (water soluble) and hydrophobic (water-insoluble) regions.
- The major phospholipids are **esters of glycerol** and **a mixture of fatty acids** and **phosphoric acid**.
- Phospholipids are important cell membrane constituents because they contain both **polar and nonpolar portion**.
- **Cephalin** is found in the brain and **acts as insulation material for nerves**.
- **Glycolipids** are primarily amphipathic carbohydrate glyceride derivatives and do not contain phosphate. These include **galactolipids** and **sulfolipids (containing sulphur)** found in plastid membranes.
- Glycolipids are important constituents of certain types of membranes, especially those found in **plant cells** and **cells of the nervous system**.
- **Steroids** are derivatives of a **four-membered ring** compound called **phenanthrene**, e.g. cholesterol, diosgenin, ergosterol.

- **Cholesterol** is one of the **most important animal steroids**. It is insoluble in water & chemically unrelative.
- Cholesterol is useful since it is a structural component of cells. Cholesterol **forms bile salts** and hence essential for absorption of fatty acid. It is synthesized from acetyl CoA or acetate (C_2) in the liver and thus not a dietary **essential**.
- Cholesterol is **not found in plants**, but the latter contain other steroids collectively known as **phytosteroids**.
- Cholesterol content is minimum in **vegetable oils**.
- **Diosgenin**, a steroid compound produced by the yam plant (*Dioscorea*) is **used in the manufacture of antifertility pills**.
- **Ergosterol** is the principal plant sterol present in high concentration in yeast and upon irradiation is converted to vitamin D.
- Bile acids are derivatives of cholesterol, synthesized in liver; they are major components of bile and aid in the **emulsification of fat** (breakdown of larger fat molecules in smaller one) in small intestine.
- Lipids constructed from the five-carbon compound isoprene are called **terpenes**.
- Isoprene and its derivatives are joined in various combinations to produce substances such as **vitamin A, coenzyme Q** and **carotenoids**.
- **Stigmasterol** and **sitosterols** are phytosterols found in **soyabean oils** and **wheat gram oil respectively**.
- **Carotenoids** are isoprenoid hydrocarbon of plant origin containing 40 carbon atoms.
- Steroids act as chemical coordinators. Sterols are required for **growth** and **flowering** in plants.
- Terpenes form a major component of **essential oils**.
- They impart characteristic **flavour and odour** to essential oils like camphor, eucalyptus oil, limonene and menthol.
- Vitamin A and chlorophyll bear terpenoid alcohol called **phytol**.
- **Lycopene** pigment present in tomato (*Lycopersicon esculentum*) is a terpenoid compound.
- Natural rubber is a **polyterpene**.
- **Spermacetic**, a wax obtained from whale is the **hardest wax**.
- Cutin and suberin are lipids associated with **plant cell walls**.
- Cutin is cross esterified and **polymerised hydroxy fatty acids** and suberin is formed from **phellonic acid** and **glycerol**.
- Suberin **provides strength & impermeability to cork cells**.
- Cutin and cutile **reduce epidermal transpiration**.
- Fats serve as food reserve in both plants & animals.
- They function as concentrated food because as compared to carbohydrates they yield more than twice as much energy per unit weight (9.3 kcal/ : 4.5 kcal/gm).
- Fats can be converted to carbohydrates. Therefore, fats stored in oil seeds (eg., groundnut, mustard, castor, sunflower, cotton, coconut) not only provide energy but also raw materials for growth of embryo.
- In seeds and spores lipids help in thermal insulation, protection from ultra violet radiations and loss of water.
- Vitamins A, D, E & K are soluble in fats.
- Edible oils extracted from many seeds are used in cooking. Animals fats present in milk yield butter and ghee.
- Drying oils having unsaturated fatty acids are used in paint industry.

AMINO ACIDS AND PROTEINS

- Amino acids are the **building blocks of proteins.**
- Each amino acid contain a centrally located carbon atom called α-carbon to which four groups are attached : a basic **amino** group ($-NH^+_3$), an acidic **carboxyl** group ($-COO^-$), a **hydrogen** atom and a group of varying chemical structures called a **side chain** (R^-) group)



(Amino group) (Carboxyl group)

- Amino acid are organic acids **having amino group** generally **attached to a carbon or carbon next to carboxylic group.**
- Amino acid **gives it a basic reaction** while **carboxylic group provides an acidic** property.
- With four different groups attached to it, the α-carbon is said to be **asymmetric.**
- Side chain R may be **straight or branched hydrocarbon chain** or **a cyclic group**. The hydrocarbon may be polar or nonpolar.
- The variously folded linear polymers of amino acids are called **polypeptides**.

- The amino acids are linked serially by **peptide bonds** (–CONH–) formed between amino group ($-NH_2$) of one amino acid and carboxylic group (–COOH) of the adjacent one.
- The sequence of amino acids present in a polypeptide is specific for a particular protein. The distinctive sequence of amino acid units is governed by the codon sequence of the gene or cistron that controls its formation.
- Only some **20 amino acids** are **used in the synthesis of the all types of proteins**.
- **Amino acids not found in proteins** are g**amma amino butyric acid** (histone), **serotonin** (ornithine) and **citrulline** (β-alanine).
- The great variety of proteins is due to the very large possible sequence of amino acids.
- **Essential amino acids** are those which are **taken from food, not synthesized in the body**.

Table : 20 different aminoacids

Amino Acid	Abbreviation three letter	One Letter Symbol	Polar/ Non polar/ acidic / basic	Essential / Non essential
Monoamino monocarboxylic acid				
Glycine	Gly	G	Polar* (neutral)	Non essential
Alanine	Ala	A	Non polar (neutral)	Non essential
Valine	Val	V	Non polar (neutral)	Essential
Leucine	Leu	L	Non polar (neutral)	Essential
Isoleucine	Ile	I	Non polar (neutral)	Essential
Monoamino dicarboxylic acid				
Glutamic acid	Glu	E	Acidic	Non essential
Aspartic acid	Asp	D	Acidic	Non essential
Diamino - Monocarboxylic acid				
Arginine	Arg	R	Basic	Essential
Lysine	Lys	K	Basic	Essential
Hydroxyl containing				
Threonine	Thr	T	Polar* (alcoholic)	Essential
Serine	Ser	S	Polar* (alcoholic)	Non essential
Tyrosine	Tyr	Y	Polar*, aromatic	Non essential
Sulphur containing				
Cysteine	Cys	C	Polar* (sulphur)	Non essential
Methionine	Met	M	Non polar (sulphur)	Essential
Phenylalanine	Phe	F	Non polar, aromatic	Essential
Heterocyclic				
Tryptophan	Trp	W	Non polar, aromatic	Essential
Proline	Pro	P	Non polar (heterocyclic)	Non Essential
Histidine	His	H	Basic (heterocyclic)	Essential
Amide containing				
Glutamine	Glu	Q	Polar* (acidic)	Non essential
Aspargine	Asp	N	Polar* (acidic)	Non essential

* These amino acid have an uneven charge distribution and are hydrophilic.

- Other amino acids may be synthesized in the body, particularly from carbohydrate metabolism. They need not be supplied in the diet and are called as **non - essential** or **dispensable amino acids**.
- **Glycine** is the **simplest amino acid**, with lowest molecular weight and no asymmetrical carbon atom.
- When amino group is free it is said to be **basic** and when carboxylic group is free it is said to be **acidic**.
- **Lysine and arginine** are examples of basic amino acid as they contain **two amino group and one carboxylic group**.
- **Glutamic acid** and **aspartic acid** bear **one amino group** and **two carboxylic group** hence they are acidic.
- Neutral amino acid contain **equal number of amino and carboxylic groups**, e.g., glycine, valine, phenylalanine etc.
- **Alcoholic amino acids** are serine and threonine.
- **Aromatic amino acids** are tyrosine, tryptophan and phenylalanine. They **possess cyclic structure with a straight side chain bearing carboxylic and amino group**.
- **Heterocyclic amino acids** are tryptophan and histidine. They **have nitrogen in the ring structure**.
- **Non polar amino acid have no difference in charge** between one part of the molecule and another, e.g., alanine, valine, leucine etc.
- **Polar amino acid have both positive and negative charge**.
- **Polar but uncharged amino acid** have two charges but they balance out each other so that amino acid as a whole is uncharged, eg. glycine, threonine, aspargine.
- **Non polar amino acids** are **insoluble** and **polar** amino acids are **soluble in water**.
- Amino acids **shows optical activity** due to which they can rotate the plane of polarised light. Amino acid have two opposite electric charges in the region of $-NH_2$ and $-COOH$ group. They can behave as **dipolar ion** or **Zwitter ion**.
- Proteins derived from **plants sources** generally lack in one or more amino acid.
- Rice, wheat and corn are all **deficient in lysine**.
- Corn also lacks **tryptophan** and rice lacks **threonine**.
- Beans, peas and other legumes are the **most complete proteins** in plants, but **they lack methionine**.
- The **most complex amino acid having double rings structure** is **tryptophan**.
- The intestinal bacteria are able to synthesize both **essential amino acids and vitamins in ruminants**.
- **Proteins** which contain most of the essential amino acids are termed **first class**, (eg animal proteins) while those do not, are called **second class** (eg proteins of pulses).
- The term protein was coined by **Berzelius (1837) and Mulder (1838).**
- Protein is the **principal organic constituents** of living cell in order of relative abundance.
- Proteins are **large sized molecules or macromolecules having one or more polypeptides** (chains of amino acids).
- Proteins are the **most abundant** and most varied on the macromolecules of the cells which **constitute about 50% of their dry weight.**
- The **minimum molecular weight of a protein** is that of adrenocorticotropin hormone (4500), insulin (brovine insulin-5733) and bacterial ferredoxin (about 6000).
- Other **common proteins** are human haemoglobin (66500), enzyme urease (483000), iso-citrate dehydrogenase (1,000,000) and pyruvate dehydrogenase complex (4,600,000).
- Being macromolecules proteins are **not freely soluble in water but form colloidal complex with the same.**
- RNA takes part in the synthesis of protein at ribosomes.
- Protein are **made of carbon** (51%), **oxygen** (25%), **nitrogen** (16%), **hydrogen** (7%), **sulphur** (0.4%) and **sometimes phosphorus is also present in traces**.
- On hydrolysis by protease enzyme, protein yield amino acids. Proteins and amino acids are **amphoteric in nature** (*i.e.,* can react with both acids and bases to form salts).
- Proteins are oxidized by **putrefaction process** and the products are amino nitrogen compounds, CO_2 and H_2O.
- Proteins are **present as a colloidal solution in protoplasm** and **in solid form as protein granules in seeds**.
- Proteins also occur as storage substances in amorphous, crystal-like or in solid form, *e.g.,* aleurone grains (in cereals below seed coat).

- The **most abundant protein** is **rubisco** (RuBP-carboxylase oxygenase enzyme system), which constitutes 16% of total chloroplast protein.
- The **smallest protein** is **adrenocorticotropic hormone** (ACTH) having 39 amino acids and mol. wt. 4500.
- The **largest protein** is **pyruvate dehydrogenase** having 72 polypeptide chains and mol. wt. 46,00,000.
- A protein can have upto **four levels of organization** – **primary**, **secondary**, **tertiary** and **quartenary**.
- **Primary structure** is the description of basic structure of a protein *i.e.,* number of polypeptides, number and sequence of amino acids in each polypeptide.
- The sequence of amino acids in each polypeptide is **determined genetically (by DNA) through transcription and translation**.
- The **first protein** to have its complete amino acids sequence determined was **insulin**, a hormone that contain 51 amino acids.
- **Secondary structure** is the development of new stearic relationships of amino acids present in the linear sequence inside the polypeptides.
- There are **three types of secondary structures - α helix**, **β-pleated** and **collagen helix**.
- **Linus Pauling** was awarded Nobel Prize in 1954 for study of α- and β-structure of proteins.
- Secondary structures **depends on hydrogen bonds** between $-C{=}O$ and –NH groups.
- In **α helix**, a single amino acids chain is coiled spirally by establishing hydrogen bonds between first and fourth amino acids [e.g. keratin (hair), myosin, epidermis (skin), fibrin (blood clot) etc.]
- In **β-pleated arrangement** a sheet is produced by holding of two or more polypeptide chains in parallel or antiparallel manner.
- In **collagen** or **tropocollagen helix**, there are generally three strands or polypeptides coiled around one another.

Table : Functions of protein

	Kind of Protein	Example	Function or Location
1.	**Structural**	Keratin Collagen Elastin Sclerotic Lipoprotein	Found in skin, hair, nails, horns, feathers and wool Component of connective tissue, bone, cartilage, tendons Elastic connective tissue Exoskeleton of insects Structural component of cell membranes, organelles.
2.	**Enzymes**	Pepsin Amylase Hexokinase	Catalyse various biochemical pathways
3.	**Hormones**	Insulin and Glucagon ACTH	Help to regulate the glucose metabolism Stimulates growth and activity of adrenal cortex.
4.	**Carriers**	P-proteins Haemoglobin Myoglobin Serum albumin	Transport of organic molecules in plants Transport of O_2 in blood Transport of O_2 in muscles Transport of fatty acids and lipids in blood
5.	**Protective**	Antibodies Fibrinogen Thrombin	Form complexes with antigens Form fibrin during blood clotting Required in blood clotting
6.	**Contractile**	Actin, Myosin	Protein filaments in muscles for contraction and locomotion
7.	**Storage**	Casein Albumin Glutelin	Form milk protein Egg white Seeds of wheat

- In **tertiary structure**, there is bending and folding of various types to form spheres, rods or fibres.
- Tertiary structure is **stabilized by several types of bonds** - hydrogen bonds, ionic bonds, vander Wall's interactions, covalent bonds, hydrophobic bonds.
- Tertiary structure **gives the protein** a **three dimensional conformation**.
- In protein structure, **covalent bonds are the strongest**.
- **Quarternary structure**, is **found only in multimeric proteins**. Each polypeptide develops its own tertiary structure and functions as subunit of the protein, e.g. haemoglobin.
- On the **basis of their constitution**, proteins are of three types - **derived**, **simple** and **conjugate**.
- **Derived proteins** are got from proteins through denaturation, coagulation and breakdown, *e.g.*, metaprotein, proteoses, fibrin etc.
- **Simple proteins** are **made up of amino acids only**. Additional non-amino groups are absent, *e.g.*, histone, keratin, albumin etc.
- **Conjugated proteins** have **non-amino prosthetic groups**.
- Depending upon the type of prosthetic group, **conjugate proteins are of several types** *i.e.*, nucleoproteins, chromoprotein, glycoproteins, lipoproteins, metalloproteins, mucoproteins, and phosphoproteins.
- Functional three dimensional form of a protein is called **native state**.
- The state is maintained by specific bonds that form its quaternary (4°), tertiary (3°), and secondary (2°) structure.
- **On the basis of their structure** protein are **divided into** – **fibrous** (thread like proteins) and **globular proteins** (rounded), eg. egg albumin, serum globulins etc.
- The breaking of forces to bring about a change in tertiary and secondary structure of protein is called **denaturation**, primary structure remains intact.
- **Denaturation is brought about** by either heating the protein or treating it with mineral acids when the water soluble proteins undergo **coagulation** with loss of biological activity.
- At a specific pH, a protein may be electrically neutral because the number of positive charges are exactly balanced by the number of negative charges. This pH is known as **isoelectric point.**
- **P-protein** is a special type of protein **present in sieve tube elements**.
- **Human memory** is believed to be stored in specific protein called **memory proteins**.
- Best source of animal proteins are - lean meat (22%), fish (16.5%) egg, milk etc.
- Soyabean is the **best source of plant protein** (43.2%).
- Animal protein are rich in lysine. Plants proteins are rich in methionine.
- **Collagen** is the most abundant animal protein.

NUCLEIC ACIDS

- Nucleic acids are the **polymer of nucleotides** which are major components of all cells.
- Nucleic acids are **found** in both **nucleus** and **cytoplasm**.
- The term **'nucleic acid'** was introduced by **Altmann** in 1889. Nucleic acid (DNA) was **first isolated** in 1868 by Swiss physician **Friedrich Miescher** from the nuclei of pus cells and called it **nuclein**.
- The link between generations is provided by **nucleic acids**.
- **Nucleotide** is a **compound of nitrogenous base, a pentose sugar** and **phosphate,** all linked together by covalent bonds.
- Nucleotides **also take part in energy transfer system of cells** and **form about 2% of the cell contents**.

The combination of a pentose sugar with a base form **nucleosides**. The combination of nucleoside and phosphate group form **nucleotides**. A number of nucleotides combine to form **nucleic acid**.
Base + Sugar $\rightarrow$ Nucleoside + H_3PO_4 $\rightarrow$ Nucleotide

- Nitrogen base and pentose sugar form **nucleoside**.
- Nitrogen bases are of two types - **purines** and **pyrimidines**.
- Purines are **9 membered double ring nitrogen bases** which possess nitrogen at 1,3,7,9 position.
- **Adenine** (A) and **guanine** (G) are purine bases.
- Pyrimidines are **6 membered single ring nitrogen bases** that contain nitrogen at 1 and 3 position.
- The **three dimensional structure of various pyrimidines and purines** has been deduced **by X-ray diffraction analysis**.

- **Cytosine** (C), **thymine** (T) and **uracil** (U) are pyrimidine bases.
- **5 methyl cytosine** occurs in wheat gram and thymus gland.
- **5 hydroxy methyl cytosine** occurs in bacteriophage.
- 4 - thiouracil, dihydroxyuracil and pseudouracil etc are **modified nitrogen bases** present in *t*RNA.
- **Uracil form nucleoside** with only **ribose sugar** while thymine forms the same with only **deoxyribose sugar**.
- Both sugars (ribose and deoxyribose) are in **furanose or pentagon** state with four carbon and one oxygen atom.
- Free purine and pyrimidine bases are easily separated by chromatographic or electrophoretic methods.
- Other nitrogen bases (A,C,G) form nucleosides with both sugars *viz.* adenosine, deoxyadenosine, guanosine, cytidine, uridine, deoxyguanosine, deoxycytidine, deoxyuridine.
- In nucleotides phosphate combine with sugar at its **5 carbon**, sugar with nitrogen base at **1′** while nitrogen base is usually attached to sugar at its **9 (purine) or 1 (pyrimidine) atom**.
- **Common nucleotides** are – AMP, deAMP (adenosine monophosphate, deoxyadenosine monophosphate), GMP, deGMP, CMP, deCMP, UMP, deUMP, TMP, deTMP.
- Nucleotides can have more than one phosphate, e.g. **two in ADP** and **three in ATP**.
- ATP (adenosine triphosphate) has **three high energy phosphate bond** while ADP (adenosine diphosphate) has **two high energy phosphate bond**.

Abbreviations of ribonucleoside 5′-phosphates

Base	**Mono**	**Di**	**Tri**
Adenine	AMP	ADP	ATP
Guanine	GMP	GDP	GTP
Cytosine	CMP	CDP	CTP
Uracil	UMP	UDP	UTP

Abbreviations of deoxyribonucleoside 5′-phosphates

Base	**Mono**	**Di**	**Tri**
Adenine	dAMP	dADP	dATP
Guanine	dGMP	dGDP	dGTP
Cytosine	dCMP	dCDP	dCTP
Thymine	dTMP	dTDP	dTTP

- For their polymerisation to nucleic acid state, nucleotides are functional only in their **triphosphate state**.
- UDP and ATP take part in **polymerisation of glucose** while CDP and CTP take part in **synthesis of phospholipids**.
- Nucleotides of nicotinamide and flavin are $NADP^+$ (nicotinamide adenine dinucleotide phosphate), NAD^+, FAD, FMN.
- All the common ribonucleosides and deoxyribonucleosides occur in cells not only as the 5′-monophosphates, but also as the 5′-diphosphates and the 5′-triphosphates.
- The nucleotides serve **four major functions- formation** of **nucleic acid** (**DNA**, **RNA**), **formation of energy carriers** (**ATP and ADP**), **formation of coenzymes** (**NAD**, **NADP**) **and regulatory chemicals**.
- There are **two kinds of nucleic acids** namely **deoxyribonucleic acid** (DNA) and **ribonucleic acid** (RNA).
- **DNA** (**deoxyribonucleic acid**) is the genetic material of most living organisms, which is a major constituent of the chromosomes within the cell nucleus and **plays a central role in the determination of hereditary characteristics by controlling protein synthesis in cells**. It is **also found in chloroplasts and mitochondria**.
- DNA is a nucleic acid composed of two chains of nucleotides in which the sugar is deoxyribose and the bases are adenine, cytosine, and thymine. The two chains are wound round each other and linked together by hydrogen bonds between specific complementary base to form a spiral ladder-shaped molecule.
- **RNA** (**ribonucleic acid**) is a complex organic compound in living cells that is **concerned with protein synthesis**.
- In some viruses, RNA is also the hereditary material.
- Most RNA is synthesized in the nucleus and then distributed to various parts of the cytoplasm.
- An RNA molecule consists of a long chain of nucleotides in which the sugar is ribose and the bases are adenine, cytosine, guanine, and uracil.
- **Three types of RNA** are – mRNA, rRNA and tRNA.
- **Messenger RNA (mRNA)** is responsible for carrying the genetic code transcribed from DNA to

specialized sites within the cell (known as ribosomes), where the information is translated into protein composition.

- **Ribosomal RNA (rRNA)** is *present in ribosomes*. It is single-stranded but helical regions are formed by base pairing within the strand.
- **Transfer RNA** (**tRNA**, **soluble RNA**, **sRNA**) is involved in the assembly of amino acids in a protein chain being synthesized at a ribosome. Each tRNA is specific for an amino acid and bears a triplet of base complementary with a triplet on mRNA.
- RNA can associate with proteins to form complexes called ribonucleoproteins.

  [*For more on DNA and RNA refer chapter Genetic Material and Protein Synthesis*].

ENZYMES, HORMONES AND VITAMINS

Enzymes

- Enzymes are **proteinaceous substances** which are **capable of catalysing chemical reactions of biological origin without themselves undergoing any change**.
- They are called as **biocatalysts.**
- Enzymes are mainly **functional inside the living cells**.
- Enzymes functional outside the living cells are called **exoenzymes**, eg., enzymes present in digestive juices.
- Enzymes function inside living cells are known as **endoenzymes**, e.g., enzymes of krebs cycle (inside mitochondria).
- Thousands of chemical reactions are taking place in the body of a living organism, all of them are mediated by enzymes.

  [*For more on Enzymes refer chapter* '*Enzymes*']

Hormones

- Hormones are **chemical substances** which are produced in minute quantity by certain tissues or organs called effectors and bring about morphological or physiological changes in certain tissues or organs called targets.
- Hormones are **needed in very small quantity**.
- Most of the body functions are regulated by hormones, like growth, vegetative and sexual development, thermal regulation, cellular oxidation, metabolism of carbohydrates, proteins, fats etc.
- Number of plants hormones are **five** as **auxin**, **cytokinins**, **gibberellins**, **abscisic acid and ethylene**.
- Number of animal hormones are numerous, e.g., **insulin**, **glucagon**, **calcitonin**, **glycocorticoids**, **sex corticoids**, **adrenaline**, **thyroxine**, **growth hormones**, **testosterone**, **progesterone**, **gastrin**, **secretin** etc.

  [*For more on Hormones refer chapters "Endocrine System and Phytohormones"*]

Vitamins

- Vitamins are essential but accessory food factors which are required in minute quantities for normal metabolism by forming coenzymes, helping in intestinal absorption, working as antioxidants, maintenance of body parts and utilisation of various food components.
- Deficiency of vitamins produces disorders and disease symptoms which can be corrected by administration of that vitamin.
- Vitamins were discovered by **Lumin (1881)** while first vitamin was isolated by **Funk (1911)**. It was **B_1 (thiamine)**.
- Vitamins are synthesized by plants and bacteria. Animals and humans depends upon them for supply of vitamins.

  [*For more on Vitamins refer chapter* '*Nutrition and Digestive System*']

End of the Chapter

Chapter 21

Enzymes

- **Enzymes** (the term coined by **Kuhne**, 1878) are **biocatalysts** that increases the speed of a chemical reaction without themselves undergoing any permanent chemical change. They are **neither used up** in the reaction **nor do they appear as reaction products**.
- **Enzymology** is the branch of science dealing with enzymes.
- **Edward Buchnar** coined the name **zymase** for the complex of biocatalysts extracted from yeast and taking part in alcoholic fermentation.
- Buchnar is credited with the actual discovery of enzyme and was **awarded Nobel Prize** for this in 1903.
- **Sumner** (1926) **found enzymes to be proteinaceous** and crystallized the first enzyme **urease** from Jack Bean (*Canavalia ensiformis*).
- **Duclaux** proposed a system for naming the enzymes by using the suffix-**ase** in 1883.
- Being by nature proteins means that **enzymes are fully biodegradable after use**.
- Within biological cells many chemical reactions occur but in the absence of enzyme they would happen **too slowly to sustain life**.
- The **basic enzymatic reaction** can be represented as follows.

  $$S + E \rightarrow P + E$$

  (where, E– represents the enzyme catalyzing the reaction; S– the substrate, the substance being changed; and P– the product of the reaction).
- **All enzymes are protein** but **not all proteins are enzyme**.
- No enzyme has been **synthesized *in vitro***.
- Some enzymes are found inside cells (**intracellular enzymes**), and some – especially digestive enzymes are released so they have their effects outside the cells (**extracellular enzymes**).
- Enzyme can **increase reaction rate by favouring or enabling a different reaction pathway with a lower activation energy** making it easier for the reaction to occur.
- **It is the magnitude of the activation energy** which determines just how fast the reaction will proceed.
- Energy must be added to the reactants to overcome the **energy barrier**, which is recovered when products are formed.
- Energy required to overcome energy barrier is called **activation energy**.
- The energy (called **binding energy**), obtained from non-covalent interaction between enzyme & substrate, is **used to lower the activation energy** of enzyme controlled reactions.
- **Simple enzyme** is an enzyme which is wholly made up of protein, no additional group is attached, eg.: pepsin, trypsin, urease.
- **Conjugate enzyme** (also called **holoenzyme**) is an enzyme, formed of two parts - **one protein** and other **non-protein**.
- Many enzymes require the presence of other compounds like cofactors - before their catalytic activity can be exerted. This entire active complex is referred to as the **holoenzyme**; *i.e.,* **apoenzyme** (protein portion) plus the non-protein part, **cofactor** is called the holoenzyme.
- **Cofactor** is a general term for any non-protein (usually) component required at the active site for enzyme activity.
- Cofactors **include metal ion activator**, **coenzymes** and **prosthetic groups**.
- Coenzymes acts as carriers of acyl groups, hydrogen atom, phosphate etc.
- A **coenzyme** is an small **organic non-protein substance** which is **dialyzable**, **thermostable** and **loosely attached to the protein part** (means must be dissociated from the enzyme in order to function).

- A **prostheticgroup** is an **organic substance** which is dialyzable, thermostable and which is **firmly attached to the protein or apoenzyme portion** during the complete catalytic cycle.
- The **part** of the enzyme **without the prosthetic group** is the **apoenzyme**.
- **Coenzymes and prosthetic group** are generally **derived from vitamins**. When there is vitamin deficiency, the coenzyme concentration decreases, consequently enzyme function is depressed.

Table : Water-soluble vitamins and co-enzymes

Vitamin	Co-enzyme
B_1 Thiamine	Thiamine pyro-phosphate (TPP)
B_2 Riboflavin	Flavin Adenine Dinucleotide (FAD) Flavin Mono-Nucleotide (FMN)
B_3 Nicotinic acid	Nicotinamide Adenine Dinucleotide (NAD), NADP
Pantothenic acid	Co-enzyme A
Biotin	Biocytin
B_6 Pyridoxine	Pyridoxal phosphate
B_{12} Cyanocobalamin	Co-enzyme B_{12}

- One of the properties of enzymes that makes them so important as diagnostic and research tools is the **specificity** they exhibit relative to the reactions they catalyze.
- In general, there are **four distinct types of specificity:**
  - **Absolute specificity** – the enzyme will catalyze only one reaction.
  - **Group specificity** – the enzyme will act only on molecules that have specific functional groups, such as amino, phosphate and methyl groups.
  - **Linkage specificity** – the enzyme will act on a particular type of chemical bond regardless of the rest of the molecular structure.
  - **Stereochemical specificity** – the enzyme will act on a particular steric or optical isomer.
- The **structure and specificity** of an enzyme depends on the **linear sequence of amino acids in polypeptide chain**, while **cofactor determines the activity of enzyme**.
- Though enzymes exhibit great degrees of specificity, cofactors may serve many **apoenzymes**. *For example*, nicotinamide adenine dinucleotide (NAD) is a coenzyme for a great number of reactions in which it acts as a hydrogen acceptor. Among them are the alcohol dehydrogenase, malate dehydrogenase and lactate dehydrogenase reactions.
- Enzyme exist in the cells as **colloid**.
- The **whole surface of enzyme** is **not reactive**.
- An enzyme contains an **active site**; a **binding site** that binds the substrate during catalyzed reaction.
- **Active site** of an enzyme is **formed of R-groups of selected amino acids** during folding and refolding of polypeptide chain.
- Part of the active site of enzyme where substrate is held is known as **buttressing group**.
- **Tertiary structure** of enzyme is **responsible for active site production**.
- More the number of active sites, more is the **turn-over number** and more is the activity of enzyme.
- The number of molecules of substrate converted to product per enzyme molecule per second is called the **turnover number**.
- Turnover number of enzyme is **dependent on active site, rapidity of reaction** and **separation of end products**.
- Turnover number of the fastest enzyme (**carbonic anhydrase**, found in red blood cell) is **36 × 10^6**.

Carbonic anhydrase is an enzyme that catalyzes the decomposition of carbonic acid into carbon dioxide and water, facilitating the transfer of carbon dioxide from tissues to blood and from blood to alveolar air.

$$CO_2 + H_2O \xrightarrow[\text{anhydrase}]{\text{carbonic}} H_2CO_3 \rightleftharpoons HCO_3^- + H^+$$

- **Enzyme activity is affected** by **enzyme concentration, substrate concentration, product concentration, temperature, pH, activators and inhibitors**.
- **Temperature range** for maximum functioning of enzymes is **25° – 40°C**.
- High temperature **denatures (permanent) enzymes** and lower temperature **inactivates enzymes**.

Above normal temperatures (say 60°C), heat alters irreversibly the enzyme molecule. This denaturation is due to molecular vibrations (caused by heat) which change the shape of the protein, altering the folding and internal cross-linkages in its polypeptide chains. These changes - especially in the region of the active site - mean that the enzyme is **inactivated**, even when returned to normal temperature.

- On heating **only apoenzyme (protein) part gets denatured** and **cofactor part remains unaffected**.
- Below normal temperatures, enzymes become **less and less active**, due to reductions in speed of molecular movement, but this is reversible, so enzymes work effectively when returned to normal temperature.
- The percentage of denaturation **depends on degree of hydration**.
- Temperature is increased from 3°C to 40°C. The rate of enzyme controlled biochemical reaction will **increase initially and then decrease**.
- High fever is dangerous to human body because it **denatures enzymes**. Hence urgent treatment (giving antipyretics and applying cold cloth on body or forehead) is required.
- **Papain** is used as meat tenderizer because it continues its action even at high temperature of cooking.
- The Q_{10} **(temperature coefficient)** for enzyme activity is 2-3 within optimum range (*i.e.,* rate of reaction increases from 2 to 3 times for 10°C increase).
- The relationship of enzyme activity to pH is represented by a bell shaped curve which has its peak at the optimum pH.
- To determine the maximum speed of an enzymatic reaction, the substrate concentration is increased until a constant rate of product formation is achieved. This is the **maximum velocity** (V_{max}) **of the enzyme**.
- In this state, all enzymes active sites are saturated with substrate. This was proposed in 1913 by **Leonor Michaelis** and **Maud Menten**. Since the substrate concentration at V_{max} cannot be measured exactly, enzymes are characterized by the substrate concentration at which the **rate of reaction is half its maximum.**
- **Michaelis Menten equation** $\left(V_o = \frac{V_{max}[S]}{K_m[S]}\right)$ describes how reaction velocity varies with substrate concentration.
- Substrate concentration at which an enzyme attains half its maximum velocity is called **Michaelis-Menten constant** (K_m).
- K_m **value** of enzyme is **substrate concentration at 1/2** V_{max}.
- K_m **does not depend on the concentration of enzyme**, but can vary with pH.
- The **lower the** K_m, the **higher is the substrate affinity of enzymes**.
- **Lineweaver Burke plot** can be used to calculate K_m & V_{max} as well as to determine the mechanism of action of enzyme inhibitors.
- Conformational changes during formation of enzyme–substrate complex have been observed through **X-ray diffraction** and **optical rotation analysis**.
- **Mechanism of enzyme action** are explained on the basis of **lock and key model** and **induced fit model**.
- **Induced fit theory** of enzyme action was given by **Koshland (1959)** and **Lock and Key model** by **Emil Fischer** (**1894**).
- Lock and key hypothesis **explain specificity**.
- Template/lock and key theory of enzyme action is supported by the fact that **compounds similar to substrate inhibit enzyme activity**.
- According to induced fit theory, the active site of the enzyme is flexible, the substrates induces a conformational change in the enzyme which is alignment of amino acids or other groups at the active site for correct orientation for substrate binding.
- **Transition state** is an intermediate state which **occurs in induced fit model**. During this, the old chemical bonds breaks, atoms assume new position and new bonds are formed.
- The transition state is **highly unstable** and **persists** for a **very short period**.'
- Many enzymes are **secreted in inactive form to protect cell proteins**.
- An **RNA enzyme** or **ribozyme** is made of RNA instead of protein generally ribozymes only catalyze RNA splicing.

Already, a synthetic ribozyme that destroys the *m*RNA encoding a receptor of Vascular Endothelial Growth Factor (VEGF) is being readied for clinical trials. VEGF is a major stimulant of angiogenesis, and blocking its action may help starve cancers of their blood supply.

- The ability of ribozymes **to recognize and cut specific RNA molecules** makes them exciting candidates for human therapy.
- **Virus carry out no metabolism** on their own and must replicate using the host cell's metabolic

machinery **because they lack their own cellular machinery and enzyme**.

- Any substance that can reduce the rate of a reaction is called an **inhibitor**. This inhibitor can either have **irreversible action** or **reversible action**.
- **Irreversible inhibition** is one in which inhibitor acts by forming covalent bonds with specific groups of enzyme. It is of permanent nature, as the enzyme conformation is harmed, dilution of enzyme-inhibitor complex does not regain activity of enzyme because of denaturation of enzyme.
- **Reversible inhibition** is one in which inhibitor bind to enzymes through non-covalent bonds and dilution of enzyme-inhibitor complex results in dissociation of the reversibly bound inhibitor and recovery of enzyme activity.
- Reversible inhibitors can be divided into three categories : **non-competitive inhibitors, competitive inhibitors** and **uncompetitive inhibitors.**
- **Non-competitive inhibition** occurs when the inhibitory chemical, which does not have to resemble the substrate, binds to the enzyme other than at the active site.
- Non-competitive inhibition occurs **when the inhibitor & substrate bind at different sites** on the enzyme.
- In non-competitive inhibition V_{max} **of the reaction decreases** as this inhibition cannot be overcome by increasing the concentration of substrate.
- Non-competitive inhibition can result in **change in enzyme structure**.
- Non-competitive inhibition is **reversible** or **irreversible**.
- **Reversible non competitive inhibitors** bind to enzymes through **non-covalent bonds**.
- Reversible non competitive inhibition occurs when the substrate has equal affinity for enzyme & enzyme inhibitor complex.
- Some irreversible poisons destroy enzyme activity by chemically modifying critical amino acid side groups, and are generally unsuitable for therapeutic purposes e.g., **TPCK** (tosyl phenylalauyl chloromethyl ketone : 1 chloro - 3 tosyl amido-4 phenyl butanone), a irreversible inhibitor of chymotrypsin, cyanides, DFP (di-isopropyl fluorophosphate, nerve gas) which reacts with hydroxyl group of serine of acetylcholinestrase, penicillin etc.
- Cyanide kills an animal by inhibiting **cytochrome oxidase**. This is an **example of non-competitive inhibition**.
- Enzyme inhibition caused by a **substance resembling substrate molecule** through blocking its active site is **competitive inhibition**.
- Competitive inhibition is **reversible**.
- Competitive inhibition **supports the lock and key hypothesis of enzyme action**.
- Competitive inhibition is due to a **substrate analogue**.
- The **activity of succinate dehydrogenase** is **inhibited by malonate** and is the **most common example of competitive inhibition**.
- **Sulpha drugs are competitive inhibitors** of folic acid synthetase in bacteria (substitute for *p*-amino benzoic acid).
- During competitive inhibition V_{max} **is same &** K_m **is increased**.
- K_m **value is same in the presence or absence of non-competitive inhibitor**, the non-competitive inhibitor do not interfere with the binding of the substrate.
- In presence of a competitive inhibitor **more substrate is needed to achieve 1/2** V_{max}.
- **Irreversible inhibition** occurs when the chemical either permanently binds to or massively denatures the enzyme so that the **tertiary structure** cannot be restored. **Nerve gas** permanently blocks pathways involved in nerve message transmission, resulting in death. **Penicillin**, the first of the "wonder drug" antibiotics, permanently blocks the pathways certain bacteria use to assemble their cell wall components.
- **Alcohol** and **temperature above 45°C** coagulate enzymes by denaturing proteins. Due to this reason, **alcohol is used as disinfectant**.
- **Leninger** *et al* (1933) **considered prosthetic group to be inorganic** (metal ions) or **organic** (coenzyme) **cofactor attached covalently to apoenzyme**.
- Reactions mediated by enzymes and catalyst are essentially reversible but forward and backward reaction usually require different optima.
- Lysozyme is an **antibacterial enzyme**, discovered by Alexander Flemming (1922). **Lysozyme is rich in tear**.

- K_i is the **dissociation constant of enzyme – inhibitor complex**. It is applicable to **competitive inhibitor**.
- **Low K_i is essential for enzyme activity** while **high K_i decreases it**.
- Decline in the activity of the enzyme hexokinase by glucose-6 phosphate is caused by **allosteric modulation (feed back inhibition)**.
- Feedback inhibition is caused by blocking of enzymes by **accumulated end products**.
- Allosteric or feedback is a type of non-competitive inhibition wherein the product of the reaction sequence may act as a specific inhibitor of the enzyme at or near the beginning of the sequence with the result, the rate of entire sequence of reactions is determined by the steady state concentration of the end product.
- The **end product** is the **inhibitor** and the **enzyme inactivated** is called **allosteric enzyme**.
- Allosteric enzymes are regulated by molecules called **effectors or modulators** that bind non-covalently at site other than the active site.
- The enzyme remains **unchanged** at the end of reaction and is free to interact again with more substrate.

$$\underset{\text{(Enzyme)}}{E} + \underset{\text{(Substrate)}}{S} \rightleftharpoons \underset{\text{(Enzyme substrate complex)}}{ES} \rightleftharpoons \underset{\text{(Enzyme product complex)}}{EP} \rightleftharpoons \underset{\text{(Enzyme)}}{E} + P \text{ (products)}$$

- Allosteric enzyme **do not obey Michaelis-Menten** or **K_m constant**, instead it gives **sigmoid kinetics**.
- Based on type of reaction, IUBMB classified enzymes into – **oxidoreductase** (catalyze a redox reaction), **transferase** (transfer a functional group), **hydrolase** (cause hydrolysis reactions), **lyase** (break C-O, C-C or C-N bonds), **isomerases** (rearrange functional groups), and **ligase** (join two molecules *i.e.*, C-S, C-N, C-C).
- The presence of elevated enzyme activity in the plasma may indicate tissue damage accompanied by increased release of intracellular enzyme.
- **Allozymes** are **similar enzymes produced by different genes**.
- **House keeping or constitutive enzymes** are those enzymes which are always present because of their requirement.
- Enzymes, vitamins and hormones are **common in regulating metabolism**.

Table : Some other examples of allosteric modulation.

	Allosteric enzyme	Allosteric activation	Allosteric inhibitor
1.	Hexokinase (= glucokinase)	ADP	ATP, glucose-6-phosphate
2.	Phosphofructokinase	ADP	ATP
3.	Diphosphofructose -phosphatase	ATP	AMP
4.	Pyruvate carboxylase	Acetyl CoA	ADP
5.	Isocitrate dehydrogenase	ADP	ATP
6.	Glutamate dehydrogenase	ADP	ATP, NADH

Table : Classification of enzymes according to IUB (International union of biochemistry)

S.N.	Group	Function	Example
1.	Oxidoreductases—oxidases dehydrogenases, reductases	Take part in oxidation & reduction reaction (transfer of electron)	Cyt. oxidases, succinate dehydrogenase, nitrate reductases.
2.	Transferases	Transfer a group of molecule to another	Glutamate pyruvate transaminase.
3.	Hydrolases	Break large molecule to smaller one	Amylase, sucrase, lactase.
4.	Lysases	Cleavage, removal of group without hydrolysis, addition of group to double bond or reverse	DNA lysase
5.	Isomerases mutase epimerase	Cause rearrangement of molecular structure.	Histidine decarboxylase, aldolase.
6.	Ligases	Catalyse bonding of two chemical with the help of energy obtained from ATP.	Phosphoenol pyruvate carboxylase (Pepco).

- **In plants**, enzymes **occur in all living cells**.
- Of the total enzymes present in a cell, **mitochondria account for 70% (maximum enzymes)**.
- Enzymes having slightly different molecular structure but performing identical activity on similar substrate are **isoenzymes**. Example: lactate dehydrogenase.
- Enzyme taking part in converting dihydroxyacetone phosphate to glyceraldehyde phosphate **belongs to the type of isomerases**.
- Enzyme catalyzing rearrangement of atomic groupings without altering molecular weight or number of atoms is **isomerase**.
- The enzymes are also an **important tool in the research studies, genetic engineering** and **other DNA recombinant technologies**.
- **Restriction endonuclease** is employed for **cutting double stranded DNA. Arber, Nathans and Smith were awarded Nobel Prize (1978) for this discovery**.
- Genetic engineering requires enzyme **restriction endonuclease**.
- In a cell, digestive enzymes mostly occur in **lysosomes**.
- Enzymes are also **used for therapeutic means to treat some disease like streptokinase is used in cleaning blood clots inside blood vessels**.
- Peroxidase is the **smallest enzyme**.
- Rubisco is **most abundant enzyme**.
- **Diastases** is the **earliest known enzyme**.
- Enzymes play an essential role in unzipping the DNA double helix, and so enabling it to reproduce and to send out the instructions for building proteins.
- The **enzymes** which are **most important in brewing are amylase enzymes** (which convert starches into sugars), and **proteolytic enzymes** (which breaks down complex proteins into simpler proteins and amino acids).
- **Antiageing enzyme** is **catalase** (non-porphyrin enzyme) **that metabolises H_2O_2**.
- **ELISA** is an enzyme linked immunosorbent assay when a protein antibody or antigen is detected by means of a specific enzyme, eg. AIDS.
- **Immobilisation of enzyme** is attaching or trapping enzymes in inert supporting materials for better efficiency and recovering them after the reaction.
- A **protein having both structural and enzymatic traits** is **myosin**.
- Antibodies that behave as enzymes are called **abzymes**.
- Flavoproteins involved in cellular oxidation are called **yellow enzymes**.
- **Biosensor** is the ability of enzyme to recognize specific molecules means they can be used as molecular probes or biosensor. One of the biosensors developed used the enzyme glucose oxidase. Such a biosensor is invaluable to people with diabetes who need to quickly monitor their blood glucose level.

Table : Enzymes as markers

1.	Succinic dehydrogenase and glutamate dehydrogenase	Mitochondrial marker
2.	DNA polymerase	Nucleus
3.	Glucose-6-PO_4	ER
4.	Acid phosphatase	Lysosomal marker
5.	LDH	Cytoplasmic fraction of cell
6.	RNA	Ribosomes
7.	Cytochrome oxidase	Mitochondria (inner membrane)

Table : Enzymes related hereditary disease

	Enzyme	**Disease**
1.	Deficiency of tyrosine	Albinism
2.	Defective galactose 1-Puridyl transferase	Galactosemia
3.	Deficient phenylalanine hydroxylase or mono-oxygenase	Phenylketonuria
4.	Defective methaemoglobin reductase	Methaemoglobinemia
5.	Defective fructokinase	Fructosuria
6.	Deficiency of hexosaminidase A by which there is excessive deposition of myelin on nerves.	Tay Sachs
7.	Defective phosphoribosyl pyrophosphate	Lesch Nyhan Syndrome
8.	Adenosine deaminase	Immunodeficiency diseases (SCID)
9.	Phosphoribosyl pyro-phosphate synthetase	Gout
10.	Calciferol hydroxylase	Rickets

End of the Chapter

Chapter 22

Cellular Metabolism

- **Metabolism** is the **biochemical modification of chemical compounds in living organisms and cells**.
- It is through the process of metabolism that organisms process nutrients into the biochemical tools and structures they need to maintain a living state.
- Cell metabolism involves extremely complex sequences of controlled chemical reactions called metabolic pathways, usually a sequence of enzymatic steps.
- Enzymes are crucial to metabolism because they allow organisms to greatly accelerate slow favourable reactions as well as couple unfavourable reactions to available energy sources.
- By providing energy (usually in the form of ATP) to metabolic processes cells can successfully power reactions that would otherwise never occur.
- Metabolism has **two distinct divisions** – **catabolism** (destructive process) and **anabolism** (constructive process).
- **Catabolism** is a type of metabolic process occurring in living cells by which complex molecules are broken down to produce energy and reducing power.
- Catabolic reactions are **primarily oxidation reactions**.
- The **primary purpose of catabolism is to regenerate ATP**, the primary energy currency of all cells. On balance, catabolic reactions are normally **exothermic**.
- **Anabolism** is a constructive metabolic process whereby **energy is consumed to synthesize or combine simpler substances**, such as amino acids, into more complex organic compounds, such as enzymes and nucleic acids.
- Anabolic reactions are **build up reactions which are generally endergonic or energy absorbing**.

CARBOHYDRATE METABOLISM

- The **major function of carbohydrate** in metabolism is **as a fuel to be oxidized** and **to provide energy for other metabolic processes**.
- The three principal monosaccharides absorbed from the food are – **glucose**, **fructose** and **galactose**.
- Carbohydrate metabolism denotes the various biochemical processes responsible for the formation, breakdown and interconversion of carbohydrates in living organisms.
- Carbohydrate metabolism includes –
  - **Carbon fixation**, whereby CO_2 is reduced to carbohydrate.
  - **Glycolysis**, the breakdown of the glucose molecule in order to obtain ATP.
  - The **pentose phosphate pathway**, which acts in the conversion of hexoses into pentoses and in NADPH regeneration.
  - **Glycogenesis**, the conversion of excess glucose into glycogen in order to prevent excessive osmotic pressure buildup inside the cell.
  - **Glycogenolysis**, the breakdown of glycogen into glucose, in order to provide a steady level of glucose supply for glucose-dependent tissues.
  - **Gluconeogenesis**, *de novo* synthesis of glucose molecules from simple organic compounds. (*i.e.* formation of glucose or glycogen from non-carbohydrates sources like fats and proteins).
  - The **oxidation of pyruvic acid to acetyl CoA**, a necessary step before the products of glycolysis could enter into the citric acid cycle.
  - **Citric acid cycle**, final common pathway for the oxidation of carbohydrate, fat and protein.

  - **Dicarboxylic acid shuttle**, additional pathway for regeneration of dicarboxylic acids.
- The reactions of carbohydrate metabolism cannot take place without the presence of the B vitamins, which function as coenzymes.
- Phosphorous, magnesium, iron, copper, manganese, zinc and chromium are also necessary as cofactors.

Carbon fixation

- **Carbon fixation** is a process found in autotrophs, usually driven by photosynthesis, whereby carbon dioxide is converted into organic compounds.
- In plants, there are **three types of carbon fixation** –
  - **C_3** plant that **uses the Calvin Cycle** for the initial steps that incorporate CO_2 into organic matter, forming a 3-carbon compound as the 1st stable intermediate. Most broadleaf plants and plants in the temperate zones are C_3.
  - **C_4** plant that **prefaces the Calvin Cycle** with reactions that incorporate CO_2 into 4-carbon compound. C_4 plants have a distinctive leaf anatomy. This pathway is found mostly in hot regions with intense sunlight. Tropical grasses, such as sugar cane and maize are C_4 plants, but there are many broadleaf plants that are C_4.
  - **CAM plant** that **uses Crassulacean acid metabolism** as an adaptation for arid conditions. CO_2 entering the stomata during the night is converted into organic acids, which release CO_2 for the Calvin Cycle during the day, when the stomata is closed. The jade plant (*Crassula ovata*) and cactus species are typical of CAM plants.

Glycolysis

- The sequence of reactions or pathway by which **glucose is degraded anaerobically to form pyruvic acid** is called **glycolysis**.
- Glycolysis occurs in all living organisms and in all types of respiration. Hence James called it as **core respiration**. This is also known as **fundamental respiration**.
- **Site of glycolysis** is **cytoplasm** (cytoplasmic matrix of a living cell).
- The **reduction of the glucose** during glycolysis produce compounds for the synthesis of protein, fats and nucleic acid.
- Most of the steps of the glycolysis are **reversible**.
- Glycolysis may be **divided into two phases** – a **preparatory phase** and an **oxidative phase**.
- In the preparatory phase **breakdown of glucose** and **low energy phosphorylation occurs**, and **energy is used**. In the oxidative phase **high energy phosphate bonds are formed** and **energy is stored**.
- All reserve substances first undergo **hydrolysis** and are finally converted into glucose.
- In majority of the organisms **glucose acts as the respiratory substrate**.
- In glycolysis one molecule of glucose is converted into **two molecules of pyruvic acid**.
- The sequence of reactions in glycolysis was traced out by **Embden - Meyerhof- Parnas** (EMP). Hence glycolysis is also called **EMP pathway**.
- No. of ATP used for phosphorylation of glucose in glycolysis is **2 (1st and 3rd reactions)**.
- No. of ATP formed during glycolysis is **4 (2 ATP for each GAP)**.
- **Net gain** of ATP during glycolysis is **2(4 – 2 = 2)**
- If fructose-6-phosphate is oxidised through glycolysis **net gain of ATP is 3 (4 – 1 = 3)**.
- **No. of *Pi* utilised** during glycolysis is **2**.
  [*For more detail refer chapter Respiration in Plants*]

Pentose phosphate pathway

- Pentose phosphate pathway is an **alternate method of aerobic respiration** which **occurs in the cytoplasm** of mature plant cells and accounting for 60% of total respiration in liver cells and also occurs in adipose tissue and lactating mammary glands.
- In this pathway, for every six molecules of glucose, **one molecule is completely oxidized** into CO_2 and reduced coenzymes while **five are regenerated**.
- The pentose pathway is **also known as phosphogluconate pathway**.
- Since, this pathway metabolizes glucose 6-phosphate by reactions that bypass the reactions of glycolysis, it is also known as **hexose monophosphate shunt** (**HMP Shunt**).
  [*For more detail refer Chapter Respiration in Plants*]

Glycogenesis

- **Glycogenesis** is the **synthesis of glycogen (in animals) and starch (in plants) from glucose**.
- The **chief sites of the formation of glycogen** are **liver** and **muscle**.
- **Liver glycogen** is mainly **concerned with maintenance of the blood glucose**, but **muscle glycogen** acts as a readily available **source of hexose units for glycolysis within the muscle itself**.

The presence of glucose in blood is called blood sugar. 100 ml of blood contains 80 – 100 mg of glucose during fasting and 100 – 120 mg per 100 ml of blood two hours after meal (post prandial).

- Glycogenesis responds to both hormonal and electrical control.
- Glycogenesis is **stimulated by pancreatic hormone insulin**, **growth hormone of pituitary** and **cortisol of adrenal cortex**.
- **Glycogenesis takes place by a series of chemical reaction**. These are –
  - Glucose is phosphorylated to glucose-6-phosphate by ATP in the presence of Mg^{2+} and under the influence of an enzyme *hexokinase* in the liver.
  - Glucose-6-phosphate is then converted to glucose-1-phosphate in an isomerization reaction catalysed by the enzyme *phosphoglucomutase*.
  - Glucose-1-phosphate reacts with uridine triphosphate (UTP) to form the active uridine diphosphate glucose (UDPG) complex, and inorganic phosphate (pyrophosphates, PPi) are released. This reaction is catalyzed by the enzyme *UDPG pyrophosphorylase.*
  - The first carbon of the activated glucose of UDPG form glycosidic bond with the carbon '4' of a terminal glucose residue of glycogen. This reaction is catalyzed by the enzyme *glycogen synthetase* and uridine diphosphate (UDP) is liberated. Hence a pre-existing glycogen chain becomes elongated as successive-1-4-linkages occur.
  - When the newly formed straight chain of glycogen molecule has been lengthened to between 6 and 11 glucose residues, a second enzyme, *branching enzyme*, amylo-1, 4-1, transglucosidase acts on the glycogen. This enzyme transfers a part of the-1-4-chain to a nearly chain forming -1, 6, linkage, thus, establishing a branch point in the molecule.
  - Hence under the combined action of *glycogen synthetase* and *branching enzyme,* the molecule of glycogen is assembled.

Glycogenolysis

- Glycogenolysis is the **conversion of glycogen to glucose** (which could occur several hours after a meal or overnight) in the liver or, in the absence of glucose-6-phosphate in the muscle, to lactate. Or **Glycogenolysis** is the catabolism of glycogen by removal of a glucose monomer and addition of phosphate to produce glucose-1-phosphate. This derivative of glucose is then converted to glucose-6-phosphate, an intermediate in glycolysis.
- Glycogenolysis transpires in the muscle and liver tissue, where glycogen is stored, as a **hormonal response to epinephrine** (e.g., adrenergic stimulation) **and/or glucagon**, a pancreatic peptide triggered by low blood glucose concentrations.
- Liver (hepatic) cells can consume the glucose-6-phosphate in glycolysis, or remove the phosphate group using the enzyme glucose-6-phosphatase and release the free glucose into the bloodstream for uptake by other cells.
- Muscle cells will not release glucose, but instead use the glucose-6-phosphate in glycolysis.
- **Glycogenolysis** occurs in the following way:
  - The breakdown of glycogen is initiated by the action of the enzyme *phosphorylase*. In the presence of inorganic phosphate, the enzyme catalyzes the removal of—1, 4 glycosyl residues from the outermost chains of glycogen molecule until about 4 glucose residues remain on either side of 1, 6 branch.
  - The hydrolytic splitting of 1, 6 linkages requires the action of a specific *debranching enzyme* (*amylo—1, 6—glucosidase*). The combined action of phosphorylase and debranching enzyme converts glycogen to glucose 1-phosphate.
  - Glucose 1-phosphate is then converted into glucose 6-phosphate by the action of enzyme *glucose 6-phosphatase* in the liver. This is the final step in hepatic glycogenolysis and this is manifested by a rise in level of blood glucose.
  - When glycogenolysis occurs in muscles, the reactions terminate at the glucose 6-phosphate stage because the *liver phosphatase* enzyme is **absent** in muscle.

Gluconeogenesis

- **Gluconeogenesis** is the **formation of glucose from noncarbohydrate sources**, such as certain amino acids (primarily alanine and glutamine) and the glycerol fraction of fats when carbohydrate intake is limited.
- **Liver** is the **main site for gluconeogenesis**, except

during starvation, period of fasting, or intense exercise and when the kidney becomes important in the process.

- The majority of the **enzymes responsible for gluconeogenesis are found in the cytoplasm**; the **exceptions** are is mitochondrial pyruvate carboxylase and mitochondrial pyruvate carboxykinase which is located in the mitochondria.
- The rate of gluconeogenesis is ultimately controlled by the action of a key enzyme fructose-1,6-bisphosphatase, which is also regulated through signal transduction by cAMP and its phosphorylation.
- Gluconeogenesis **cannot be considered to be a reverse process of glycolysis**, as the three irreversible steps in glycolysis are bypassed in gluconeogenesis. This is done to ensure that glycolysis and gluconeogenesis do not operate at the same time in the cell, making it a *futile cycle*. Therefore, it is *reciprocal regulated* between glycolysis and gluconeogenesis. Many regulations, which inhibit glycolysis, will activate gluconeogenesis in reverse.
- The **three irreversible steps** in glycolysis are –
  - Phosphoenol pyruvic acid + ADP $\xrightarrow{\text{Pyruvic Kinase}}$ Pyruvic acid + ATP
  - Fructose 6-phosphate + ATP $\xrightarrow{\text{Phosphofructokinase}}$ Fructose 1, 6-bisphosphate + ADP
  - Glucose + ATP $\xrightarrow{\text{Hexokinase}}$ Glucose 6-phosphate + ADP.
- In gluconeogenesis the three irreversible reactions of glycolysis are bypassed by the following –
  - **Phosphoenol pyruvate—formed from pyruvate *via* oxaloacetate :** First, pyruvic acid is carboxylated to oxaloacetic acid at the expense of an ATP. The enzyme *pyruvic carboxylase* present in the mitochondria contains a covalently attached prosthetic group, *biotin*, which serves as a carrier of activated CO_2.

    Pyruvic acid + CO_2 + ATP + H_2O $\underset{Mg^{2+}}{\overset{\text{Acetyl CoA}}{\rightleftharpoons}}$ Oxaloacetate + ADP + Pi + $2H^+$

    Oxaloacetic acid, the product of pyruvic carboxylase reaction does not diffuse readily from the mitochondria. To achieve this end, oxaloacetic acid is reduced to malic acid inside the mitochondrion by an NADH-linked *malic dehydrogenase*. Malic acid then diffuses across the mitochondrial membrane into the cytosol where it is reoxidized to oxaloacetic acid by an NAD^+ linked cytoplasmic *malic dehydrogenase.*

    Oxaloacetic acid + NADH + H^+ $\xrightarrow[\text{dehydrogenase}]{\text{Mitochondrial malic}}$ Malic acid + NAD^+

    Mitochondrial malic acid $\xrightarrow[\text{Mitochondrial membrane}]{\text{Diffusion through}}$ Malic acid in the cytoplasm

    Malic acid + NAD^+ $\xrightarrow[\text{dehydrogenase}]{\text{Cytoplasmic malic}}$ Oxaloacetic acid + NADH + H^+

    In the cytosol, oxaloacetic acid is simultaneously decarboxylated and phosphorylated by a second enzyme *phosphoenol pyruvic carboxylase*, at the expense of a second high energy phosphate bond provided by GTP.

    Oxaloacetate + GTP $\overset{Mg^{2+}}{\rightleftharpoons}$ Phosphoenol pyruvic acid + CO_2 + GDP.

    The CO_2 that was added to pyruvic acid by *pyruvic carboxylase* comes off in this step.
  - **Fructose 6-phosphate is formed from Fructose 1, 6-bisphosphate :** The hydrolysis of fructose 1, 6-bisphosphate is catalyzed by a specific enzyme *fructose 1, 6-bisphosphatase*. This is a key enzyme for the conversion of pyruvic acid and triose-phosphate to glucose during gluconeogenesis. It is present in liver, kidney and striated muscle.
  - **Glucose is formed by hydrolysis of Glucose 6-phosphate :** The conversion of glucose 6-phsophate to glucose is catalyzed by another specific phosphatase, *glucose 6-phosphatase*. It is present in intestine, liver and kidney, where it allows these tissues to add glucose to the blood. The enzyme is absent from the muscle and adipose tissue.
- **Six high energy phosphate bonds** are **used to synthesize one molecule of glucose from 2 moles of pyruvic acid in gluconeogenesis** but only 2 ATP were generated in glycolysis in the conversion of glucose to pyruvate.

2 pyruvic acid + 4ATP + 2GTP + 2NADH + $2H_2O$ → Glucose + 4ADP + 2GDP + 6Pi + $2NAD^+$

- During gluconeogenesis **one mole of ATP is utilized in the conversion of each pyruvic acid to oxaloacetic acid in the mitochondria** and another one during the phosphorylation of 3 phosphoglyceric acid to 1, 3-diphosphoglyceric acid in the cytoplasm. In addition to 2 GTP, 4 moles of ATP are required in the synthesis of one mole of glucose from 2 moles of pyruvic acid.
- Gluconeogenesis occurring in the liver and kidney **maintains the glucose level in the blood** so that brain and muscle which have a high demand for the glucose can extract sufficient amount of this vital substance to meet their metabolic demands.

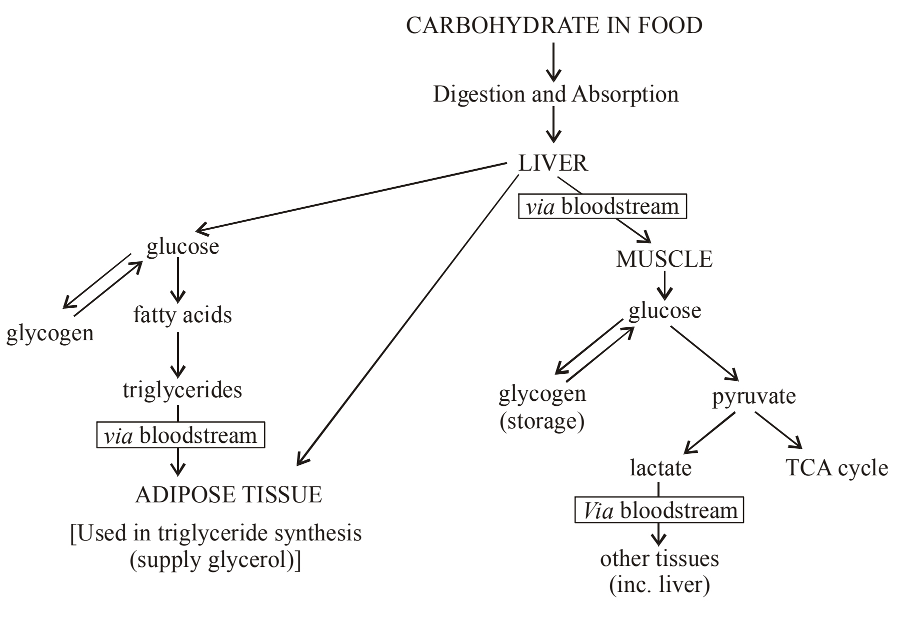
Oxidation of pyruvic acid

- Pyruvic acid **does not directly enter** the Kreb cycle. It enters the Kreb cycle in the form of **acetyl Co.A**.
- The conversion of pyruvic acid into acetyl Co.A takes place by **pyruvic oxidase**.
- Both **decarboxylation and dehydrogenation** occur in this complex reaction and this together is called **oxidative decarboxylation**.
- This is the **first oxidative decarboxylation** in respiration.
- One carbon of $CH_3COCOOH$ (pyruvic acid) is liberated in the form of CO_2.
- The **essential cofactors for pyruvic oxidase** are – **TPP** (thiamine pyrophosphate), **Mg^{++} ions, lipoic acid** (LA) **Co.A.** and **NAD^+.**
- The **residue of pyruvic acid** is **acetyl CoA**.
- The **connecting link between** glycolysis and Krebs cycle is **Acetyl Co.A.**

[*For more detail refer Chapter Respiration in Plants*]

Citric acid cycle

- **Krebs cycle** is the major pathway for the synthesis of reduced coenzymes and controlled release of energy during respiration.
- It is a **common pathway of oxidative breakdown of carbohydrates, fatty acids, and amino acids**.
- Kreb cycle is the second step (basically the third step after glycolysis and intermediate step) in plant respiration.
- Krebs cycle occurs in **the mitochondrial matrix**.
- **First organic acid formed** during Krebs cycle is **citric acid**. Hence Krebs cycle is also called **citric acid cycle**.
- Tricarboxylic acids formed during Krebs cycle are **citric acid, cis–aconitic acid, isocitric acid** and **oxalosuccinic acid**. Hence Krebs cycle is also



Flow chart : Summary of carbohydrate metabolism known as **tricarboxylic acid cycle (TCA cycle)**.

- High energy compound directly formed during Krebs cycle is **GTP**.
- **One glucose molecule** gives two molecules of pyruvic acid. We get $6CO_2$, 8NADH, $2FADH_2$ and 2ATP molecule in Krebs cycle.
- Krebs cycle is useful for the **conversion of fats into carbohydrates through Glyoxyllate cycle**. Main enzymes useful in this cycle are *isocitritase* and *malic synthetase*.
- The **intermediate substances of Krebs cycle** are useful in intermediary metabolism and also act as precursors and structural units of life.

[*For more detail refer chapter Respiration in Plants*]

Dicarboxylic acid shuttle

- Dicarboxylic acid shuttle is a way of forming phosphoenol pyruvate from pyruvic acid by overcoming the pyruvic kinase block. In this process, oxaloacetic acid is first generated by the introduction of a CO_2 molecule into a three carbon molecule, pyruvic acid in the mitochondria. Oxaloacetic acid is then shuttled into the cytosol and converted to phosphoenolpyruvate.

Disorders due to carbohydrate metabolism

Lactose intolerance (or hypolactasia)

- Lactose intolerance (or hypolactasia) is the condition in which **lactase enzyme** needed for proper metabolization of lactose (a sugar that is a constituent of milk and other dairy products), is not produced in adulthood.
- Lactose intolerance can sometimes be confused with **milk allergy**, the former is a lack of the enzyme lactase, while the latter is an aberrant **immune response** (usually) to milk proteins.

Hereditary fructose intolerance

- Hereditary fructose intolerance (HFI) is a hereditary condition **caused by a deficiency of liver enzymes** that metabolise fructose.
- The deficient enzyme is **fructose-1-phosphate aldolase-B**, this means that the fructose cannot be further metabolised beyond fructose-1-phosphate. This traps phosphates; which are needed to phosphorolyse glycogen phosphorolase to carry on to make glucose. Therefore glucose cannot be made through the breakdown of glycogen nor from gluconeogenesis, resulting in severe hypoglycaemia.
- If fructose is ingested, vomiting, hypoglycaemia and eventually kidney failure will follow.

Galactosemia

- Galactosemia is a rare genetic metabolic disorder which affects an individual's ability to properly digest the sugar galactose.
- Goppert first **described the disease in 1917**.
- Lactose in food (such as dairy products) is broken down by the body into glucose and galactose.In individuals with galactosemia, the needed enzymes are severely diminished, leading to toxic levels of galactose to build up in the blood, resulting in hepatomegaly (an enlarged liver), renal failure, cataracts, and brain damage.
- **Type 1 galactosemia** is caused due to GALT deficiency.
- Galactose is converted into glucose by the enzyme GALT (galactose-1-phosphate uridyl transferase). This enzyme is the most common cause of galactosemia.
- There are two variants of the GALT gene responsible for galactosemia.
- One variant causes so-called **classic galactosemia**, in which there is an extreme deficiency in galactose-1 phosphate uridyltransferase. It is an **autosomal recessive condition**. The gene for GALT was mapped at 9p13. Most serious conditions are prominent.
- The variant gene, responsible for **Duarte galactosemia**, leads to about half the normal levels of GALT. Individuals with Duarte galactosemia may experience few or none of the serious symptoms of classic galactosemia.
- The severity of the symptoms is dependent on a number of factors, most importantly the **amount of lactose in the individual's diet**. It is also possible to have one each of the classic and Duarte genes, in which case GALT activity is intermediate.
- **Types 2 and 3 galactosemia** are caused by deficiencies of **galactokinase** and **UDP galactose epimerase**, respectively.

Glycogen storage disease

- Glycogen storage disease (synonyms: **glycogenosis**, **dextrinosis**) is any one of several inborn errors of metabolism that result from enzyme defects that affect the processing of glycogen synthesis or breakdown within muscles, liver, and other cell types.

Diabetes mellitus

- Diabetes mellitus is a metabolic disorder characterized by hyperglycemia (high blood sugar) and other signs.
- The World Health Organization recognizes three main forms of diabetes: *type 1*, *type 2*, and *gestational diabetes* (occurring during pregnancy), which have similar signs, symptoms, and consequences, but different causes and population distributions.
- **Type 1** is usually due to autoimmune destruction of the pancreatic beta cells which produce insulin.
- **Type 2** is characterized by tissue-wide insulin resistance and varies widely; it sometimes progresses to loss of beta cell function.
- **Gestational diabetes** is similar to type 2 diabetes, in that it involves insulin resistance; the hormones of pregnancy cause insulin resistance in those women genetically predisposed to developing this condition.

FAT (LIPID) METABOLISM

- Fat catabolism, also known as lipid catabolism, is the process of lipids or phospholipids being broken down by lipases.
- The opposite of fat catabolism is fat anabolism, involving the storage of energy, and the building of membranes.
- Fats contain mostly carbon and hydrogen, some oxygen, and sometimes other atoms.
- The **three main forms of fat** found in food are – **glyceride** [principally **triacylglycerol** (triglyceride), the form in which fat is stored for fuel], the **phospholipids**, and the **sterols** (principally **cholesterol**).
- Fats **provide 9 kilocalories per gram** (kcal/g), compared with **4 kcal/g for carbohydrate and protein**.
- The **main pathways of lipid metabolism** are **lipolysis**, **beta-oxidation**, **ketosis**, and **lipogenesis**.
- **Lipolysis** (**fat breakdown**) and **beta-oxidation occurs in the mitochondria**.
- **Lipogenesis occurs in the cytosol**. The **main sites of triglyceride synthesis** are the **liver**, **adipose tissue**, and **intestinal mucosa**.
- Fats (lipids) are **stored in adipose tissue**.
- These stored fat molecules are synthesized in the body from the breakdown products of fat digestion (**glycerol** and **fatty acids**), in a process known as **lipogenesis**.
- When needed as an energy source, the fat reserves are mobilized, moved out of adipose tissue, and broken down into glycerol and fatty acids in the **liver** by the process of **lipolysis**.
- Fatty acids are changed in a series of reactions called **beta-oxidation** into acetyl CoA molecules, which enter cell metabolism at the Kreb's Cycle.
- When fats are being **used as the primary energy source** such as in starvation, fasting or untreated diabetes, **an excess amount of acetyl CoA is produced**, and **is converted into acetone and ketone bodies**.
- **Ketosis** occurs when the rate of **formation of ketones by the liver is greater than the ability of tissues to oxidize them**.

Oxidation of triacylglycerol

- Triacylglycerols are hydrolyzed to their constituent fatty acids and glycerol in the adipose tissue.
- Free fatty acids (FFA) are released into the blood plasma, where they are found combined with serum albumin. This is followed by free fatty acid uptake into tissues like liver, kidney, muscle, lung, testis and adipose tissue itself.
- In these tissues, fatty acids undergo β-oxidation.
- Several hormones – epinephrine, norepinephrine, glucagon, ACTH, growth hormone and thyrotropic hormone – stimulate the release of fatty acids from adipose tissue.
- Triglyceride synthesis and lipolysis **do not follow the same pathway in the adipose tissue**.

β-oxidation of fatty acid

- The process of fatty acid oxidation is termed β-oxidation since it occurs through the sequential removal of 2-carbon units by oxidation at the β-carbon position of the fatty acyl-CoA molecule.
- These reactions **occur in the mitochondria** and thus are **closely associated with the electron transport chain to produce energy in the form of ATP**.
- **Each round** of β-oxidation **produces one mole of NADH**, **one mole of $FADH_2$** and **one mole of acetyl-CoA**. The acetyl-CoA – the end product of each round of β-oxidation – then enters the TCA cycle, where it is further oxidized to CO_2 with the concomitant generation of three moles of NADH,

one mole of $FADH_2$ and one mole of ATP. The NADH and $FADH_2$ generated during the fat oxidation and acetyl-CoA oxidation in the TCA cycle then can enter the respiratory pathway for the production of ATP.

- The **oxidation of fatty acids yields significantly more energy** per carbon atom than does the oxidation of carbohydrates.
- **Knoop** (1905) proposed β-oxidation theory which has since been confirmed by isotopic and other techniques.
- According to this theory oxidation of fatty acid **occurs at the β-carbon**, resulting in the formation of a molecule of acetate from the terminal two carbons and leaving a residue of a fatty acid containing two carbons less than the original.
- The enzymes which activate fatty acids by converting them to fatty acyl-CoA are called **'thiokinases'** or **'acyl-CoA synthetases'**.
- These enzymes are **present** in the **outer mitochondrial membrane**.
- All the **enzymes required for β-oxidation are present in the mitochondria**.
- **Fatty acyl-CoA** is formed in the cytoplasm. This **is impermeable to mitochondrial membrane**.
- The **acetate** (acetyl-coenzyme A) produced as a result of β-oxidation can **enter the citric acid cycle** and be oxidized in that cycle to carbon dioxide and water and yield energy.
- Acetyl-coenzyme A or active acetate can thus be formed from carbohydrate, lipid as well as protein and can be oxidized in citric acid cycle to provide energy or it may be used for synthesis of fatty acids, cholesterol or ketone bodies.
- **α-oxidation of fatty acids** is found to occur in the microsomal fraction of brain and other tissues and plants.

Metabolism of glycerol

- Metabolism of glycerol **takes place in the liver, kidney, lactating mammary gland** and **intestinal mucosa**.
- The enzyme *glycerokinase*, catalyzes the activation, by phosphorylation of glycerol to glycerol 3-phosphate or phosphoglyceraldehyde, (PGAL).
  Glycerol + ATP + NAD^+ → Glycerol 3 phosphate + ADP + NADH + H^+.......... to oxygen : 3 ATP
- This reaction requires 1 ATP for the phosphorylation but yields 3 ATP in the transfer of H_2 from NAD to oxygen. PGAL, a normal intermediate in carbohydrate decomposition, can then be respired *via* glycolysis (5 ATP) and the citric acid cycle (12 ATP); processes that yield 17 ATP per molecule of PGAL.
- Complete aerobic respiration of one molecule of glycerol, therefore, produces a total net gain of 2 + 17 = **19 ATP moles**.

Ketone bodies

- **Ketone bodies** are synthesized from acetyl CoA in the liver mitochondria from where they diffuse into the blood and are transported to peripheral tissues.
- Acetoacetic acid, β-hydroxybutyric acid and acetone are called the **ketone bodies**. They are readily interconvertible.
- Ketone bodies are normally **produced by liver** and **utilized by extrahepatic tissues**.
- These three acids are formed by the consequent reactions when acetyl CoA formed in fatty acid oxidation, enters the citric acid cycle. The entry of acetyl CoA basically depends on the availability of oxaloacetic acid for the formation of citric acid cycle.
- Ketone bodies production is **regulated primarily by availability of acetyl CoA**.
- If mobilization of fatty acids from adipose tissue is high hepatic β-oxidation will occur at a high rate, & so will synthesis of ketone bodies from the resulting acetyl CoA.
- Hydroxy butyryl-CoA and acetoacetyl-CoA are normally produced in the penultimate steps of β-oxidation.
- During starvation and in diabetes mellitus, oxaloacetate is diverted to form glucose. On account of its non-availability in adequate amounts, much of acetyl-CoA is converted to acetoacetyl-CoA by condensation of two molecules of acetyl-CoA.
- The blood levels of ketone bodies do not exceed 1 mg/100 ml and less than 1 mg are excreted in urine in 24 hours.
- Ketone bodies are **utilized exclusively by extrahepatic tissues**, **heart and skeletal muscle use them particularly effectively**.
- Both acetoacetic acid and β-hydroxybutyric acid are moderately strong acids and are buffered when present in blood or the tissues. Their continual excretion causes some loss of buffer cation Na^+ which progressively depletes the alkali reserve, causing **ketoacidosis**.

- The ketoacidosis is **associated with nausea, additional fluid loss** and **depression of the central nervous system** leading ultimately to profound coma.
- The concentration of total ketone bodies in the blood of well-fed mammals does not normally exceed 1 mg/100 ml. Loss *via* the urine is usually less than 1 mg/24 hrs in man. Higher than normal quantities present in the blood or urine constitute **ketonemia** or **ketonuria** respectively. The overall condition is called **ketosis**.
- **Causes of ketosis** are –
  - The simplest form of ketosis occurs in **starvation**. In the absence of food, glycogen stores are rapidly depleted and survival depends largely on energy derived from fat deposits in the body.
  - Clinically, the **most important cause of ketosis is diabetes mellitus.** In the diabetic individual, glucose is present in excessive amounts in the fluids of the body but the metabolic defect *viz.,* insulin deficiency, prevents glucose utilization from operating at a normal rate. From the point of view of the effect upon lipid metabolism, diabetes and starvation resemble one another. Since glucose is not being catabolized at a normal rate in muscle or in liver, **excessive mobilization of depot fat leads to lipaemia and fatty liver**.
  - Abrupt replacement of a normal diet by one low in carbohydrate and very rich in fats often leads to ketosis.
  - Renal glycosuria and severe exercise in the post absorptive state may also result in ketosis.

Synthesis of fatty acid

- The biosynthesis of long fatty acids chain in animal tissues, plants & micro-organisms is not a direct reversal of fatty acids oxidation, although acetyl CoA is the starting material.
- Fatty acid synthesis **occurs in the cytoplasm of cells** (compared to β-oxidation which occurs inside the mitochondria).
- The process of fatty acid synthesis **involves two regulatory steps**:
  - The **first step** is the **carboxylation of acetyl CoA** in the cytosol to form malonyl CoA. The acetyl CoA and malonyl CoA are transferred to ACP (acyl carrier protein) by the action of *acetyl CoA transacylase* and *malonyl CoA transacylase* respectively. Catalyzed by the biotin-dependent acetyl-CoA in the cytosol CoA carboxylase (*known to be key enzyme of fatty acid synthesis*), an enzyme that transfers CO_2 to substrates, this step is the rate-limiting step and therefore a very important site in the regulation of fat accumulation. If sufficient biotin is not

Table : Differences between fatty acid synthesis and beta oxidation.

The two processes are superficially the reverse of one another. There are however several important differences allowing for differential control, with one process inhibited while the other is stimulated.

	Fatty acid Synthesis	**Beta Oxidation**
Place	Cytoplasm	Mitochondrial matrix
Bounding of intermediates	ACP (acyl carrier protein)	CoA (coenzyme A)
Enzymatic activities	Combined in a Multienzyme complex FAS (fatty acid synthetase)	The enzyme needed are structurally not linked
	Reducing agents are NADPH	Oxidation agents are NAD^+ & FAD
	Synthesis occur by the addition of two carbon units (derived from acetyl CoA) but the actual donor is malonyl CoA	Results in the removal of two carbon acetyl CoA units
	Regulated by acetyl CoA carboxylase	Regulated by acetyl CoA availability

available for carboxylation of acetyl-CoA, fatty acid synthesis will not occur.

- The **second major point of regulation in fatty acid synthesis** is the **decarboxylation of the malonyl group**, catalyzed by *fatty acid synthase*. The multienzymatic activity of *fatty acid synthase* (FAS) regulates fatty acid synthesis in higher organisms like yeast, birds and mammals. FAS is present in the cytosol of many tissue like kidney, brain, lung, mammary gland and adipose tissue. Synthesis of fatty acids by the FAS complex stops after sixteen carbons have been added (Palmitate) and further elongation and the addition of double bonds are carried out by other systems.

- The rate of fatty acid synthesis is controlled by the equilibrium between the monomeric and polymeric acetyl CoA carboxylase.
- Hormones plays an important role in lipid metabolism. Fatty acid synthesis is regulated by phosphorylation dephosphorylation reactions.
- Insulin stimulates the dephosphorylation of acetyl CoA carboxylase, activating fatty acid synthesis. Phosphorylation of acetyl CoA carboxylase by the hormones epinephrine, norepinephrine and glucagon result in the inactivation of this enzyme, inhibiting synthesis of fatty acids from acetyl CoA.
- The **role of fatty acid synthesis** is to –
  - Supply the body's needs for particular fatty acids not supplied in the diet.
  - To convert excess dietary glucose to fatty acids for storage.
- Glucose is the **major source of acetyl CoA for fatty acid synthesis**.

Abnormalities in lipid metabolism

- **Obesity:** Excessive deposition of fat in the depots with decreased mobilization causes obesity. Obesity of non-endocrinal causes is always due to ingestion of more food than necessary to meet the metabolic needs of the adult.
- **Gaucher's disease:** Cerebrosides are increased in brain, liver and spleen. There is an imbalance between the synthesis and the breakdown of this lipid.
- **Niemann-Pick's disease:** Sphingomyelins accumulate in liver, spleen, bone marrow, lung and lymph nodes, Gangliosides or brain show degeneration. Several variants of the disease occur. The abnormality here also is an imbalance between synthesis and breakdown of the sphingomyelins.
- **Tay-Sachs Disease:** Abnormal glycosides accumulate in brain. There is retarded development, paralysis, dementia and blindness. The child does not usually survive beyond 2 to 4 years.
- **Fabry's Disease:** An abnormal galactosyl-sphingolipid accumulates in many tissues. Death occurs due to cardiac or renal failure.

PROTEIN METABOLISM

- Proteins contain carbon, hydrogen, oxygen, **nitrogen**, and sometimes other atoms.
- They **form the cellular structural elements**, are **biochemical catalysts**, and **important regulators of gene expression**.
- **Nitrogen** is **essential for the formation of twenty different amino acids**, the building blocks of all body cells.
- The amount of intake of nitrogen in food (mainly as protein) will be balanced by excretion of an equal amount of nitrogen in urine (in the form of urea mainly; uric acid, creatinine, creatine and amino acids contribute to a minor extent) and faeces (mainly unabsorbed nitrogen). The animal is said to be in **nitrogen balance**.
- Amino acids can also be converted into glucose and used for energy, through gluconeogenesis.
- **Amino acids** are characterized by the presence of a terminal carboxyl group and an amino group in the alpha position, and they are connected by peptide bonds.
- **Protein catabolism** is the **breakdown of proteins into amino acids and simple derivative compounds**, for transport into the cell through the plasma membrane and ultimately for the polymerisation into new proteins *via* the use of ribonucleic acids (RNA) and ribosomes.
- The **final products of protein catabolism** include carbon dioxide, water, ATP, urea, and ammonia.
- There is **no special storage form for protein** like glycogen for carbohydrate or adipose tissue for fat.
- Protein storage is always **accompained by tissue growth**.
- Amino acid metabolism includes **biosynthesis of amino acids** and **degradation**, conversion of the

carbon skeletons of the amino acids to amphibolic intermediate urea synthesis, and the formation of a wide variety of physiologically active compounds such as serotonin.

- Liver, kidney and several other tissues contain D- and L-amino acid oxidases, active in deamination of the D- or L-amino acids as the case be.
- Most of the **deamination occurs in liver normally**.

Biosynthesis of amino acids

- Biosynthesis of amino acids takes place in association with those organic compounds which occur in the environment in oxidised states such as SO_4^{2-}, N_2 and NO_3.
- The environmental forms of nitrogen and sulphur are reduced to metabolically available forms and are combined with intermediates of carbohydrates metabolism to synthesize the 20 amino acids, characteristics of all living form.
- The collection of free amino acids in the body (blood) is called **amino acid pool**. They represent the relation between the removal and addition of amino acids.

Protein catabolism

- The amino acid enters respiratory routes in two ways—**deamination** and **transmination**.
- **Liver plays an important role in protein catabolism**.

Deamination

- The first stage in the breakdown of amino acids is the removal of their nitrogenous groups as ammonia. It is a catabolic process in which the amino group is removed and convert the amino acid into a keto acids. This is known as *deamination*.
- Such deamination results from the action of a variety of enzymes—which are either **oxidative** or **hydrolytic**.
- **Oxidative deamination** –
  - Catalyzed by a group of flavin enzymes as amino acid oxidases which are auto-oxidizable flavoproteins *i.e.* the reduced FMN or FAD is reoxidised directly by molecular oxygen forming hydrogen peroxide (H_2O_2) without participation of cytochromes or other electron carriers.
  - H_2O_2 is then split to O_2 & N_2O by catalase, which occurs widely in tissues, especially liver.

  In the amino acid oxidase reactions, the amino acid is first dehydrogenated by the flavoprotein of the oxidase, forming an α-amino acid. This spontaneously adds water, then decomposes to the corresponding α-keto acid with loss of the α-amino nitrogen as NH_3.
- **Hydrolytic deamination** – In addition to the amino acid oxidases, there are a number of hydrolytic enzymes that deaminate specific amino acids, particularly the sulphur-containing amino acids, aspartic and glutamic acids. For example, in the non-oxidative deamination of glutamic acid, the enzyme *glutamic dehydrogenase* removes two hydrogen atoms from a combination of glutamic acid and water, with NAD as coenzyme, and a keto acid is again formed. The reaction is readily reversible.

$$\text{Glutamic acid} + H_2O \underset{\text{in Liver}}{\overset{\text{Glutamic Dehydrogenase}}{\rightleftharpoons}} \alpha\text{ Ketoglutaric acid} + H + NH_3$$

- The ammonia liberated by deamination reactions is not allowed to accumulate but rapidly metabolized with the result that very little escapes into the blood.
- **Blood ammonia** is normally **10-12mg/100 ml**. Incease in blood ammonia is **highly toxic to the central nervous system and may be fatal**.
- Ammonia is toxic to the nervous system and its accumulation rapidly causes death. Therefore it must be detoxified to a form which can be readily removed from the body.
- Ammonia is converted to **urea** (in liver), which is water soluble and is readily excreted *via* the kidneys in urine.
- **Liver** is the **main site of ammonia metabolism**.
- The steps in the synthesis of urea in the liver were elucidated by **Krebs** and **Henseleit**.
- After deamination, carbon atoms of degraded amino acids emerge in major metabolic intermediates that can be converted into glucose or be oxidised by the citric acid cycle. To economize the metabolic conversions, the carbon skeletons of twenty diverse amino acids are funnelled into only 7 molecules: Pyruvate, Acetyl CoA, Acetoacetyl CoA, α-Ketoglutarate, Succinyl CoA, Fumarate and Oxaloacetate.
- On the basis of the amphibolic fates of their carbon

skeletons, amino acids are classified into three types: purely glucogenic, purely ketogenic and glucogenic.

Transamination (Transfer of amino groups)

- The process involves the transfer of the amino group ($-NH_2$) from a donor amino acid to the recipient keto acid to form the analogous amino acid and to produce the keto acid from the original amino donor. The donor amino acid thus becomes a keto acid and the recipient keto acid becomes an amino acid. The keto acids so formed are normal participants of glycolysis or Krebs cycle.
- An example of transamination is the formation of the amino acid alanine by the transfer of the amino group from glutamic acid to pyruvic acid, in the course of which α-ketoglutaric acid is produced. The enzyme involved are *transaminases* or *aminotransferases*.
- Enzymes called 'transaminases' or 'amino-transferases' catalyze the transfer of the amino group of an amino acid to an alfa keto acid to form a new amino acid and a new keto acid.
- Aminotransferases are **present in the liver**, **kidney and the brain**.
- Each enzyme is named in terms of the two amino acids involved, e.g. *glutamic-alanine transaminase*.
- Pyridoxal phosphate (PLP), the coenzyme form of vitamin B_6, forms the essential part of the active site of transaminases.

Glutamic acid + Pyruvic acid

$$\xrightarrow[\text{transaminase, pyridoxal phosphate}]{\text{Glutamic-alanine}} \alpha \text{ Ketoglutaric acid + Alanine acid}$$

Another example of transamination is

Glutamic acid + Oxaloacetic acid

$$\xrightarrow[\text{pyridoxal phosphate}]{\text{Glutamic-aspartic transaminase}} \alpha \text{ Ketoglutaric acid + Aspartic acid}$$

- In almost all instances of transaminations, glutamic acid is one of the reacting partners. A specific aminotransferase promotes each specific transamination. The alanine and aspartic amino-transferases are the most abundant.
- Transaminations are reversible, and the equilibrium constant for all these reactions is close to 1. Hence the direction in which the reaction proceeds will be governed by the needs of the cell.
- **Significance of transamination** are –
  - Transamination provides a means for redistributing amino nitrogen.
  - Transaminations occur in all cells and they permit any amino acid to be respired *via* the citric acid cycle. Actually, certain transaminations produce keto acids that are normal components of the citric acid cycle. The common examples are:

Amino acid		**Keto acid**
(i) Alanine	→	Pyruvic acid
(ii) Aspartic acid	→	Oxaloacetic acid
(iii) Glutamic acid	→	α-Ketoglutaric acid

  - Transaminations also carry out interconversions of protein with fat.

$$N_2, NO_3^- \xrightarrow{\text{Fixation}} NH_3$$

$$\xrightarrow{\text{Assimilation into } \alpha\text{-ketoglutaric acid}} \text{Glutamic acid}$$

$$\xrightarrow[\text{with } \alpha \text{ keto acids}]{\text{Transamination}} \text{other } \alpha \text{ amino acids}$$

  - Assimilation of NH_3 into arginine *via* carbamyl phosphate: After the initial fixation of NH_3 into glutamic acid as given above, three reactions take place for the synthesis of amino acid arginine. These reactions are – synthesis of glutamine, synthesis of carbamyl phosphate, and arginine synthesis.
- In adult man (70 kg), about **400 grams of proteins** is synthesized daily and that much is also degraded.
- Vitamin B_6 is involved in the metabolism (especially catabolism) of amino acids, as a cofactor in transamination reactions that transfer the nitrogen from one keto acid (an acid containing a keto group [-CO-] in addition to the acid group) to another.
- The **liver** is the **main site of catabolism for all essential amino acids**, except the branched-chain amino acids, which are catabolized mainly by muscle and the kidneys.
- **Disorders of amino acid metabolism** include **phenylketonuria**, **albinism**, **alkaptonuria**, **type 1 tyrosinaemia**, **nonketotic hyperglycinaemia**, **histidinaemia**, **homocystinuria**, and **maple syrup urine disease**.

End of the Chapter

Chapter 23

Cell Reproduction

- All cells arise from pre-existing cells by process of cell division.
- There is a definite balance (ratio) between nucleus and cytoplasmic mass of cell called **karyoplasmic ratio** or **nucleo-cytoplasmic ratio** or **kernplasma ratio**.
- Due to continuous cell growth, this balance or correlation (ratio) is disturbed, which leads to cell division.
- Further cell division is also necessary for continuity of organism or species.
- The phenomenon of **production of daughter cell from parent cell** is known as **cell division**.
- A cell born after a division proceeds to grow by synthesizing new macromolecules and then reaches a stage where it is ready to divide again.
- Cell reproduction is more complex in eukaryotes than in other organisms.
- The **process of cell reproduction has three major parts**. The *first part* of cell reproduction involves the replication of the parental cell's DNA. The *second major issue* is the separation of the duplicated DNA into two equally sized groups of chromosomes. The *third major aspect* of cell reproduction is the physical division of entire cells, usually called cytokinesis.
- The **division and replication of cells** are the **basis for both sexual and asexual reproduction in most organisms**.
- All those changes which occurs during cell growth and cell division are collectively called **cell cycle**.
- The interval between two division phases is called **interphase**.
- The mechanism of cell reproduction or cell division is fundamentally similar in all organisms showing kinship and unity of life.
- The **different factors controlling cell division** are– cell size, karyoplasmic ratio and mitogens (agents, factors or substances that trigger cell division).

CELL CYCLE AND PHASES

- The sequence of events involving growth and division, a cell undergoes from the time of its formation by division of the parent cell to its own division into daughter cells is called **cell cycle**.
- Cell cycle is divided broadly into **2 phases** – the **I-phase** (or interphase) and **M-phase** (or cell division phase).
- **Interphase** (also called **intermitosis**) is the **longest phase in the mitotic cycle**.
- Interphase is the **metabolically active stage** and **period of intense biosynthetic activity**.
- Repair of damaged DNA sequences also takes place in the interphase.
- Interphase is the **most suitable period to carry out FISH** (Fluorescence *in situ* hybridization). FISH is used for detecting and locating gene mutations and chromosome abnormalities.
- The I-phase is further divided into **G_1** (first growth phase), **S** (DNA synthesis phase), and **G_2** (second growth phase).
- In **G_1- phase** synthesis of protein, RNA, amino acids, ATP, and nucleotides occur.
- G_1 phase is **also called antephase** as during this phase **the cell stores ATP for cell division**.
- The **decision for cell division** occurs in G_1 phase.
- In **S-phase** synthesis of DNA and histone protein occurs.
- S phase is also called **invisible stage of M-phase**.
- In **G_2-phase** synthesis of RNA and protein, continues and formation of macromolecules for spindle and organelle formation occurs.

Table : History of cell division

	Name of the Scientist	Contributions
1.	Prevost and Dumas (1824)	First studied cell division. They described cleavage in the fertilized egg of frog.
2.	Remak (1841)	Found new cells to develop from pre-existing cells while studying cleavage in eggs. Discovered amitosis (1855)
3.	Rudolf Virchow (1855, 1859)	Postulated cell lineage theory that cells arise by division of pre-existing ones-*omni-cellulae-cellula*.
4.	Strasburger (1873)	Found that new nuclei develop from pre-existing ones.
5.	Boveri and Flemming (1879-1880)	Studied details of somatic cell division.
6.	Flemming (1882)	Coined the term 'Mitosis'.
7.	Braur, Sutton, Van-Benden, Strasbarger and Winiwater (1887-1900)	Studied the process of cell division before the formation of gametes (meiosis)
8.	Farmer and Moore (1905)	Coined the term "Meiosis"
9.	Gregoire	Differentiated Meiosis I and II
10.	Howard and Pele 1953	Described cell cycle.
11.	Montegomery	Introduced the term synapsis.
12.	Montose J. Moses (1955)	Synaptonemal complex

- In G_2 phase, the quantity of DNA within the cell has increased to 4C but the cell is still considered diploid.
- Metabolic activities in regard to growth of cytoplasm and its constitutents **occur during G_2 phase**.
- During cell division, **oxidative processes are minimum in M-phase** and therefore deficiency of oxygen has no visible effect on the speed of mitosis.
- The G_0 phase is a period in the cell cycle where cells exists in a quiscent state. The cells, which are not to divide further, do not proceed beyond the G_1 phase and start undergoing differentiation into specific types of cells. Such cells are said to be in **G_0 Phase** to distinguish them from G_1 cells which will soon enter S phase. Some of them, such as fibroblasts, which help in healing of wounds, grow and divide again on demand of the body. Some types of cells do not divide after attaining full differentiation and finally die. These include nerve cells, skeletal muscle cells and red blood cells.
- **Cells that are permanent in the G_0 phase** are called **postmitotic cells**. An example of such cells are neurons.
- **G_0 state** is the condition of a cell whose division has been arrested at G_1 state.
- Cells that have permanently stopped dividing due to age or accumulated DNA damage are said to be senescent.
- Cell cycle is regulated by **cyclin–dependent protein kinases.**
- **Cyclins** are proteins which **activate protein kinases regulating eukaryotic cell cycle**.
- These kinases are **synthesized in G_2 phase** and cause phosphorylation of proteins of nuclear lamina leading to breakdown of nuclear membrane in late prophase.
- **p53** is a protein that **functions to block the cell cycle if the DNA is damaged**. If the damage is severe this protein can cause apoptosis (cell death).
- p53 levels are **increased in damaged cells**. This allows time to repair DNA by blocking the cell cycle. A p53 mutation is the most frequent mutation leading to cancer. An extreme case of this is Li Fraumeni syndrome, where a genetic defect in p53 leads to a high frequency of cancer in affected individuals.
- **p27** is a protein that **binds to cyclin and CdK blocking entry into S phase**.
- There are a number of cell cycle checkpoints, beyond which the cell cycle does not proceed.
- **A check on completion of S phase** : The cell seems to monitor the presence of Okazaki fragments on the lagging strand during DNA replication. The cell is not permitted to proceed in the cell cycle until these have disappeared.
- **DNA damage checkpoints** sense DNA damage before the cell enters S phase (a G_1 checkpoint);

CELL CYCLE

- **Interphase** (I-phase)
  - Non dividing phase
  - Also called **intermitosis** (period between two mitotic cycle) or preparatory phase or energy phase
  - Divided into three regions
    - **G_1-phase** → **S-phase** → **G_2-phase** → enter M phase
    - **G_1-phase**
      - Longest phase & period of maximum growth
      - Takes place at the end of cell division
      - RNA & protein synthesizes
      - Duration: 5 **hour**
      - At the end of this phase cell reaches **antephase** (Bullough, 1952) where it will divide under unfavourable conditions having abundant storage of energy in the form of ATP
    - **S-phase**
      - Also called synthesis phase
      - DNA replication
      - Duration: **7 hour**
      - After duplication one chromosome of a pair is called **chromatids**. Pairs are joined by the **centromere**
    - **G_2-phase**
      - DNA synthesis stops
      - Macromolecules synthesizes
      - Nuclear volume increases
      - Duration: **2 to 5 hour**
- **M phase**: Actual dividing phase
  - Involves two steps
    - **Karyokinesis** (Nuclear division)
      - occurs in 4 main steps
        - Prophase
        - Metaphase
        - Anaphase
        - Telophase
    - **Cytokinesis** (Cytoplasmic division)
      - occurs in
        - **Plant cell** by cleavage and cell plate formation
        - **Animal cells** by cleavage furrows
    - after that daughter cell enters either G_1 Or G_0
      - G_0: A stage when cell cycle is arrested. Therefore further division stops due to activation of certain genes & the cell may then grow in size & become differentiated. Lajtha introduced the term G_0 phase in 1963
  - Occurs in
    - Mammalian cartilage, diseased cells *Paramecieum* etc.
      - **Amitosis**
        - Also called direct cell division
        - Occurs without formation of spindle & appearance of chromosomes
        - No differentiation
    - Somatic cells
      - **Mitosis**: It is an equational division in which parent cells divides into 2 identical daughter cells
    - Germ cells
      - **Meiosis**
    - Mitosis and Meiosis are called indirect cell division

Flow chart : Cell cycle

during S phase, and after DNA replication (a G_2 checkpoint).

- **Spindle checkpoints** : Some of these that have been discovered are –
  – Detect any failure of spindle fibres to attach to kinetochores and arrest the cell in metaphase (M checkpoint).
  – Detect improper alignment of the spindle itself and block cytokinesis.
  – Trigger apoptosis if the damage is irreparable.
- The spindle checkpoint **blocks entry into anaphase** until all chromosomes are properly attached to the mitotic spindle.
- The spindle checkpoint is an active signal produced by improperly attached kinetochores.
- The spindle checkpoint **blocks anaphase entry** by inhibiting the anaphase-promoting complex.
- Cell division is **absent in RBC** and **brain cells** and highly specialized cells like muscle and nerve cells.
- In gymnosperm in development of gametophytes and embryos, free nuclear division occurs and after completion of nuclear division **wall formation occurs** from periphery towards centre.
- **Actual cell division occurs** in **M-phase** which may be mitotic or meiotic.
- **M-phase** is itself composed of two tightly coupled process - **mitosis** (in which the cell's chromosomes are divided between the two daughter cells) and **cytokinesis** (in which the cell's cytoplasm physically divides).
- **Karyokinesis** (division of nucleus) is usually followed by **cytokinesis** (division of cytoplasm).

TYPES OF CELL DIVISION

- Cell division, cell reproduction or cell multiplication is the process of formation of new or daughter cells from the pre-existing or parent cells.
- Cell division occurs in three ways – **amitosis**, **mitosis** and **meiosis**.

Amitosis

- In **amitosis**, division of nucleus occurs without visible chromosome.
- Amitosis was discovered by **Robert Remak.**
- Amitosis is called **direct nuclear division** because of the absence of the formation of spindle and absence of changes in chromosomes.
- Amitosis is an **asexual means of reproduction** in bacteria (binary fission) and in yeast cells (budding).
- Amitosis is seen in the cartilage cells, in some degenerating cells of diseased tissues and in the old tissue, foetal membrane cells etc.

Drawbacks of amitosis

- Elongated chromatin fibres do not condense to form chromosomes.
- Elongated chromatin fibres break during constriction of the nucleus.
- There is no mechanisms for separation and equitable distribution of daughter chromosomes.
- Amitosis causes unequal distribution of chromatin material amongst the daughter nuclei.
- It results in structural and functional abnormalities in the cells.

Mitosis

- The cell division that takes place in somatic cells is **mitosis**.
- The **site of mitotic cell division in plants** are – meristematic regions like stem tip, root tip, intercalary meristem, lateral meristem, growth of embryo leaves, flowers, fruits, seeds etc. In **animals mitosis is found in** embryo development and some restricted regions in the mature form like skin and bone marrow.
- Mitosis is the process by which a cell separates its duplicated genome into two identical halves. It is **generally followed immediately by cytokinesis** which divides the cytoplasm and cell membrane. This **results in two identical daughter cells with a roughly equal distribution of organelles and other cellular components**.
- Mitosis and cytokinesis together is defined as the **mitotic (M) phase of the cell cycle**, the division of the mother cell into two daughter cells, each the genetic equivalent of the parent cell.
- Because cytokinesis usually occurs in conjunction with mitosis, "mitosis" is **often used interchangeably with "mitotic phase"**.
- Mitosis is called **equational division** because it results in the formation of two identical daughter nuclei.
- In mitotic division the **chromosomes replicates and are equally distributed into 2 daughter cell**.
- Mitosis is also called **indirect nuclear division**

because of the formation of spindle and visible changes in chromosomes.

- Mitosis is **divided** mainly into **two phases : interphase** and **division phase**.

Phases of mitosis

- For convenience of study, cell division is divided into **4 phases - prophase, metaphase, anaphase** and **telophase**.

1. **Prophase**

- **Early prophase** is also called **spireme stage.** In this stage chromosomes are overlapping with one another.
- In **mid prophase**, the chromosomes appear **coiled** and **shortened**.
- The chromosomes appear to consist of 2 longitudinal fibres called **chromatids** attached at the centromere.
- The **nuclear membrane** dissolves and the **nucleolus degenerates** at the end of prophase.
- In animal cell **two centrioles are formed from the centrosome**.
- **Spindle formation** begins at **late prophase**.

2. **Metaphase**

- Metaphase is **short and simple**.
- Centromeres are arranged in a row in the middle of the cell during **prometaphase** of mitosis. But the arms of chromosomes show deviations.
- During metaphase **fibres of spindle apparatus**, made of microtubules, are of **three types – kinetochore microtubules, polar microtubules and aster microtubules.**
- The structure formed by the arrangement of chromosome at the centre of a cell during metaphase is called **metaphase plate** or **equatorial plate**.
- Spindle apparatus is formed from the **microtubules of cytoplasm.**
- In animal cell, spindle fibres are formed due to **division of centriole** where asters are present, so spindle of animal cell is called **amphiaster.**
- Spindle of plant centromere cell is called **anastral.**
- Spindle fibres extending from one pole to the other are called **continuous spindle fibres.**
- Fibres extending from a pole to the centromere of a chromosome are called **chromosomal spindle fibres or discontinuous spindle fibres.**
- Fibres which develop between the separating centromeres are called **interzonal fibres** (during anaphase). Interzonal fibres are also called **interchromosomal fibres.**
- The daughter chromosomes move towards the opposite poles due to **repulsion between centromere**, **contraction of spindle fibres** and **relaxation of interzonal fibres**.
- Metaphase is the **best stage in mitosis for analysing the chromosomes** and to study their morphology.
- Graphic representation of a chromosomal complement of a species is called **karyogram.**
- Karyotypic analysis **helps** in prenatal diagnosis of chromosomal numerical abnormalities, gene location and relationship between chromosomal change and developmental defects.
- **Karyotype** is **prepared at metaphase of diploid somatic cells.**

3. **Anaphase**

- Anaphase **begins with the separation of the centromeres and the pulling of chromosomes to opposite poles of the spindle**.
- In anaphase movement, the **chromosomes appear as V, L, J and I-shaped** depending upon the **position of centromere** and named as **metacentric** (centromere is in middle), **submetacentric** (centromere is partly middle), **acrocentric** (centromere is present at one end of the chromosome) and **telocentric** (centromere is at the apex of the chromosomes).
- Division of centromere **indicates the separation of chromatids**.
- **At the end of anaphase**, two groups of chromosomes are formed, one at each pole.
- Chromosomes are **shortest** at **metaphase**, while **thickest at anaphase.**
- The **number of chromosomes at each pole is equal to the number of chromosome in the parent nucleus**.

4. **Telophase**

- Telophase is a **reversal of prophase and prometaphase events**.
- At **telophase chromosome became decondensed** and **uncoiled** and **form chromatin.**
- **Nucleolus, nuclear envelope and nucleoplasm is reformed** and hence two **daughter nuclei are formed at two poles during telophase**.
- **Sachs** reported that **temperature influences the process of karyokinesis (mitosis)**.

- **Cytokinesis** is the **division of cytoplasm**.
- **Cleavage** or furrowing **cytokinesis** occur in **animal cells** where an invagination occur at the equator which deepens and finally cleaves into 2 daughter cells and are separated.
- **Plant cytokinesis** takes place by two methods - cleavage (usually in lower plants) and cell plate.
- In **plant cell**, **cell plate** is formed from golgi apparatus between the two groups of chromosomes. The cell plate grows from the middle towards the periphery and finally joins the cell wall. The early cell plate is the middle lamella of the many layered cell wall.
- In *Saccharomyces* small protuberances arise from cell and part of nucleus after **mitosis** or **amitosis** migrate into the outgrowth to form new cell.

Mitotic poisons are inhibitor of cell divisions, eg: **azides and cyanides** (inhibit prophase); **colchicine**. **vinblastin** and **granosan** (inhibit spindle formation at early metaphase by inhibiting assembly and polymerization of microtubular spindle fibres); **chalones** check cell division *in vivo* and *in vitro* both; **ribonuclease** suppresses prophase; and **heat shocks** prevents cell division.

Significance of mitosis

- **Essential for growth and development of a multicellular organism**.
- **Helps to maintain the stability of chromosome number**, and **hence provides genetic stability**.
- Method of **multiplications of unicellular organisms.**
- **Mechanism for repair of old and worn out cells**.
- Restores the surface volume ratio of cell.
- Restore the nucleoplasmic index.
- Produces multicellular condition and provides opportunity for differentiation.
- Repair of body takes place because of addition of cells by mitosis.

Types of mitosis

- When karyokinesis is not followed by cytokinesis the division is called **free nuclear division.**
- Repeated free nuclear divisions **result in the formation of a multinucleate cell or a coenocytic cell**.
- In unicellular organisms, such as *Amoeba* and yeast, mitotic events usually occur within the nuclear envelope, which remains intact and the nucleus divides by furrowing along with the cytoplasm. Such a mitosis is called **intranuclear**.
- In multicellular organisms, the nuclear envelope breaks down and the mitosis is termed **extranuclear**.
- Replication of chromosomes without karyokinesis is called **endomitosis** (or) **endoploidy.**
- Endomitosis **results in polyploidy** when chromatids separate from chromosome.

Meiosis

- Meiosis **forms the basis of sexual reproduction** and can only occur in eukaryotes. In meiosis, the diploid cell's genome, which is composed of ordered structures of coiled DNA called chromosomes, is replicated once and separated twice, **producing four sets of haploid cells each containing half of the original cell's chromosomes**. These resultant haploid cells will fertilize with other haploid cells of the opposite gender to form a diploid cell again.
- In meiotic cell division, reduction in chromosome number occurs, which gives rise to 4 haploid cells, each having half the number of parental chromosomes.
- Meiosis was **discovered by Strasburger.**
- **Term meiosis** was **used by Farmer & Moore.**
- **If meiosis does not take place in an organism** the **chromosome number will be doubled in each generation.**
- Meiosis must take place in an organism to **maintain the chromosome number constant.**
- The **cell which undergoes meiosis** is called a **meiocyte.**
- The meiocyte is comparatively large and possesses a large nucleus. It **contains diploid number of chromosomes which form a network**.
- In animals, the meiocytes are the primary **spermatocytes** and **primary oocytes** present in the gonads while in plants these are represented by **sporocytes** found in the sporogonia.
- There are **three types of meiosis** –
  - **Zygotic or initial meiosis** which occurs immediately after fertilization in certain protozoan groups, fungi and some algae;

- **Sporogenetic** or **intermediate meiosis** which occurs at the time of spore formation in higher plants; and
- **Gametic** or **terminal meiosis** which occurs at the time of gametogenesis in a few lower plants, most animals and many protozoans.

- Meiosis occurs only in **reproductive** or **germinal** cells.
- Meiosis consists of **2 divisions - meiosis I** and **meiosis II**.
- **First nuclear division** of meiosis is called **meiosis - I or reductional division** or **heterotypic division.**
- **Second nuclear division** of meiosis is called **meiosis - II or equational division or homotypic division**.
- **Meiosis II** is of **shorter duration** than the typical mitotic division.

Meiosis I

- Meiosis I consists of 4 stages – prophase I, metaphase I, anaphase I and telophase I.

1. Prophase I

- Prophase - I is a **lengthy phase** when compared to **mitotic prophase.**
- Prophase I - is divided into **5 subphases.** They are **leptotene** or leptonema; **zygotene** or zygonema; **pachytene** or pachynema; **diplotene** or diplonema and **diakinesis**.
- A large nucleus is seen in the meiocyte during **leptotene.**
- In **leptotene** the nuclear membrane enlarges, and **chromosomes became distinct**.
- Chromosomes appear as **long and slender threads** (single threads) bearing bead like structures called **chromomeres** during **leptotene.**
- In many animal cells during leptotene stage all chromosomes in a cell converge to a common point near centrosomes (centrioles) through a structure called attachment plate. It gives a basket like appearance. This is called **bouquet stage** (synizesis).
- The cells undergoing meiosis have **diploid number** of chromosomes and are called **homologous chromosomes**.
- During zygotene the chromosomes become shorter and thicker. Lengthwise pairing of homologous chromosomes begins.
- **Each chromosome** of the homologous pair is contributed by **either parent**.
- Pairing is exact and takes place chromomere for chromomere.
- **Paring of homologous chromosomes** (maternal and paternal) is called **synapsis** or **syndesis** and **occur in zygotene**.
- The process of attachment of homologous chromosomes (called **synapsis**) leads to formation of **bivalents**.
- **Synaptonemal complex** is formed at the region of **synapsis**. This complex **has one central** and two **lateral longitudinal element** which are connected by lateral element.
- Each lateral element occurs in between **two chromatids** of a chromosome and **central element** lies between two homologous chromosomes.
- Each chromosome of homologous pair have **2 chromatid**, known as **sister chromatids**.
- Each **bivalent pair consists of 4 chromatids** which is called **tetrad stage**.
- **Pachytene** is also known as **tetrad stage of meiosis**.
- Pachytene is the **longest stage in mammalian spermatogenesis**.
- It is said to begin when synapsis is completed.
- The number of bivalents is half the diploid number of chromosomes.
- In most species condensation of the chromosomes increases after zygotene, so that the bivalents appear as thick threads. Shortening and thickening of the chromosomes takes place due to longitudinal, contraction.
- The two chromatids belonging to the same chromosome are called **sister chromatids** and those belonging to two different homologous pair are termed as **nonsister chromatid**.
- The **chromatid is the unit of crossing over**.
- **Crossing over** is **exchange of chromosomal segments between non-sister chromatids of homologous pair**.
- **Crossing over brings about gene recombinations or new combination of genes**. It **also produces genetic variations**.
- The homologous chromosomes remain attached at the region of crossing over and these points are called **chiasma**. This formation **occur in pachytene stage**.

Meiosis

Involves 2 set of division

Meiosis I

(called **reductional division**)
Also called **heterotypic division** because it brings about change from diploid to haploid state

Subdivided into 4 phases

Prophase I
(Long and complex)

Divided into 5 stages

Leptotene
- Beaded, long chromosomes
- Chromosomes shows **bouquet arrangement**

Zygotene
- chromosome becomes shorter and thicker
- **Bivalents** (paired homologous chromosomes) are seen.
- **Synapsis** or syndesis (pairing of chromosomes) occur
- **Bivalents** from **synaptonemal complexes** to stabilize paired condition of chromosomes

Pachytene
- **Longest stage** (because it takes time to crossover) in mammalian spermatogenesis
- Tetrads appear as spirally arranged chromosomes of homologous pair
- **Crossing over** (recombination) occurs

Involves mutual exchange of the corresponding segments of non-sister chromatids of homologous chromosomes

Diplotene
- Bivalents repel each other
- **Chiasmata** (sites of crossing over) points strongly appear

Diakinesis
- **Terminalization** occurs (the terminal chiasma slips off the ends of the chromosomes and its position is taken by an interstitial chiasma)
- Nuclear membrane dis-appear, centrioles migrate to poles and spindle fibres begin to form

Metaphase I
Arrangements of chromosomes at equator & maximum condensation of chromosomes

Anaphase I
Movement of homologoues without centromere breakage, nuclei form

Telophase I
- Chromosomes elongate
- Formation of two haploid cells

Meiosis II

(called **equational division**)
also called **homotypic division**, meant for maintaining haploid number.

Subdivided into 4 phases

Prophase II, Metaphase II, Anaphase II, Telophase II

All these phases are similar to the phases of mitosis. Exception is that these processes occur in two haploid cells and hence result in four haploid daughter cells

Gene codes differ in all 4 cells

Results in

Gametes
(Two gametes combine both of chromosomes into one cell)

then **Fertilization**

Forms completely new set of chromosomes for expression, crossing over

Source of Variations

- Chiasmata are found in the meiosis of almost all eukaryotic organisms. However, achiasmatic meiosis (meiosis without chiasma) has been reported in some organisms, e.g., males of higher Diptera (including *Drosophila*), *Panorpa* (scorpion fly), many mantids and roaches, some grasshoppers and scorpions.
- A chiasma formed at the ends of chromosomes is called **terminal chiasma**. Chiasmata formed along the lengths of chromosomes are called **interstitial chiasmata**.
- The homologous chromosomes start separating (called disjunction) as the nucleoprotein complex of synapsed chromosomes dissolves. This occurs in **diplotene**.
- **Diplotene** is the **longest** and **most active subphase of prophase-I of meiosis**.
- **Dictyotene** is an arrested diplotene noticed during oogenesis (oocyte stage) in the foetal development.
- In **diakinesis terminalization of chiasmata occurs**.
- Terminalization is the disappearance of chiasmata of sliding towards the tips of the chromosomes due to tight condensation.
- The degree of terminalization is expressed by the terminalization coefficient (T).
- The nucleolus **degenerates** and nuclear envelope **disintegrates in diakinesis**.

2. **Metaphase I**

- In metaphase-I spindle apparatus appear and the chromosomes are arranged on equatorial plate, with the centromeres towards the pole.
- The spindle is formed. Spindle fibres becomes attached to the centromeres of the two homologous chromosomes.

3. **Anaphase I**

- In anaphase-I, the homologous chromosomes **break apart**, and this process is termed **disjunction**.
- The separated chromosomes are termed as **dyads**.
- At **the end of anaphase-I**, two groups of chromosomes are produced at two poles, having half the number of parental chromosome.
- Because the chromosomes undergo crossing over during prophase the composition of the separating homologous chromosomes is different from that of the chromosomes undergoing synapsis.
- In each homologous chromosome one chromatid is unchanged, while the other has undergone mixing of maternal and paternal sections.
- The division of centromeres, which is characteristic of the anaphase of mitosis, does not take place in meiosis.
- Nondisjunction and breakage of chromosomes may occur during anaphase I due to nondissolution of chiasmata. It produces chromosomal aberrations, aneuploidy and polyploidy.

4. **Telophase I**

- In telophase-I polar groups of chromosomes arrange themselves into haploid nuclei, nucleolus, nuclear membrane appear at each poles, thus 2 daughter nuclei are produced.
- **Interkinesis** is the stage between telophase I and prophase-II where chromosomes are elongated, centrosome undergoes replication but DNA synthesis does not occurs, protein and RNA synthesis occurs.
- It is important for bringing true haploidy.

Meiosis II

- **Meiosis II** is essential to separate the chromatids of **univalent chromosomes** which differ from each other in their linkage groups due to crossing over.
- It differs from mitosis in that DNA does not duplicate but centromere do so.
- **Meiosis II** is subdivided into 4 phases – prophase II, metaphase II, anaphase II and telophase II.
- In **prophase II** nucleolus (nucleoli) and nuclear envelope **degenerates** and **the chromosomes shorten a little**.
- Centrioles move to the polar regions and are arranged by spindle fibres.
- In **metaphase-II** the chromosomes arrange themselves in the centre with the help of spindle fibres.
- The **centromere of each chromosome** divides and **chromatids separate**, to form daughter chromosomes in anaphase II.
- At the **end of anaphase II, 4 groups of haploid chromosomes are produced**.
- The process ends with **telophase II,** which is similar to telophase I, marked by uncoiling, lengthening, and disappearance of the chromosomes occur as the disappearance of the microtubules. Nuclear envelopes reform; cleavage or cell wall formation eventually produces a total of four daughter cells, each with a haploid set of chromosomes. Meiosis is now complete.

Nondisjunction (Bridges)

- The normal separation of chromosomes in meiosis 1 or sister chromatids in meiosis II is termed **disjunction**. When the separation is not normal, it is called **nondisjunction**. This results in the production of gametes which have either more or less of the usual amount of genetic material, and is a common mechanism for trisomy or monosomy. Nondisjunction can occur in the meiosis I or meiosis II phases of cellular reproduction, or during mitosis.
- This is a cause of several medical conditions in humans, including –
  - Down syndrome - trisomy of chromosome 21.
  - Patau's syndrome - trisomy of chromosome 13.
  - Edward syndrome - trisomy of chromosome 18.
  - Klinefelters syndrome - an extra X chromosome in males.
  - Turner syndrome - only one X chromosome present in females.
  - XYY syndrome - an extra Y chromosome in males.
  - Triple X syndrome - an extra X chromosome in females.

- In **successive type**, cytokinesis occur after **every nuclear division**, meiosis I, and meiosis II, giving rise to isobilateral tetrads.
- **Simultaneous type** occurs only after meiosis II giving rise to tetrahedral tetrads.
- **Chiasmata and crossing over** are the **two exclusive features of meiosis.**
- Chiasmata may be **terminal or interstitial**. The chiasmata **mark the site of crossing over between the non-sister chromatids of homologous chromosomes**.

Significance of meiosis

- **Formation of gametes** – Meiosis forms gametes that are essential for sexual reproduction.
- **Genetic information** – It switches on the genetic information for the development of gametes or gametophytes and switches off the sporophytic information.
- **Meiosis facilitates stable sexual reproduction** – Without the halving of ploidy, or chromosome count, fertilization would result in zygotes that have twice the number of chromosomes than the zygotes from the previous generation. Successive generations would have an exponential increase in chromosome count, resulting in an **unwieldy** genome that would cripple the reproductive fitness of the species.
  Most importantly, however, meiosis produces genetic variety in gametes that propagate to offspring. Recombination and independent assortment allow for a greater diversity of genotypes in the population. As a system of creating diversity, meiosis allows a species to maintain stability under environmental changes.
- **Crossing over** – It introduces new combination of traits or variations.
- **Mutations** – Chromosomal and genomatic mutations can take place by irregularities of meiotic divisions. Some of these mutations are useful to the organism and are perpetuated by natural selection.
- **Evidence of basic relationship of organisms** – Details of meiosis are essentially similar in the majority of organisms showing their basic similarity and relationship.

ABNORMAL CELL GROWTH

- Cell division is a gene controlled process. The *telomere* of chromosome contains repetitive sequence of six nucleotide. These regions code for an enzyme *telomerase* which control cell division. As cells go on dividing with each division the number of nucleotides decreases and ultimately cells stop dividing.
- Uncontrolled cell division may lead to the formation of undifferentiated aggregate of cells termed **tumor or neoplasm**.
- Uncontrolled cell division is of the following types – hyperplasia, hypertrophy, metaplasia, neoplasia, and Hela cell.
- **Hyperplasia :** The increased production and growth of normal cells in a tissue or organ is termed **hyperplasia**. It is an accelerated rate of cell division resulting from an increased level of cell metabolism. This generally **results in an enlargement of tissue mass and organ size. It occurs only in tissues capable of mitosis such as the epithelium of skin, intestine, and glands**. Some cells do not divide

and thus can not undergo hyperplasia, for example, nerve and muscle cells.

- **Hypertrophy :** An increase in the size of a tissue or organ brought about by the enlargement of its cells is termed **hypertrophy**. When cells hypertrophy, components of the cell increase in number with increased functional capacity to meeting increased cell needs. Hypertrophy **generally occurs in situations where the organ or tissue can not adapt to an increased demand by formation of more cells.** This is **commonly seen in cardiac and skeletal muscle cells,** which do not divide to form more cells.
- **Metaplasia :** The process of conversion of normal tissue cells into an abnormal form in response to stress or injury or infection is termed **metaplasia**. It is a cellular replacement process.
- **Neoplasia :** The new and abnormal development of cells that may be benign or malignant is termed neoplasia. There are **two types of neoplasm** – **benign** and **malignant**.
  – **Benign growth:** The *benign growth* is restricted to a particular site of the body and the cells never spread out to different parts of the body, e.g. simple tumor.
  – **Malignant growth:** In *malignant growth* after the cells are being formed at a particular site, the cells move out to different parts of the body and initiate similar type of growth. The stage of malignant growth in which the cells spread out through the body fluid to different parts of the body is termed *metastasis*. Malignant growth is also termed cancerous growth.
- **He La cell :** He La cells (an aneuploid epithelial cells) are cell line culture of first human cancerous cells donated by **Henrietta Lacks** from their uterine carcinoma cells since 1952. These cells are **maintaned for use in studying cellular processes**.

End of the Chapter

Chapter 24

Origin of Life

- **Origin of life** is the process by which living organisms developed from inanimate matter, which is generally thought to have occurred on Earth between 3500 and 4000 millions years ago.
- **Methane** which has **helped develop life on Earth** occurs on Jupiter, Saturn and interstellar space.
- Origin of life is known as **biopoiesis** means biopoiesis is the development of living matter from complex organic molecules that are themselves nonliving but self replicating.
- **First life evolved 3800-4200 million years back.**
- There are **several theories about the origin of life.** These are – theory of special creations, theory of eternity, theory of catastrophism, cosmozoic theory or theory of panspermia, theory of spontaneous generation and Oparin Haldane theory.
- **Theory of special creation** was **proposed by Hebrew** *et.al.* and **supported by Father suarez** (Spanish Priest).
- According to this theory life was created by supernatural power either once or at successive intervals.
- The **theory of eternity of life**, also called the **steady state theory**, states that the life has ever been in existence as at present and will continue to be so for ever, changing only in form. It neither had a beginning nor will have an end.
- Steady state theory **does not accept the palaeontological evidence** that, presence or absence of a fossil indicates the origin or extinction of the species represented and quotes, as an example the case of coelocanth, *Latimeria*.
- According to this theory, scientist like **Richter**, **Preyer**, **Helmholtz**, **Arrhenius**, **Hoyle**, **Bondi**, believed that life is immortal.
- Sudden creation of life from inorganic material was supported by **George Cuvier**. This theory is called **theory of catastrophism** or **Catacylsm**.
- **According to this theory**, the abrupt faunal changes geologists saw in rock strata were the result of periodic devastations that wiped out all or most extant species, each successive period being repopulated with new kinds of animals and plants.
- **Cosmozoic theory** was **proposed by Richter** (1865) and **supported by Arrhenius** (1908).
- Cosmozoic theory is also called **theory of panspermia** and **spore theory**.
- This theory states that life had reached the Earth from some other heavenly body in the form of resistant spores of simple organisms (called cosmozoa) in meteorites or in spaceships.
- **Theory of spontaneous generation or abiogenesis or autogenesis** states that life originated from non living things in a spontaneous manner. For eg., insects were believed to originate from dew, frog and toads from moist soil under the influence of Sun, butterflies from cheese and fly and maggots from flesh.
- The theory of abiogenesis was believed and supported by **Thales**, **Anaximander**, **Newton**, **Descrates** & **Van Helmont**.
- Theory of spontaneous generation was **disproved by Francesco Redi** (1668), **Abbe Lazzaro Spallanzani** (1767) and **Louis Pasteur** (1867).
- **Francesco Redi** (1626-1698) performed a series of experiments to disproof the theory. He placed meat or fish (eel) under clean muslin coverings and demonstrated that while flies laid eggs on muslin, maggots or larvae appeared only when those eggs were transferred to the meat and allowed to hatch. He **concluded that maggots develops only from pre-existing flies and were not spontaneously generated by any other form of material**.

- In 1765, **Abbe Spallanzani**, an Italian scholar prepared flasks of meat broth which were boiled for several hours and then sealed. The broth remained clear for months, and when the seals were broken and the broth tested, it was shown to be free of microbes.
- Louis Pasteur (in 1864) used a swan-neck flask and prepared a meat broth in this flask, and boiled it for several hours. He then left the flask unsealed on a laboratory bench. The flask was not sealed, and there was a free exchange of air with the environment, so the system did not lack oxygen. Still, the swan-neck remained free of microbial contamination for months, because, their swan-necks were shaped so to trap viable microbial particles and to allow only air to enter the flask. After several months when he broke the neck of one of these flasks, contamination by air and proliferation of micro-organisms in the fluid ensued. **This experiment** thus **disproved the concept of spontaneous generation completely**.
- Pasteur is **famous for germ theory of disease**.
- The process of destroying all living organisms is called **sterilization**.
- Sterilization is done to surgical instruments to kill all the pathogens present on the instrument.
- All three scientists (Redi, Spallanzani and Pasteur) **developed theory of biogenesis**.
- According to theory of biogenesis **life originated from pre-existing life**.
- **The modern hypothesis of origin of life was formulated by Haeckel.** This idea was elaborated in the chemical theory by two workers independently : a Russian biochemist **A. I. Oparin** (in 1923) and an English biologist **J.B.S. Haldane** (in 1928). It was summarized by Oparin in his book : The '*Origin of Life*', published as an English edition (in 1938).
- Oparin and Haldane state that –
  – Spontaneous generation of life under the present environmental conditions is not possible.
  – Earth's surface and atmosphere during the first billion years of its existence were radically different from today's conditions.
  – Initial atmosphere of Earth was reduced
  – First life arose from a collection of chemicals through a progressive series of chemical reactions.
  – Solar radiation, heat radiated by earth & lightning provided energy for evolution of molecules.
- **Modern theory of origin of life** was **propounded by Oparin** which is based upon **chemical evolution.**
- The Oparin Haldane theory (also called **protobiogenesis**) was **experimentally supported by Stanley Miller in 1953**.
- Modern views regarding the origin of life include **origin of Earth & its primitive atmosphere; chemical evolution** (**chemogeny**) and **biological evolution**.
- It is considered that the Earth was formed about 4600 million years ago.
- **Four basic requirements for the life to arise** are **- primitive atmosphere** [**with little or no oxygen, (O_2)**],

Table : Some notable milestones in origin of life showing approximate origins in million years.

S. No.	Origin of	Time in million years
1.	Universe	10,000-20,000 [through big bang hemaitre (1931) of cosmic material]
2.	Solar system	4,600
3.	Earth	4,600
4.	A biotic origin of anaerobic life	4,200
5.	Anaerobic photosynthetic bacteria	3,500-3,800
6.	Beginning of traces of oxygen	3,800
7.	Oxygen producing photosynthetic cyanobacteria	3,300-3,500
8.	Eukaryotes with a nucleus	1,600-1,200
9.	First land plants	459
10.	First mammals	220
11.	Man (*Homo sapiens*)	3.5
12.	Traces of O_2	3.8

right chemicals (including water, various inorganic ions & organic molecules); an **energy source**, and **infinite time**.

- The **energy** needed for the chemical evolution on the primitive Earth mainly **came from solar radiation & cosmic rays; electric discharges; volcanic eruptions, heat etc**.
- Early earth had innumerable free atoms of all those elements which are essential for formation of protoplasm.
- The lightest atoms of nitrogen, hydrogen, oxygen etc. **formed the primitive atmosphere**.
- Free atoms combined to form molecules and simple inorganic compounds.
- **Primitive atmosphere** was **reducing atmosphere** because hydrogen atoms (most numerous and most reactive) combined with all available oxygen atoms to form water and leaving no free oxygen.
- **Water and ammonia** were **probably the first compound molecules of primitive earth**.
- **Chemical evolution** (also called **chemogeny**) **involves the synthesis of simple organic molecules**.
- With slight lowering of the surface temperature of the earth, the lighter elements interacted to form water, methane **(first organic compound)**, ammonia, CO_2, HCN etc.
- The **early compounds interacted and produced simple organic compounds** such as simple sugars, nitrogenous bases, amino acids, glycerol etc.
- Simple organic compounds were formed with the help of **external sources** (UV rays, cosmic rays, lightning etc) acting on the mixtures.
- **Experimental evidence for formation of simple organic compounds** was given by **Stanley Miller**.
- The **Oparin-Haldane theory** suggests that complex organic molecules would have been formed through a series of chemical reactions in the earth's '**primordial soup**'.
- Synthesis of complex organic compounds from their simple constituent molecules were experimentally proved by Stanley Miller with the help of **'simulation experiments'**.
- The apparatus used by Miller is called **'Spark discharge apparatus'**.
- Miller passed an electric discharge in a mixture of **methane, ammonia**, **hydrogen** (ratio 2 : 1 : 2) and **water** (steam).
- By simulation experiments, **Miller synthesized about 15 amino acids** and identified as glycine, alanine, glutamic acid and aspartic acid.
- The energy used in the Miller Urey experiment was **electric spark**.
- The first simplest organic compounds to arise were **methane, ethylene, acetylene,** etc. (hydrocarbons).
- Carried to the earth's surface by rainwater, the simple organic compounds then would have accumulated in the ocean as a warm, **dilute** "**soup**".
- The oceanic water rich in mixture of organic compounds was termed by **J.B.S. Haldane** (1920) as '**hot dilute soup** of organic substances, or **'Prebiotic soup'**.
- The large organic molecules which were synthesized abiotically on primitive earth later came together and formed large colloidal aggregates.
- **Protenoids** are protein like substance formed by polymerization of aminoacids under inorganic conditions such as heating to over 140ºC.
- **The formation of protein molecules** can be **considered a land mark in the origin of life**.
- Colloidal aggregates were named **microspheres** by **Sydney Fox** and **coacervates by Oparin**.
- The model proposed by **S.Fox** of protenoid microsphere for protocells is widely accepted because of its following significances : (1) Such protenoid microspheres arise from monomers, rather than from polymers obtained from organisms already in the biota, as is true for the usual experiments with coacervate droplets. (2) This model suggests that protenoids are informational and it shows the origin of communication which may be intercellular or intergenerational communication.
- **Nucleic acid**, formed by the polymerization of nucleotides, are the basis of life as these represents the genetic material of an organism and is the molecular basis of heredity.
- **Nucleoproteins** gave most probably the **first sign of life**.
- **Biological evolution** (or **biogeny**) involves formation of prokaryotes to eukaryotes.
- More complex coacervates and microspheres **function as precells or prebionts**.
- The **first living form** named **protocell or eobiont or protobiont**, originated in the primitive ocean.
- Amino acids, sugars, glycerol and fatty acids gave rise to polymers, which may have assembled into spherical structures called **protobionts**.

1. **Free Atoms** .... H (Hydrogen), C (Carbon), N (Nitrogen)
↓
2. **Inorganic Molecules** .... H_2 (Hydrogen), H_2O (Water), CH_4 (Methane), NH_3 (Ammonia), CO_2 (Carbon dioxide)
↓
3. **Simple Organic Molecules (Precursors)** .... CH_4, H_2O ⟶ Sugars, Fatty Acids, Glycerol
   CH_4, H_2O, NH_3 ⟶ Amino Acids
   CH_4, H_2O, NH_3, HCN ⟶ Nitrogenous Bases (Purines, Pyrimidines)
↓
4. **Complex Organic Molecules of biological origin** .... Sugar + Sugar ⟶ Polysaccharides
   Fatty Acids + Glycerol ⟶ Fats
   Amino Acid + Amino Acid ⟶ Proteins
   Nitrogen Bases + Sugars + Phosphates ⟶ Nucleotides, Adenosine Phosphates
   Nucleotides + Nucleotides ⟶ Nucleic Acids
↓
5. **Coacervates (Oparin)** .... Aggregates of large complex organic molecules capable of growth and division
↓
6. **Eobionts** .... Nucleic acid—controlled coacervates
↓
7. **Free gene** .... Self replicating nucleoprotein complex.
↓
8. **First Primitive cells** .... Lipid-protein membrane-bound units with enzyme-controlled metabolism and nucleic acid regulation without organised nucleus
   ↓
   Prokaryotes .... Chemoheterotrophs and anaerobic (due to absence of free oxygen from the environment)
   ↓
   Eukaryotic Cells (With well organised nucleus)
   ↓
   Multicellular organisms

Flow chart : Main steps in the origin of life according to the Oparin–Haldane theory and Modern views.

- **Protocells** were prokaryotic unicells which had naked DNA, protein manufacturing machinery, mode of energy liberation and its utilization.
- Protobionts made of polypeptides are called **microspheres**, those of lipids are called **liposomes** and those of combinations of polypeptides, nucleic acids and polysaccharides are called **coacervates**.
- The **origin of prokaryotes were probably from protocell**.
- The **first prokaryotes** were **anaerobes and chemoheterotrophs**.
- Chemoautotrophs were formed when environment over the earth became cooler.
- The organisms performing chemosynthesis are called **chemoautotrophs**.
- Simple one celled organisms somewhat similar to today's cyanobacteria were present on earth about 3600 million years ago.
- **Atmosphere become richer in oxygen due to photoautotrophs**.
- Free living eukaryotic cell like organisms originated in the ancient ocean presumably about 1.5 billion years ago.
- Primitive eukaryotes **led to the evolution of protists, plants and animals**.
- The oxygen present in the modern atmosphere must have been liberated as a result of photosynthesis of green plants.
- The **most important condition for the origin of life** is the **presence of water** because life can originate from abiogenetic materials in water.

- There is **no life on the moon** because there is no water.
- **Life originated in the ocean (water)** presumably about 3.7 billion years ago in **precambrian era**.
- The prokaryotes evolved before the eukaryotes. The oldest known fossil cells are about the same size as modern prokaryotes.
- Some of the oldest known fossil cells appear as parts of **stromatolites**, which are formed today from sediments and photosynthetic prokaryotes.
- The **earliest autotrophs** must have been **anaerobic chemoautotrophs.**
- The first organisms to give off oxygen were probably **cyanobacteria**.
- When a primitive bacterium is exposed to oxygen gas, it dies.
- Organisms that can grow with or without oxygen gas are called **facultative anaerobes**.
- Organisms that are poisoned by oxygen gas are **obligate anaerobes**.
- Organisms that cannot grow without oxygen gas are **obligate aerobes**.
- Prokaryotes were limited in genetic variability because they reproduced by binary fission.
- Haeckel (1894) proposed to create a separate subkingdom **protista** to include all unicellular eukaryotic plants and animals.
- Prokaryotes are more diverse than eukaryotes in terms of metabolism.
- Of the planets of our solar system, only **Mars** is supposed to have life, but no evidence of life has yet been found by the scientists.

End of the Chapter

Chapter 25

Relationship Among Organisms & Evidences of Evolution

- All living organism have arisen through the evolutionary process and shows diversity.
- Although microbes, plants and animals show a great diversity, these shows a number of life processes which are common to all organisms like all are formed of living protoplasm, derive energy and matter from their environment, maintain homeostasis through a number of metabolic process, etc.
- **Evolution** is the formation of newer types of organisms from the pre-existing ones through modification. Evolution is, therefore, often called **descent with modification** (Darwin, 1859).
- Evolution has **occurred through mutation, natural, selection and isolation.**
- **Term evolution** was **coined by Herbert Spencer** and has been derived from latin word *'evolvere'* which means unfold and literally means the process of continuous change.
- Evolution is an orderly change from one condition to another, eg when planets and stars change in between their birth and death, then it is called as **stellar evolution**.
- When matters, elements change from time then it is called as **inorganic evolution**.
- Evolution is of several kinds, like –
  – **Progressive evolution :** formation of more complex, elaborate and specialized structures from simpler ones.
  – **Retrogressive evolution :** development of simpler and less elaborate forms from complex ones.
  – **Microevolution :** development of minute changes due to gene mutations and

Historical Aspect of Evolution—Ancient Thoughts

- According to Indian mythology, **Brahma** created various forms of life in one stroke.
- According to **Anaximander,** a Greek philosopher of 6th century B.C., water was the material source for evolution.
- **Heraclitus** (510 B.C.) proposed the idea of struggle among living organisms.
- **Plato** (428-348 B.C.) proposed that each species has an unchanging **ideal form** (*eidos*) in his idealistic concept. According to him, all earthly representatives are imperfect imitations of such true essence of an ideal unseen world. God is perfect and everything that existed on Earth was His ideas.
- **Aristotle** (384-322 B.C.) constructed a **"Scala Naturae",** also called **Ladder of Nature** or **Great chain of Being**, in which he grouped the living organisms from simpler ones to the most complex ones. So he proposed a gradual transition from imperfect to perfect.
- The ancient Indian texts of philosophy and Ayurveda deal with the origin of life.
- Manu's texts in Sanskrit, **Manu-Samhita** or **Manu-Smriti** (200 A.D.) also made a mention about evolution.

recombinations. The changes occur below the level of species.

- **Macroevolution :** development of large changes like formation of new species and genera due to mutation causing large scale changes in chromosomes.
- **Megaevolution :** large change giving rise to new families, orders, classes etc.
- **Parallel evolution :** independent formation of similar traits by related groups of organisms.
- **Convergent evolution (adaptive convergence) :** formation of similar traits by unrelated groups of organisms as wings in insects, bird and bats.
- **Divergent evolution (adaptive radiation) :** formation of different structures from a common ancestral form, e.g., forelimbs in horse, bat and human beings.
- **Coevolution :** evolutionary changes in one or more species in response to changes in other species of the same community.

- There are **many types of evidences which supports the process of organic evolution**. These evidences are – **anatomical or morphological; embryological; palaeontological; physiological or biochemical; cytological; molecular; biogeographical; taxonomic and from genetics;** animal breeding, behaviour, hosts and parasites, formation of new species and experimental production of new species.
- Study of functional anatomy is known as **tectology**.

ANATOMICAL OR MORPHOLOGICAL EVIDENCES

- Comparative study of the morphology & anatomy of groups of animals or plants shows that certain structural features are basically similar. These features includes – body organization & gradual modification.
- Morphological and anatomical evidences **include homologous & analogous organs**, **connecting links**, **vestigial organs** and **atavisms**.
- Organs having similar embryonic origin & construction but differing in external form and functions are called as **homologous organs**.
- Homologous organs are found in forms **showing adaptive radiation** from a common ancestor, so these **give evidence of divergent evolution**.
- The vertebrate fore-limbs, insect legs, insect mouth parts, vertebrate epidermal derivatives, tail and vertebral column and thorns of *Bougainvillea* and tendrils of *Passiflora* are some **common examples of homologous organs**.
- The **fore-limbs of these animals** (seal, bird, bat, horse and man) have the **same general function of locomotion** but have different shapes and bring about different types of locomotion. They are used for – **swimming** in seal, **flying** in bird and bat, **running** in horse and **grasping** in man.
- **Legs of all insects** consists of 5 parts, named as coxa, trochanter, femur, tibia and 1-5-jointed tarsus, and are **used for locomotion**. They all have different form and perform different specific functions in different insects. The same basic structure of the legs shows that all the insects have a common ancestor. The variation is due to adaptive modification during the evolution of the group.
- **Vertebrate tail** is composed of vertebral column, blood vessels, nerves, muscles and skin. It lacks coelom and viscera. Tail is **used for swimming** in fish, mud puppy (amphibian), crocodile, and whale; **for holding onto objects** in seahorse, chamaeleon, scaly ant eater and new world monkeys; **as a balancing organ** in kangaroo; **to keep off** flies in cattle; and **for defence** in spiny tailed lizard and wall lizard.
- **Homologies** are of **two types** – **phylogenetic** (eg hand of man and leg of horse) and **serial homology** (invertebrates).
- **Analogous organ** are those organ which have the similar function and are superficially appear similar and are different in fundamental structure and embryonic origin.
- **Examples of analogous organs** are – wings of insects, birds and bats (meant for flying) ; phylloclades, cladodes and phyllodes (perform the function of leaf as photosynthesis).
- The **analogous organs** are the **result of convergent or parallel evolution in separate lineage**.
- There are different modified roots, stems and leaves. Sweet potato is an underground tuberous root and potato is an underground stem but the modifications are meant for storage of food. These are therefore examples of analogous organs.
- The organisms which possess the characters of two different groups are called **connecting links** and shows the possible path of evolution.
- Connecting links are the **living intermediate forms.**

Table : Important connecting links.

➢ *Chimaera* (Rabbit or rat fish)	–	Between cartilaginous and bony fishes
➢ Virus	–	Between non-living and living
➢ *Euglena*	–	Between plants and animals
➢ *Proterospongia*	–	Between protozoa and porifera
➢ *Neopilina*	–	Between mollusca and annelida
➢ *Peripatus*	–	Between annelida and arthropoda
➢ *Balanoglossus*	–	Between echinoderms and chordates
➢ Lungfish *Protopterus*	–	Between fishes and amphibia
➢ *Latimeria*	–	Between fishes and amphibia
➢ *Seymouria*	–	Between amphibia and reptiles
➢ *Archaeopteryx*	–	Between reptilia and birds
➢ Spiny ant eater (*Echidna*)	–	Between reptilia and mammalia
➢ Duck Billed *Platypus*	–	Between reptilia and mammalia
➢ Lycaehaps	–	Between reptilia and mammalia

- **Missing link** are the transitional forms between two groups of organisms occurring only in the fossil state, eg *Archaeopteryx*.
- **Vestigial organs** are the useless and functionless degenerate structures which were large and functional in some other animals. They are rudimentary, relatively smaller in size and do not function.
- **Some of the vestigial organs in animals** are given as follows : vermiform appendix, coccyx, plica semilunaris, pinna muscles and wisdom teeth **in man**; rudiments of hindlimbs **in python and boa**; pelvic girdle **in whales**; splint bones (vestigial 2nd & 4th digit of fore and hindlimb) **of horse**; wings of kiwi and eyes in **cave animals**.
- **Atavism** is the sudden reappearance of those ancestral characteristic in an organism or in the organisms of a group, which do not occur normally or which represent the reminiscent of normal structures possessed by the individuals of other groups.
- Atavism is also known as **reversion**.
- **Examples of atavisms** are –
  - **Cervical fistula** : In man only one pharyngeal pouch perforates to form an opening from the pharynx to the exterior in the form of the external ear canal and Eustachian tube. But, rarely neck may possess an additional opening representing the cervical fistula.
  - **Tail** : Tail is absent in man but occassionally a human baby is born with a short fleshy tail.
  - **Hairs on the body and face**
  - **Homodont dentition in cetaceans** : Cetaceans are mammals with heterodont dentition. But piscivorous cetaceous possess simple conical homodont teeth. Their ancestors are known to possess heterodont teeth of mammals. This is true reversal of evolution.
- The **principle of atavism** was **proposed by L. Dollo** and is called **Dollo's law**. It states that living organisms do exhibit evolutionary irreversibility.
- **Types of atavism** are – **family atavism, race atavism** & **atavism of teratology**.
- **Family atavism** includes the transmission of individual characteristic or characteristics within the members of a family in latent condition for several generation and their sudden reappearance in the offsprings after a number of generation. This phenomenon is controlled at gene level and can be explained by simple Mendelian laws of inheritance.
- **Race atavism** includes those cases of reversal where one or more characters of one race appear in the individual of another race, e.g. profuse growth of hair on the body & face of Irish dogman etc.
- **Atavism of teratology** includes the appearance in a race of such abnormal characters, which were normal in other supposedly ancestral races. Eg. appearance of cervical fistula in man which actually corresponds to gill slits etc.

EVIDENCES FROM EMBRYOLOGY

- **Embryological development** reveals a unity of plan. Embryos of the vertebrate series exhibit many features that are absent in the adults. *For example*, all the embryo's a vertebrates including human develops a row of vestigial gill slits just behind the head.

Evidences from embryology
1. Similarity in early development.
2. Resemblance among vertebrate embryo's in shape and structure.
3. Recapitulation theory or biogenetic law by Ernst-Haeckel stating that an animal in its development from egg to adult repeats or recapitulates in a condensed form the stages through which its ancestors have passed in the course of evolution *i.e.* ontogeny repeats phylogeny.
4. Temporary nonfunctional embryonic structures.
5. Retrogressive metamorphosis
6. Neoteny.

Egs.
1. Larva of *Herdamania* shows characters of chordates (presence of notochord)
2. Change of a fish like embryo of human to a seventh month human foetus resembling a baby ape to a human baby.
3. Origin of gymnosperms from pteridophyte like ancestor.
4. Fish like tadpole of frog shows it has evolved from fish like ancestor.
5. The protonema of moss and fern shows an algal ancestory.
6. The presence of primordia of leg in each segment of the embryo of insect shows that they arose from an ancestor having segmentally arranged appendages.

- Evidences for embryology are **based on the comparative study of the embryos of various animals** (*See the above flow chart*).
- In 1828, **Von Baer put forward Baer law**. **E. Haeckel later called it the biogenetic law** (in 1868). The view was summarised as ontogeny recapitulates phylogeny. **Ontogeny** is the life history of an organism while **phylogeny** is the evolutionary history of the race of that organisms.
- The recapitulation theory **not only supports the concept of organic evolution, but also discloses the stages in the evolution of an animal**.
- Recapitulation is **seen in invertebrates also**, eg.- adult insects have three pairs of walking legs but in embryo, each body segment has one pair of primordia of legs. This shows that insects have evolved from an ancestor having segmentally arranged appendages.
- Certain animals show complicated larval forms and simple adults, e.g. ascidians, parasitic copepods, parasite like *Sacculina*. In **retrogressive metamorphosis**, due to parasitic habit, adult organs are highly reduced.
- In some animals (eg. axolotl larva of *Ambystoma*) the larva fails to undergo metamorphosis. It develops gonads, attains sexual maturity and starts reproduction. This is called **neoteny** or **paedogenesis**.
- Retention of primitive or larval features provides evidences in favour of evolution that under specifically favourable circumstances natural selection favours retention of primitive or larval characteristics.

Ecogeographical Rules–Size, Shape and Colour
- **Cope's Law :** In the course of evolution, there is tendency in animals to increase in size, eg dinosaurs.
- **Bergman's Law :** Warm blooded animals are larger in size in the colder regions as compared to hotter parts.
- **Allen's Law :** Extremities like tails and ears become smaller in colder areas.
- **Gloger's Rule :** Warm blooded animal have more melanin in hot wet areas but develop yellow-red pigment in hot dry areas.
- **Rapoport's Rule :** Species adapted to cooler climates have a wide range of latitudinal distribution than the species adapted to warmer climates.
- **Jordan's Rule :** Fishes of colder waters have larger size with more vertebrae than the fishes of warmer waters.
- **Dollo's Law :** States that evolution is irreversible. Proposed by L.Dollo in 1893.
- **Gause's Law (Gause 1934) or the competitive exclusion principle (Hardin 1960) :** It states that the two species having the same ecological requirements cannot continue to occupy indefinitely the same habitat.

PALAEONTOLOGICAL EVIDENCES

- **Palaeontology** is the study of the past life based on fossil records. Their study reveals the existence of life in past and illustrate the course of evolution. The **organic remains** like bones, hairs, nails, claws, shells or impressions of the organisms **found in rocks are called fossils**.

- **Father of palaeontology** is **Italian Leonard de Vinci** (1542-1519) while **founder of modern palaeontology** is **Cuvier** (1769 - 1832).
- **Fossils** are remains of extinct organisms buried and preserved by natural process.
- The science of palaeontology links biology with geology and is concerned with finding cataloguing and interpreting evidences.
- The **study of fossil plants** is called **palaeobotany** while the **study of fossil animals** is called **palaeozoology**.
- **Charles Darwin** was the **first to show that fossils provides direct evidence for organic evolution** because it deals with the actual organisms which lived in the past.
- The **different methods of fossilization** (a continuous process) are– **intact preservation**, **petrifaction, moulds & casts**, **impression**, **mummies**, **tracks & trails** etc.
- The **media in which the fossil occur** include **sedimentary rocks**, **amber**, **asphalt**, **volcanic ash**, **ice**, **peat bogs**, **sand** and **mud**.
- **Age of fossils** is **determined by dating the rocks** in which fossils occurs.
- The dating of rocks are called **geochronology** and dating system is called **clocks of rocks.**
- Rocks are of **three types** :
  - **Sedimentary rocks** formed by gradual settling down of fragments in regions such as lakes or sea, eg. conglomerate, sandstone, shale, limestone, gypsum etc.
  - **Igneous rocks** formed by the cooling down and solidification of molten material of the earth .
  - **Metamorphic rocks** are actually sedimentary rocks which are changed by heat and pressure, eg. schist, gneiss, slate & marble.
- The method for determining the age of rocks or of the fossils are– **carbon dating method** (discovered by **W.F Libby**); **radioactive clock method** (uranium lead method) which is based upon the disintegrating property of radioactive elements [proposed by **Boltwood** (1907)], and **potassium argon method**.
- **Half life period of C^{14}** is about **5600 years.**
- The common radioactive elements which lose their radioactivity and change into their non-radioactive isotopes at a fixed rate are:
  Potassium^{40} $\longrightarrow$ Argon^{40}
  Carbon^{14} $\longrightarrow$ Nitrogen^{14}
  Uranium^{238} $\longrightarrow$ Lead^{207}
  Rubidium^{87} $\longrightarrow$ Strontium^{87}
  Thorium^{232} $\longrightarrow$ Lead^{206}
- **Half-life of** K^{40} is 1.3×10^9 years.
- **Potassium-Argon method** is useful because potassium is a common element found in all sorts of rocks. Potassium decays into argon extremely slowly.
- Potassium-Argon method has **recently been used to determine the age of hominid fossils in East Africa**.
- **Living fossils** are those plants and animals which have become extinct excepting one or two representatives, eg *Sphenodon*, *Ginkgo*, *Equisetum* etc.
- Death and disappearance (extinction) of large groups of plants and animals over a short span of time is called **mass extinction**.
- Mass extinction may be due to the crash of a meteor or comet with earth **(impact theory)** or to the drifting, coalescing and breaking apart of continents **(continent movement theory).** Mass extinctions shape the overall pattern of macroevolution.
- The **largest mass extinction came at the end of the Permian,** about 250 million years ago. This coincides with the formation of Pangaea II, when all the World's continents were brought together by plate tectonics.
- The **most well-known extinction occurred at the boundary between the cretaceous and tertiary periods**. This called the **K/T Boundary** and is dated at around 65 million years ago. **This extinction eradicated the dinosaurs**.
- **Fossil/Forests/Parks** are large-sized exposures of fossil bearing rocks, dug out and conserved by experts so as to give glimpses of what sorts of plants and animals existed in that period.
- **Birbal Sahni Institute of Palaeobotany** at Lucknow is exclusively **engaged in study of fossil plants**.
- Some **national fossil parks** are – (i) 50 million years old fossil forest in intertrappean lava sediments at Mandla in M.P. (ii) 100 million years old fossil forest in Rajmahal Hills, Bihar, (iii) 260 million years old coal forming forest of Orissa. (iv) National fossil park. Tiruvakkarai is found in South-Arcot-District of Tamil Nadu. Fossilized trunks of

Table : Types of fossils, their formation and examples.

Fossil	Fossilization process	Example
Entire organism	Frozen into ice during glaciation	Woolly mammoths found in siberian permaforst (25000 years ago)
Entire organism	Encased in the hardened resin (amber) of coniferous trees	Insect exoskeletons found in oligocene rocks in Baltic coast
Entire organism	Encased in tar	'Mummies' of mammals and birds found in asphalt lakes of California
Entire organism	Trapped in acidic bogs; lack of bacterial and fungal activity prevents total decomposition	'Mummies' found in bogs and peat in Scandinavia
Hard skeletal materials	Trapped by sedimentary sand and clay which form sedimentary rocks, e.g. limestone, sandstone and slit	Bones, shells and teeth (very common in British Isles)
Moulds and casts	Hard materials trapped as above. Sediments harden to rock. The skeleton dissolves leaving its impression as a mould of the organism. This can be infilled with fine materials which harden to form a cast. Great detail is thus preserved	Gastropods from Portland Stone, Jurassic. Casts of giant horsetails (Calamites) of carboniferous forest. Internal casts of molluscs shells showing muscle attachment points, Fossils of Pompeii city, which was buried by volcanic ash from mount vasuvius in AD 79, presents moulds & cast of men and their domestic animals.
Petrifaction	Gradual replacement by water-carried mineral deposits, such as silica, pyrites. calcium carbonate or carbon. Slow infilling as organism decomposes producing fine detail	Silica replacements of the echinoderm *Micraster*
Impressions	Impressions of remains of organisms in fine-grained sediments on which they died	Feathers of *Archaeopteryx* in Upper Jurassic. Jellyfish in Cambrian found in British Columbia. Carboniferous leaf impressions
Imprints	Footprints, trails, tracks and tunnels of various organisms made in mud are rapidly baked and filled in with sand and covered by further sediments	Dinosaur footprints and tail scrapings indicate size and posture of organisms
Coprolites	Faecal pellets prevented from decomposing, later compressed in sedimentary rock. Often contain evidence of food eaten, e.g. teeth and scales	Coenozoic mammalian remains

tree, twenty million years old are kept in the Children Park, Guindy, Chennai.

Geological time scale

- **Geological time scale** is a chronological order or history of evolution based upon the study of fossils.
- Geologists have divided the history of the earth into **eras,** the **periods** and **epochs.**
- The **precambrian** is very long period of time. It comprises about 87% of the geological time scale.
- **Palaeozoic** and **mesozoic** eras are subdivided into periods but **coenozoic** is divided into periods and epochs.
- During **ordovician** the vertebrates originated, the first fish was **ostracoderm**.
- **First reptiles appeared during carboniferous period** of palaeozoic era from stem reptiles called **'cotylosaurs',** the ancestral genus being *Seymouria*.
- **North America** was the **main centre of dinosaur evolution.**

- First indication of **fishes appeared in cambrian period.**
- In **devonian, diversification of fishes and evolution of amphibia occurred**.
- The **large devonian** is characterised by the appearance of the first land vertebrates. These animals were called **stegocephalians.**
- In **pensylvanian, amphibians became dominant on land, and appearance of first reptiles occurred**.
- In **triassic, transition of reptiles to mammals occurred**.
- In **jurassic period**, there were **dominance of dinosaur on earth**.
- **First toothed bird** appeared in **jurassic period**.
- Toothed bird as well as dinosaur **became extinct in cretaceous period.**
- **Evolutionary explosion of mammals** occurred in **palaeocene period.**
- **First man like apes** appeared in **miocene.**
- In **pleistocene**, extinction of many large mammals occurred and also referred to as **age of man.**
- **Recent epoch** (the period of last 10000 years of earths history) is the **age of man** and where the **development** of **human cultures occurred**.
- **Elephants of pleistocene period** are commonly known as **woolly mammoths.**
- Elephants have originated from some common proboscidean sirenean ancestor.
- True elephants belonging to the genus *Loxodonta* and *Elephas* appeared in **pliocene**.
- True camels belonging to the genera *Camelus*, appeared in latter portion of **coenozoic era**.
- **Mesozoic era** is known as era of **intermediate life** and "**age of reptiles or dinosaurs**".
- The **phylogeny of horse** has been traced from the fossils **discovered from the tertiary rocks of North America**.
- The first known horse like animal which forms the starting point in the **equine evolution** is *Hyracotherium* (also called **eohippus**). It is commonly known as "**dawn horse**".
- **Merychippus** (ruminant horse) **in upper miocene, marked the completion of transition from browsing to grazing.**
- Modern horse, *Equus* **is the direct descendent of** *Pliohippus.*
- The **first representative of** *Equus* **appeared in late pliocene** and during pleistocene achieved world wide distribution.

Evolutioury sequence of horse

Eohippus Eocene period → **Mesohippus** (Oligocene period) →
Merychippus (Miocene period) → **Pliohippus** (Pliocene period) → **Equus** (Pliocene period)

- *Recent epoch* – Age of man and limbs. *(Holocene)*
- *Pliocene* – Age of mammals, birds and angiosperms.
- *Cretaceous* – Age of reptiles and gymnosperms.
- *Jurassic* – Period of dinosaurs.
- *Permian* – Age of amphibians and ferns.
- *Devonion* – Age of fish.
- *Silurian* – Age of higher invertebrates.

BIOGEOGRAPHICAL EVIDENCES

- **Biogeography** is the study of distribution of animals and plants in different parts of the earth.
- **A.R. Wallace** (an English Naturalist) divided earth into six **biogeographic realms** – **palaeoarctic, oriental, ethiopian, australian, nearctic,** and **neotropical**.
- **Wallace line** is an **imaginary line between oriental and australian realms**.
- **Two zoogeographical regions separated by high mountain ranges** are **palaearctic** and **oriental**.
- Prototherians, the most primitive mammals which provide an evidence of organic evolution from geographical distribution, are found in Australia.
- **Charles Darwin** during his voyage around the world **studied the fauna and flora of Galapagos islands** (off the west coast of south America).
- Galapagos islands are called **'a living laboratory of evolution'**.
- Darwin studied 20 related varieties of the bird belonging to family Geospizidae which are different in shape and size of beak. These birds are now called **'Darwin's finches'.**
- Some years **after Wallace's line**, **Weber drew an imaginary line on the map between the oriental and Australian region,** because it was considered to divide the fauna of two regions better than Wallace's line. The Weber's line is further east than Wallace's line.

- **Wallacea** is a **transitional area between Wallace's line and Weber's line** in which some of the animals of both the regions are found. Thus the islands *i.e.*, Celebes, Flores and Lombok lying between the two lines, are neither the geologically part of oriental region nor part of Australian region.
- **Biogeographical evidences** are **based on** –
  - **Discontinuous distribution** : descendants of a common ancestor inhabit different continents so mutated and slightly different but closely related species of the same genus, eg alligator, mangolicas, *Tulip sassafras* etc.
  - **Restricted distribution :** the continent has peculiar flora and fauna, eg. pouched animals in Australia.
  - **Life on oceanic island :** the animals and plants of oceanic islands resemble those of mainland yet include distinct species, eg. Darwin finches of Galapagos islands and the large sized *Inguana* & tortoises.
  - **Convergent or parallel evolution :** in this natural selection can induce animals of two different groups to adapt similar habitats for survival, eg., marsupials.

PHYSIOLOGICAL OR BIOCHEMICAL EVIDENCES

- Comparative biochemistry also shows relationship among the animals.
- The aspects of biochemistry that indicate biochemical affinity are – metabolic processes, enzymes, hormones, blood and lymph, blood proteins, blood groups, and molecular homology.
- The **metabolic processes,** such as digestion, biosynthesis, respiration, muscle contraction and transmission of nerve impulses, occur almost in a similar manner in all animals.
- The **enzymes** are essentially alike in their nature and action in most animals, *for example*, trypsin is found in many animals from sponges to man. This shows that all animals are related to one another.
- The **hormones** resemble in their chemical nature and function in all the vertebrates.
- Thyroxine plays a role in the metamorphosis of tadpole into a frog. If the thyroid glands are removed, the tadpole fails to turn into a frog. Such a larva starts metamorphosis if fed on thyroid gland of another animal.
- The **blood and lymph fluids** are similar in their composition and physiological role in all vertebrates. This indicates relationship among the vertebrates.
- The **blood proteins** of various mammals are similar to a large extent, but are sharply distinguishable from those of other vertebrates. The blood protein tests have shown that the man is nearest the great apes (gorilla and chimpanzee), and next nearest, in order, are the old world monkeys, the new world monkeys and the tarsiers. The same is indicated by the anatomical facts. Thus, the blood protein tests reveal man's genetic relationship.
- Four blood groups: A, B, AB and O, occur in humans. The blood groups A and B are found in apes but not in monkeys. This suggests that human beings are more closely related to apes than to monkeys, though all the three have a common ancestory. The same is shown by blood protein tests mentioned earlier.
- The occurrence of similar biochemicals in animals is called **biochemical homology** just as anatomical homology shown by similarity in organs and tissues.
- Similarity among animals at the molecular level is called **molecular homology**.
- Human DNA differs in only 1.8% of its base pairs from chimpanzee DNA, and there is no difference between the two in the amino acid sequence for the protein cytochrome C. Close relationship indicated by these sequences conforms to that shown by other means such as anatomical or fossil evidence.
- Physiology of excretion in vertebrates clearly indicates that they have been evolved gradually from simple forms to complex ones. The nitrogenous waste in many fishes (*e.g.,* bony fishes) is in the form of ammonia, in case of amphibia it is urea as amphibia are more evolved and adapted for life both in water and on land.

TAXONOMICAL EVIDENCES

- **Taxonomy** is the study of the theory, practice and rules of classification of living and extinct organisms.
- The naming, description, and classification of a given organism draws an evidence from a number of fields like **classical taxonomy** (based on morphology and anatomy), **cytotaxonomy** (compares the size, shape and number of chromosomes of different organism),

and **numerical taxonomy** (uses mathematical procedures to assess similarities and differences and establish taxonomic groups).

- In the present system of classification different systemic levels or taxons are employed, like species, genus, family, order, class, phylum etc.
- Different species possessing similar features are included in a genus. Several genera with certain common characters are grouped into a family. Similarly families form orders, classes and phyla.
- The classification further shows the grading of different phyla in the order of increasing complexity of organisation.
- Thus **classification reveals a positive relationship between different animals** which is due to their descent from a common stock.

EVIDENCES FROM GENETICS

- **Genetics** is the study of heredity, the transmission of parental characters to the offspring.
- A number of sudden inheritable variations are called **mutations**.
- In mutation new genetic material is created which never existed before. Mutations provide raw material for evolution and can give rise to new species.
- Hereditary variations also occur due to **genetic recombination**. The latter causes hybridization. Examples of hybridization and mutations are available which show that evolution has taken place.
- Pattern of transmission of characters is also similar in various organisms. It shows inter-relationship among different living beings.
- Man has developed many varieties of useful animals (*e.g.*, cows, ancon sheep, horses, hornless cattles etc.) and crops (*e.g.*, wheat, rice, cotton, etc.). Some varieties of fruits like mango, citrus, etc. have also been improved. Hybridization and induction of polyploidy has given rise to new plants like *Triticale, Raphanobrassica*. Such studies have provided useful evidence concerning the evolution.

End of the Chapter

Chapter 26

Theories of Evolution

- Evolution is the process of gradual development from a simple unorganized condition into a complex organized form.
- The process of evolution is continuous, taking place even now.
- The **concept of organic evolution** postulates that:
  - Organisms that appeared earlier were simpler.
  - Earlier organisms have gradually changed into existing complex organisms.
  - All organisms are inter-related because of common origin.
- **Four main theories** to explain the theories of evolution are–**Lamarck's theory of inheritence of acquired character**; **Darwin's theory of natural selection**; **mutation theories by Hugo de Vries** and **modern concept of evolution**.

LAMARCKISM OR LAMARCK'S THEORY

- In 1809 French biologist, Jean Baptist de Lamarck (1744-1829) explained this theory, in his famous book *Philosphie Zoologique*. He was originally a botanist but in later life became a zoologist.
- **Lamarckism** is popularly known as **theory of inheritance of acquired characters** or **theory of use and disuse organs.**
- **Propositions of Lamarckism** are -
  - **Internal vital force -** It tends to change the size and form of different organisms, generally making them larger and more complex.
  - **Effects of environment** - Variations in the environmental factors such as temperature, light, pressure, humidity, wind etc affect the living things and produce changes in their bodies.
  - **New needs** - New needs produce a new movement in the body that brings about modification of existing organs and formation of new organs.
    It is also known as **doctrines of desires** or **appetency.**
  - **Use and disuse of organs -** Constant use of an organ makes it more efficient and specialized. Disuse of an organ brings about degeneration.
  - **Inheritance of acquired character** - The traits acquired due to the above reasons passed on to the next generation. After several generation, it gives rise to a new species.
- **Long neck and high forelimbs of giraffe** developed due to their stretching for obtaining foliage from trees when ground vegetation become sparse is the prime example of Lamarckism.
- Lamarckism **cannot be accepted fully**. **Weismann** (1883 - 1885) and **Payne** (1911) **criticised his theory of inheritance of acquired characters**.
- **Neo - Lamarckism** is an attempted revival of Lamarckism by modifying it and finding evidences for direct effect of environment on germ cells and the effect of somatic cells on germ cells.
- **Features of Neo - Lamarckism are**–
  - It refers to the **modified version** of Lamarck's theory (Lamarck's views + new facts).
  - It **does not include** factors like inner will and **use and disuse of organs** etc.
  - It differentiates between somatic cells and germ cells.
  - It holds that **only the variations affecting germ cells** are inheritable.
- The **theory of germplasm** (Weismann, 1892) states that inheritance of characters from parents to

offspring is mediated through germplasm which continues generation after generation hence it is known as **theory of continuity of germplasm.**

- Lamarckian postulate of use and disuse of organs is supported by:
  - Fairly developed and strong biceps of blacksmith,
  - Elongated limbless body of snake,
  - Bottom dwelling flatfish whose larvae have normal eyes while in adults eyes migrate to one side of the head.
- Some other examples of use and disuse of organs are:
  - Lengthening of neck of giraffe,
  - Rudimentary eyes of cave dwellers,
  - Vestigial organs of living animals,
  - Webbed feet of swimming birds.
- Sumner's experiments on white mice, Kammerer's experiment on *Proteus anguinus* and Tower's experiments on potato beetle proved the effect of environment and temperature bringing about inheritance of acquired characters.
- The greatest blow to lamarckism came from the work of the German scientist **August Weismann**.
- **Neo-Lamarckians** believe that only those characters, whatever be their origin and nature, that could affect germplasm are heritable and others are not.
- **Objections to Lamarckism**–
  - August Weismann conducted experiments of cutting the tails of rats for 80 generations but tailless rats were never born.
  - Nose boring and ear boring Indian women to wear ornaments has been in a practice for several generations but this acquired character is not inherited. Similarly circumcision practiced by some communities for last several centuries is not inherited.
  - The small feet of Chinese women confined by using wooden shoes are never inherited, similarly the strong muscles of an athlete, wrestler are not inherited.

DARWINISM OR DARWIN'S THEORY

- **Darwinisms** is the term coined for the explanation offered by Darwin for the origin of species by natural selection.
- Darwin gave the biological world a master key that unlocked the previous intricacies about evolution.
- The **theory of natural selection** was announced on June 30, 1858 by the English naturalist **Charles Darwin** (1809-1882) and **Alfred Russel Wallace** (1823-1913).
- This theory is also known as **Darwin - Wallace theory.**
- Darwinism was published in 1859, in the book **"The Origin of Species by Means of Natural selection".**
- The **theory of natural selection** is based on the following factors :
  - Rapid multiplication and limited food and space which leads to struggle for existence.
  - Struggle for existence and variations which leads to natural selection or survival of the fittest.
  - Natural selection and inheritance of useful variation over many generation which leads to formation of new species.
- The **struggle for existence** is **three-fold for every individual** :
  - **Intraspecific struggle :** This is between the individuals of the same species. This is the keenest form of struggle as the needs of the individuals of the same species are identical.
  - **Interspecific struggle :** This is the struggle between the individuals of different species. This struggle is illustrated by the efforts of a snake for catching a rat, and of the rat for escape.
  - **Environmental struggle :** This is the struggle of the animals with the changes in environmental factors, such as heat, cold, drought, flood, storm, famine, light etc.
- Evidence of Darwinism can be shown by **entomophily.** Many pollinating insects have proboscis length exactly matching the position of nectary in the flower. This can develop gradually through **natural selection.**
- **Industrial melanism** (appearance of dark or melanic forms in some organisms like moths in the industrial regions) is the **appropriate example of natural selection.**
- **Inheritance of small variations, perpetuation of vestigial organs, over-specialization of organs** go against Darwinism.

Darwinism passed these 2 phases –

- **Romantic period -** For about 40 years from the enunciation of theory of Natural Selection by Darwin.
- **Agnostic period -** Period of criticism of 'Natural Selection' for about 30 years due to continuous variations, pangenesis and arrival of the fittest.

- **Darwin's theory fails** to explain inheritance of small variations, perpetuation of vestigial organs, over-specialization of organs.
- Darwin was British naturalist; in 1831 at the age of 22 he was appointed upon a world survey ship of British government, **H.M.S Beagle**.
- **Alfred Russel Wallace** (1823–1913) also travelled widely. Evolutionary ideas similar to those of Darwin developed independently in Wallace's mind.
- **Both Darwin and Wallace jointly propounded the 'Theory of Natural selection'.**
- The thinking of both Darwin and Wallace was greatly influenced by essays on **'Principles of population'** written by **T.R.Malthus** in 1798.
- Malthus in his essays on population has said that food increases in arithmetic progression while number of animals increases in geometric progression.
- Darwin's thinking was also influenced by **Charles Lyell's** (1832) essays on '**Principles of Geology**'.
- Darwin's theory is based on the following five principles:
  - Overproduction
  - Struggle for existence
  - Variations and their inheritance
  - Survival of fittest
  - Natural selection and species formation
- Continuity of existence of the fittest was called '**survival of fittest**' by **Herbert Spencer** while Darwin called it **natural selection**.
- Darwin and Wallace published a joint paper titled '**Origin of Species**' in 1858'.
- Some **drawbacks of Darwin's theory** are:
  - He considered minute fluctuating variations as principal factors.
  - He did not distinguish between somatic and germinal variations.
- One **major criticism against Darwin's theory was his failure to give a satisfactory explanation for variations**.
- **Neo - Darwinism** is refinement of original theory of natural selection to remove objections.
- **Important features of Neo - Darwinism are** –
  - It is a modification of Darwinism in the light of genetic research.
  - It incorporates causes of variation.
  - It considers only genetic variations (mutations) inheritable and raw material for evolution.
  - Unit of evolution is a population in this concept.
  - Natural selection is referred to as differential reproduction, leading to changes in gene frequency.
  - It considers reproductive isolation as an essential factor in speciation.
- According to **Neo-Darwinism** both mutations and natural selection are responsible for evolution.
- The chief Neo-Darwinians are **Weismann, Mendel** and **de Vries**.
- Neo-Darwinians believe that the main causes of difference in members of a species are – **difference in genetic pattern**; and **influence of different environment**.
- **Resistance of mosquitoes to DDT** and **sickle cell anaemia** are also **examples of natural selection**.
- The **Lederberg replica plating technique** demonstrated the adaptation to be a result of the *pre-existing mutant forms of bacteria*. It **supported Darwinism** and illustrated that the introduction of penicillin (a change in the environment) gave a selective advantage to the already present penicillin resistant bacteria over the penicillin sensitive bacteria.
- **Supplementary theories** of Darwinism are– **artificial selection**, **sexual selection** and **theory of pangenesis**.
- To explain the various non-adaptive variations found in domesticated plants and animals he proposed the concept of **artificial selection**.
- Artificial selection is **practised for better crop varieties** and **in domestic animals by selective breeding**.
- **Sexual selection** : Secondary sexual characters do not play any significant role in the struggle for existence. Darwin concluded that modes of origin of secondary sexual characters are beyond the purview of natural selection.
- His theory (of sexual selection) is **based on these assumptions** :
  - In general males are more abundant than the females, so there is competition among males for females.

  - Females often choose the males with brilliant colours or ornamentation.
    So, in this struggle animals with superior qualities will be favoured and others get eliminated.
- To explain the transmission of characters from generation to generation, Darwin proposed '**pangenesis theory**' in 1868.
- According to **theory of pangenesis** every somatic cells produces gemmules and the actual germ cells are the sites of collections of gemmules coming from different somatic cells. This theory has been completely discarded.
- **Objections to Darwinism**–
  - It does not explain the adaptability of certain organs, in their initial stages which are of use to the organism only in perfectly developed condition, e.g. protective colouration, mimicry, electric organs of fishes etc.
  - It does not account for the occurrence of vestigial organs, over specialisation (antlers in Irish deers, tusks in Mammoth), degeneration and regeneration of certain organs.
  - It does not make any distinction between heritable and non-heritable variations. He referred mutations in the process of evolution as sports of nature.
  - If species have evolved by natural selection of small and useful variations, a number of transitional forms must be met with, but such forms are not found in several cases.
  - Sterility of hybrids (e.g. mule) and the occurrence of neutral flowers in plants are not explained by the theory of natural selection.

MUTATION THEORY

- The **mutation theory** was put forward in 1901 by **Hugo de Vries**, a Dutch botanist, to explain the mechanism of evolution.
- **Features of mutation theory** are–
  - Mutations **form the raw material for evolution**.
  - **Mutations appear suddenly** and produce their effect immediately.
  - Mutants are markedly different from the parents and there are **no intermediate stages** between the two.
  - Same mutations can appear in several individuals of a **species**.
  - Mutations can appear in **all directions**.
  - All mutations have a genetic basis and are, therefore, **inheritable**.
  - A single mutation may produce a **new species**.
  - Nature selects beneficial mutations and **eliminates lethal mutations**.
  - Evolution is a **discontinuous** or jerky process.
- The plant on which de Vries had experimented was *Oenothera lamarckiana* **(Evening primrose).**
- The mutation observed by de Vries in *Oenothera* essentially was chromosomal number variant.
- Mutations are discontinuous variations, called '**sports**' by **Darwin** and '**saltatory variations**' by **Bateson**.
- Role of mutations in evolution is genetic variations.
- Mutations are due to changes in chromosomes, genes or DNA.
- To be a successful event for evolution, a mutation must occur in germplasm DNA.
- Mutations are the changes which may or may not be inherited.

SYNTHETIC THEORY

- **Dobzhansky** (1937) in his book **'Genetics and Origin of Species'** provided the initial basis of synthetic theory.
- **'Modern Synthetic Theory of Evolution'** was designated by **Huxley** in 1942.
- Some of the important workers who have contributed to the modern synthetic theory are: **Th. Dobzhansky, R.A. Fischer, J.B.S. Haldane, Sewall Wright, Ernst Mayr** and **G.L. Stebbins.**
- According to synthetic theory there are five basic factors involved in the process of organic evolution These are: **gene mutations; changes in chromosome structure and number; genetic recombinations; natural selection;** and **reproductive isolation**.
- The first three factors are **responsible for providing genetic variability,** the last two are **responsible for giving direction to the evolutionary processes**.
- The **most accepted and recent theory of organic evolution** is the synthetic theory.
- Modern concept of evolution is a modification of Darwin's theory of natural selection by replacing favourable variation with genetic variation or mutation. It is often called **neo darwinism or synthetic theory** also.

Genetic variation

- Genetic variation form the raw material of evolution.

- **Causes of genetic variation** are – **environmental factors** (including light, temperature, food, humidity etc) and **genetic factors** (migration, non–random mating, genetic drift, mutation, gene recombination & hybridization).
- The removal of alleles from one population or addition of alleles into another population is called **gene flow or gene migration**.
- **Non-random mating** results in a deviation from the Hardy Weinberg distribution.
- The **Hardy-Weinberg Equilibrium Principle,** which was proposed by G. H. Hardy and W. Weinberg, independently, in 1908, describes that under certain conditions of stability allelic frequencies remain constant from generation to generation in sexually reproducing organisms.
- This means that, if all other factors remain constant, the frequency of particular genes and alleles will remain constant in a population through generations. This kind of stability at the genetic level is called **genetic equilibrium**.
- Hardy-Weinberg Principle **gives the geneticists a tool to determine when evolution is occurring**.
- Population geneticists use this principle to calculate a starting point allele frequency and then compare it to frequencies measured at some future time.
- In other words, evolution is a departure from Hardy-Weinberg Equilibrium.
- **Genetic drift** is the change in number and frequency of genes in small isolated population due to intensive inbreeding causing permanent fixation of some alleles, disappearance of a number of alleles and change in frequency of others.
- Genetic drift in a new colony is called **founder effect** because only a few founders carrying a small fraction of genetic variability of the parent poputation begin the colony.
- The theory of genetic drift was developed by geneticist **Sewell Wright in 1930**.
- It is also called **Sewell Wright effect or scattering of variability**.
- Genetic drift always influences frequencies of alleles and is inversily proportional to the size of population.
- Drastic short-term reduction of population size caused by natural disasters, disease, or predators may result in (by chance) the survivors representing only a small portion of the original gene pool. Even when the population increases to its original size, a portion of its original genetic diversity remains lost. This feature, termed a **genetic bottleneck**, is a problem with many endangered species.
- The bottleneck effect **prevents most genotypes from participating in production of next generation**.
- **Mutation** is the **major source of genetic variation**. It alters the base sequence of a gene.

Three types of mutations

Gene mutations (Changes in sequence of nucleotides in DNA) — 3 types
1. Deletion
2. Addition or Insertion
3. Substitution or Replacements
   (a) Transitions
   (b) Transversions
   (c) Tautomerism

Chromosomal aberrations (Changes in structure of chromosomes) — 4 types
1. Deletion or Deficiency
   (a) Terminal
   (b) Intercalary
2. Duplication
   (a) Tandem
   (b) Reverse
3. Translocation
   (a) Simple
   (b) Reciprocal
4. Inversion
   (a) Paracentric
   (b) Pericentric

Chromosomal numerical mutations (Changes in number of chromosomes) — 2 types

Aneuploidy (Gain or loss of one or two chromosomes)
1. Hypoploidy
   (a) Monosomy
   (b) Nullisomy
2. Hyperploidy
   (a) Trisomy
   (b) Tetrasomy

Euploidy (Gain or loss of one or more genomes)
1. Hypoploidy
2. Polyploidy
   (a) Autopolyploidy
   (b) Allopolyploidy

Flow chart : Types of mutations.

- **Re-combination** is the process of bringing together new combinations of existing genes and alleles.
- **Hybridization** is a method of mixing the genes of two populations. It can occur by migration of a section of a population of a new place or by cross breeding by man. It changes the gene frequencies and alters the phenotypes of the offspring.
- **Natural selection** is the process of differential survival and reproduction that inevitably leads to changes in allele frequencies over time as those individuals who are the most fit survive and leave more offsprings.
- Biologist recognize three major categories of natural selection based on its effect on the population over time – **stabilizing selection**, **directional selection** and **disruptive selection**.
- **Stabilizing or balancing selection** leads to the elimination of organisms having over-specialized characters and maintains homogenous population which is genetically constant. It favours the average or normal phenotypes, while eliminates the individuals with extreme expressions.
  – **For example**, house sparrows killed in a severe snowstorm in New York were found to have wings markedly longer or shorter than the mean.
- **In directional or progressive selection**, the population changes towards one particular direction alongwith change in environment. As environment is undergoing a continuous change, the organisms having acquired new characters survive and others are eliminated gradually.
  – **For examples,**
  (a) **Industrial melanism** In this, number of the light coloured moth (*Biston betularia*) decreased gradually while that of the melanic moths (*B. carbonaria*) increase showing **directional selection**. It provides a well studied example of directional selection from nature.
  (b) **DDT-resistant mosquitoes.**
  (c) **Resistance of bacteria to drugs.**
- **Disruptive selection** is a type of natural selection which favours extreme expressions of certain traits to increase variance in a population. It breaks a homogenous population into many adaptive forms. **It results in balanced polymorphism.**
- This kind of selection is rare and eliminates most of the members with mean expression so producing two peaks in the distribution of a trait. **Example.** A clear example is the different beak sizes of the African fire-bellied seedcracker finch *Pyronestes ostrinus*.

Speciation & Reproductive isolation

- **Speciation** is the phenomenon of formation of new species from the pre-existing ones.
- Speciation is **allopatric** if new species develops from a spatially isolated population.
- Speciation is **sympatric** if new species develops from a segment of population.
- **Breeding species** is a group of organisms capable of interbreeding and producing fertile offspring.
- **Ecological species** is a group of organisms sharing the same ecological niche; no two species can share the same ecological niche.
- **Genetic species** is a group of organisms showing close similarity in genetic karyotype.
- **Evolutionary species** is a group of organisms sharing a unique collection of structural and functional characteristics.
- **Phyletic speciation** is the transformation of a species with the passage of time due to piling up of variations.
- **Gradual speciation** is slow transformation of an isolated population or populations into new species due to gradual accumulation of variations.
- **Reproductive isolation** is the segregation of the population of a species into smaller units or sections by certain mechanism, so as to prevent interbreeding among them and help in maintaining their hereditary integrity.
- Reproductive isolation between species may be maintained by one or more of several mechanism collectively called **premating isolating mechanism** & **post mating isolating mechanisms**.
- **Premating isolating mechanism** include – geographicial, ecological, temporal, behavioural, mechanical and **post mating isolating mechanisms** include gametic incompatibility, hybrid inviability and hybrid infertility.
- In **geographic isolation** two population of the same species are separated by some physical or geographic barriers or they occupy different geographic areas.

- **Climatic isolation** - In the absence of any geographic barrier, the abrupt climatic differences within the range of distribution of a species are found to produce isolation of its members into units.
- **Seasonal or temporal isolation** - Differences in the breeding season prevent mating and interbreeding among the individuals of different populations or of different species.
- **Habitat isolation or ecological or environmental isolation** is caused due to differences in the habits and habitats of organisms such as food and physiological requirements and place of living.
- **Ethological isolation** refers to the barriers to mating among the individuals of different species due to differences in their courtship behaviour.
- In **mechanical isolation** the complex structure of genitalia in many animals does not permit copulation among different species.
- In **physiological isolation** certain species are established only on the basis of some physiological differences developed between them.
- **Gametic incompatibility** is the inability of sperm from one species to fertilise eggs of another species.
- **Hybrid inviability** is the failure of a hybrid offspring of two different species to survive to maturity.
- **Hybrid infertility** is reduced fertility (often-complete sterility) in hybrid offspring of two different species.

Table : Types of isolation with their cause and examples.

Types of Isolation	Cause	Examples
Mechanical isolation	Differences in morphology of ♀ and ♂ genital organs. Mechanism include the inability of the sperm to bind to egg in animals or the female reproductive organ of a plant preventing the wrong pollinator from landing.	Insect pollinated species.
Behavioural isolation (Ethological isolation)	Behavioural differences in courtship, nest building, dancing.	Stickle backs (fishes). Closely related grey tree frog and pine woods tree frog.
Seasonal isolation	Differences in time of sexual maturity, breeding season prevent mating and interbreeding.	Plants and invertebrates and insects.
Gametic isolation	Due to external and internal fertilization	Sea urchin
Genetic isolation include		
- Incompatibility	Mating inability	– –
- Hybrid inviability	Interspecific interbreeding.	Warwick and Berry (1949) showed that the cross between goat and sheep produce normal embryos but they die much before birth
- Hybrid sterility	Interspecific sterility due to gene mutation	Mule fail to reproduce (they are reproductively sterile but otherwise healthy and vigorous).
- Hybrid breakdown	– –	Tetraploid species of *Gossypium hirsutum* etc produces fertile and vigorous F_1 hybrids but in F_2 generation the hybrids are inviable.

POLYMORPHISM

- **Ford** (1984) defined polymorphism 'as the occurrence together in the same locality of two or more distinct forms of individuals in the same population or species.
- **Salient features of polymorphism** are –
  – It is due to the existence of more than two types of genotypes.
  – Different forms are adapted to different types of environments
  – All Mendelian populations are polymorphic
  – Increases the efficiency in exploitation of resources of the environment.
  – Helps the species to survive efficiently in a variety of environments.
- **Type of polymorphism** are– **balanced polymorphism** and **transient polymorphism**.
- In **balanced polymorphism**, individuals with two or more forms (morphs) coexist in the same population of a species in stable environment and show almost constant ratio. It means that in a population showing balanced polymorphism, the genotypic frequencies of various forms occur at equilibrium. There can be following reasons for this genetic equilibrium –
  – There is balance of selective forces so that no forms tend to be eliminated or both the alleles are maintained at appreciable frequencies in the population.
  – Each form (morph) has a selective advantage of equal intensity.
  – None of the forms has selective advantage over others.
  – Heterozygotes are at a selective advantage (*i.e.* **heterozyote superiority**).
  – The rare or the rarest allelomorph is advantageous. As it becomes common its advantage decreases and it is converted into a disadvantage.
- **Examples of balanced polymorphism** are – sickle cell anaemia, ABO blood group, Tay-sach's disease, polymorphisms in land snail and *Drosophila* polymorpha.
- **Sickle cell anaemia**
  – In human beings, the persons exhibiting sickle cell anaemia have R.B.Cs which become distorted and sickle-shaped in oxygen deficiency. The sickle-shaped RBCs are fragile and clog the blood vessels which leads to necrosis of various tissues and damage to organs. This causes severe anaemia and heart failure.
  – This disease was discovered by the American physician **James B. Herrick** (1904) who examined an anaemic West Indian black student in Chicago.
  – **James V. Neel** (1940) established that sickle cell anaemia is inherited as a simple Mendelian character –
    (a) **Normal haemoglobin** is produced by two dominant genes Hb^A/Hb^A.
    (b) **Sickle cell anaemic patients** have both the genes recessive Hb^s/Hb^s.
    (c) Persons heterozygous for these alleles (Hb^A/Hb^s) exhibit **sickle cell trait**. These have low capacity of carrying oxygen and posses both kinds of haemoglobin in nearly equal quantities.
  – In normal human population natural selection tends to eliminate gene Hb^s from the population. But **A. C. Allison** (1959) found that the frequency of gene Hb^s is unusually high in areas prone to malaria in East Africa, where Hb^s gene frequency reaches as high as 20% or more. In some African tribes, its frequency is as high as 40%. Allison (1959) explained that high frequency of Hb^s gene is due to selective advantage of heterozygotes (Hb^A/Hb^s).
  – In malaria infested areas, sickle cell heterozygotes (Hb^A/Hb^s) or the carriers are resistant to malarial infection and are less infected with the parasite than the homozygous dominant nonsicklers. Thus the heterozygotes have better chances of survival than the normal homozygotes. This advantage of heterozygotes results in stable polymorphism for gene Hb^s. In West Africa, there is a third allelomorph Hb^c which produces another abnormal haemoglobin – C. The homozygote Hb^c/Hb^c suffers from severe anaemia similar to Hb^s/Hb^s. The heterozygotes Hb^s/Hb^c also suffer from anaemia, but heterozygotes Hb^A/Hb^c are at an advantage over homozygotes Hb^c/Hb^c. The above two cases strongly support the view that the polymorophism for Hb gene is maintained by natural selection in malaria infested areas.

- **ABO blood groups –** In human population, the existence of A, B, AB and O blood groups are also examples of balanced polymorphism. Persons of blood group O have a greater life expectancy than those of other blood groups, but are prone to duodenal ulcer.
- **Tay-Sach's Disease –** This disease is common in children of Jewish heritage, because 1 out of 40 Jewish persons is a heterozygote whereas 1 out of 380 non-Jewish persons is a heterozygous carrier. This is because the grandchildren of persons suffering from Tay-Sach's disease were resistant to pulmonary tuberculosis in Bethesda, Maryland. The incidence of Jewish tuberculosis patients from eastern Europe is relatively high. This finding indicates that the heterozygous carrier of Tay-Sach's disease is resistant to pulmonary tuberculosis.
- **Polymorphism in land sail – Cain, Currey** and **Shephered** (1954) studied balanced polymorphism in common land snail, *Cepaea nemoralis.* Their shells exhibit polymorphism in colour and band patterns. The colour polymorphism in these snails is maintained by selection and the selection force is **predation**. These snails are predated upon by thrushes and the visually conspicuous forms were at a disadvantage –
  - In areas with uniform background like grasslands or woodlands with decaying leaves, the unbanded pink, yellow and brown shells or single banded shells were particularly common because of selective advantage.
  - In areas with tangled and mottled ground cover as in rough pasture or hedge-rows, the dark banded shells had a selective advantage.
  - Yellow shells with 5-bands were common among rough green herbage. Less green was the background, the less were the number of yellow shells.
- **Drosophila polymorpha –** The population of *D. polymorpha* presents three types of colouration of their abdomen. These are-light colour, dark colour and intermediate colour. The light colour is due to recessive genes (aa) in homozygous state and dark colour due to homozygous dominant genes (AA). The heterozygotes with intermediate colour are most abundant. It means heterozygous flies have some adaptive advantage.
- Balanced polymorphism is **important in evolution because it permits variability in the population**. This variability helps the population to react rapidly to an environmental change and to avoid extinction or to pave way to origin of new species. Thus balanced polymorphism represents **stablizing selection**.
- **Transient polymorphism** is found in populations undergoing a strong selection pressure and one form or morph is being strongly favoured and the other is getting eliminated. Thus transient polymorphism lasts for a short period, because polymorphism exists till the disadvantageous form is either completely eliminated or is reduced to such a low frequency that it is only retained due to recurrent mutation.
- **Industrial melanism** in peppered moth, *Biston betularia*, **is an example of transient polymorphism**.
- Upto 1848 peppered moths found in and around Manchester were creamy white with black dots and darkly shaded areas. These were called **nonmelanic forms**. In 1848, a single black coloured moth appeared among nonmelanic forms.
- The black or melanic form **arose by a recurring random mutation**. The nonmelanic forms were able to successfully camouflage with the lichens while resting and were able to survive, while the melanic forms were easily spotted out and preyed upon and were eliminated. As a result of rapid industrialization in Great Britain, large amount of soot and other gases were poured into the atmosphere. These were deposited in the environment making it sooty and dark and destroying the lichens.
- Thus polymorphism in peppered moth was only for a short period and favoured strong selection. The transient polymorphism is seen during directional selection, where one form or character is gradually being replaced by another.

End of the Chapter

Chapter 27

Human Evolution

- Human evolution states that humans developed from primates or ape like ancestors.
- Charles Darwin published his idea about man's ancestory in the book '**Descent of man and selection** in **Relation to sex**'. He suggested that man, apes and monkeys have a common ancestor.
- **Anthropology** is the study of human evolution and culture. It deals with fossils of prehistoric and living man.
- **Genelogy** is the sequential arrangement of stages in evolution.
- The field of science which studies the human fossil record is known as **palaeoanthropology.**
- It is the intersection of the disciplines of **palaeontology** (the study of ancient life forms) and **anthropology** (the study of humans).
- All human beings are classified as *Homo sapiens* (*Homo* is the genus name meaning man, *sapiens* is the species name meaning wise).
- The **fossils of prehuman and ancestral human forms** are **obtained from** widely diverse regions of **Africa, Asia** and **Europe** which indicate that man's centre of origin was probably in Asia and Africa.
- More precisely man has originated in central Asia, because –
  – The oldest known fossils have been obtained from Asia, China, Java and India (Shivalik hills).
  – The number of domesticated animals and plants is maximum in Asia.
  – Climatic conditions in Asia and nearby places were most conducive for human evolution.
- **Prehuman evolution** includes origin of mammals and origin of primates.
- **Mammals evolved in the jurassic period**, about 195 million years ago **from the cynodont reptiles** which branched off from the stem reptiles called cotylosaurs.

Cotylosaurs are the earliest and most primitive of reptiles. They evolved from the amphibians during the early carboniferous period some 340 million years ago, but were all extinct by the end of the Triassic, about 90 million years later. From among their members came 2 major evolutionary lines – one led to the mammals & the other to the archosaurs, ruling reptiles.

- The **first mammals** were **shrew like terrestrial insectivores** or **rat like creatures.**
- The **primates originated in the beginning of the tertiary period** (palaeocene epoch) about 65 million years ago from the small, terrestrial shrew like insectibores, a stock from which other types of existing mammals also arose.
- The **primate** (order of placental mammals) **contains two suborders** : **prosimians** and **anthropoids.**
- The insectivore mammals namely, tree shrews, gave rise to the primitive primates called **prosimians in the beginning of the tertiary period**.
- Among living primates, the prosimians (suborder Prosimii) (Gr.*pro,* before and *simos,* monkey, ape) include **tarsiers, lemurs** and **lorises**.
- **Tarsiers** are **found in forests of Philippines and East Indies.** They are **insectivorous mouse-sized animals** with enormous eyes suitable for nocturnal life.
- **Lemurs,** squirrel-like animals, are confined largely to the island of **Madagascar**. They feed on plant material, including fruits.
- **Lorises** occur in **Africa** and **Asia** including **South India**.

Primates

- **Lemuroidea**
  Eg. Lemuroidea (Tree shrews, Lemurs, Aye-Aye)
  Lorisiformes (Lorises)
- **Tarsiodea**
  Eg. Tarsiers
- **Anthropoidea**
  (Monkey, apes, man)

Lemuroidea + Tarsiodea: Earliest ancestor of man **(Prosimii)**

Tarsiodea —ancestral to→ Anthropoidea

Anthropoidea → Super families:

- **Hominoidea**
  - **Apes**
    Belong to single family Pongidae
    Have four living genera
    (i) *Hyalobates*—**The Gibbon**. It is the smallest and most primitive of the apes.
    (ii) *Simia* (*Pongo*)—**The Orangutan.** It builds nests on the trees.
    (iii) *Pan*—**The Chimpanzee.** It is the most intelligent among the apes. The chimpanzee can make and use tools.
    (iv) *Gorilla*—**The Gorilla.** It is the largest ape and is very dangerous.
  - **Man**
    Belong to single family hominidae (Ramapithecus, Kenyapithecus, Paranthropus, Zinjanthropus, Australopithecus, Homo)
    Includes a single genus, *Homo*, which has a single living species, *sapiens* and a single living sub-species, *sapiens*.

  Apes + Man: **called simian evolution**
- **Ceboidea or Platyrrhini**
  (New World monkeys)
  Eg. Spider monkey
- **Cercopithecoidea or Catarrhini**
  (Old World monkeys)
  Eg. Rhesus monkey

Flow chart : Division of Primates.

- The **anthropoids** (suborder anthropoidea) (Gr. *anthrop*, man, and *oid*, like) are classified into three superfamilies: **new world monkeys** (ceboidea), **old world monkeys** (cerco-pithecoidea) and the **hominoids** (hominoidea).
- The tarsiers seem to have produced higher primates termed simians (monkeys, apes, humans) in the oligocene epoch through parapithecus.
- **New world monkeys (platyrrhini)** possess a flat nose, long, sensitive and prehensile tail, non-opposable thumbs and clawed digits.
- New world monkeys are **found in South America**, *e.g., Alouatta* (howler monkey) and *Ateles* (spider monkey).
- **Old world monkeys (catarrhini)** possess a narrow nose, short and non-prehensile tail, opposable thumbs and nailed digits.
- Old world monkeys are **found in Africa and Asia**, *e.g., Papio* (baboon), *Macaca mulatta* (rhesus monkey), *Presbytis* (langur), etc.
- **Hominoids** includes apes and the hominids (humans and direct ancestors).
- **Four types of apes have survived** until today; the **gibbon** and the **orangutan** are found in Asia, the **gorilla** and the **chimpanzee** inhabit Africa.
- The *Gibbon* (prmitive ape) is the **smallest of the apes** (5.5–11 kg) and the *Gorilla* (developed ape), the **largest of the apes** (180 kg).
- **Brachiation** is a way of travelling through trees by means of swinging and hanging from links and branches. Gibbon implements this technique.
- The **closest relative of modern man** is considered to be chimpanzee.
- Simian shelf is a character of apes, it connects the anterior part of the mandibles.
- **Mammals,** the class to which humans belong,

evolved **210 - 240 million** years back from **cynodont/ synapsid reptiles.**

- The term **anthropoid apes** is used for ancestral anthropoids from which monkeys → apes → human evolved.
- **Apes** are characterised by **absence of tail.**
- Human are placed in the family **hominidae.**
- The evolutionary line of old world monkeys diverged from parapithecus in the oligocene.
- **Evolution of man from ape like ancestors is supported by molecular and anatomical evidences** besides the fossil evidence.
- In modern classification, **humans have been placed in class mammalia and order primates.**
- Some anthropologists divide human beings into six races, *viz*. **caucasoids, negroids, mongoloids, Australian natives, American Indians,** and **Polynesians**.
- All human races **have the same chromosome number and gross morphology**.
- The diploid number of chromosomes in gorilla, chimpanzee and orangutan is 48.
- *Homo* is the genus which is divided into the following species : *habilis*, and *sapiens*. It is the genus to which humans belong.
- **Common origin of man and chimpanzee** is best **shown by chromosome number** and **banding pattern**. Chimpanzees are the most human like of the apes and frequently used in psychological experiments.
- Evidences for common ancestory of great apes & man are :–
  - **Chromosomal evidence** – Somatic cells of man have 46 (23 pairs) chromosomes. In apes their number is 48. Man has evolved from an ancestor having 48 chromosomes by the centromeric fusion of two chromosomes. Chromosomes of man and apes have been studied with special staining techniques and it has been established that –
    - (a) chromosomes of man and apes have similar banding pattern.
    - (b) some chromosome of man and apes have identical bands.
    - (c) the banding pattern of human chromosome number 3 and 6 are compared with those of particular autosomes in the chimpanzee. It shows a common origin for man and chimpanzee.
  - **Evidence from blood proteins** – It has been proved by the blood protein tests that man is most closely related to great apes (Chimpanzee and Gorilla) and next closest, in order, are the old world monkeys, the new world monkeys and tarsiers.
  - **Evidence from blood groups** – In humans four blood groups A, B, AB and O occur. The blood groups A and B are found in apes but not in monkeys. This indicates that **human beings are more closely related to apes than to monkeys**.
  - **Evidence from haemoglobin** – There is 99% homology in haemoglobin of man and gorilla. This suggests that the two are closely related.
- **Characteristics of primates** are –
  - Arboreal (tree dwelling) habit.
  - Opposable great toe and thumb for grasping.
  - Eyes in front of head for stereoscopic vision (depth perception)
  - Expanded forebrain.
  - Lengthy gestation, one birth at a time.

EVOLUTION OF MAN

- **Evolution of man** probably **took place in central Africa**.
- **Carolus linnaeus** gave the scientific name *Homo sapiens* to man.
- **Erect posture**, **perfect bipedal locomotion**, **orthognathus (flat) face, grasping hands, upright neck** are the **characteristic of modern man**.
- **In modern man, cranial capacity is high, 1300 - 1600 cc** with brain to body weight ratio being highest 1:46.
- *Dryopithecus* is **common ancestor of human and apes** that lived in arboreal life in Asia as well as Africa.
- Origin and evolution of man were explained under the following headings – **prior to ape man; ape man including prehistoric man; and true man including the living modern man.**

Prior to Ape men

- *Parapithecus* – It was **discovered from the oligocene epoch in Egypt**. This **fossil is believed to represent the ancestors of today's old world monkeys, apes and humans.**
- *Propliopithecus* – This fossil was **discovered from miocene strata of Faiyum depression**.

- *Limnopithecus* and *Pliopithecus* – These fossil apes represent altogether a different line of evolution which diverged from the hominid line quite early and become extinct during pliocene.
- *Dryopithecus* – Fossil of *Dryopithecus africanus* was **discovered from miocene rocks of Africa and Europe**. It lived about 20 - 25 million years ago. *Dryopithecus africanus* is **regarded as common ancestor** of **man and apes.**
- *Proconsul* – *Proconsul africanus* was **discovered** by **S.B. Leaky (1948) from the rocks around lake Victoria of Kenya**, **Africa**. It lived in early miocene epoch.
- *Shivapithecus* – This fossil was **discovered from middle and late pliocene rocks of Shivalik hills** of India, hence it is named *Shivapithecus*.
- *Ramapithecus* – It has been established that in late miocene epoch *Dryopithecus* gave rise to *Ramapithecus* which was on the direct line of human evolution. *Ramapithecus* survived from late miocene to pliocene. Thus he appeared about 14 - 15 million year ago.
- Fossil of *Ramapithecus* was discovered by **Edward Lewis** from pliocene rocks of **Shivalik hills of India**.
- Similar to *Ramapithecus*, *Kenyapithecus wickeri* was discovered from pliocene rocks of **Kenya (Africa)**.
- There is a gap of about 9 - 10 million years in *Ramapithecus* and *Australopithecus*.

Ape man including prehistoric men

- *Australopithecus* **(first ape man)** – The early human stock gave rise to *Australopithecus.*
  - Commonly called southern ape, *Austratopithecus* appeared about 4 to 1.5 million years ago (**early pleistocene**).
  - **Tuang baby** (*A.africanus*) was **discovered by Raymond Dart from Africa**.
  - **Lucy** (*A. afarensis*) excaveted by **Donald Johanson.**
  - He **had both human and ape characters** with **bipedal locomotion, omnivorous diet** and **erect posture** (ancestor of man who first stood erect).
  - His **cranial capacity** was **350 - 480 c.c.**
  - Six species of *Australopithecus* known as *A.ramidus, A. afarensis* (Lucy), *A. africanus* (Tuang baby), *A.aethiopicus, A. robustus* and *A. boisei.*
- *Homo habilis* (**first homonid tool maker or Handy man**).
  - *Homo habilis* [*Homo* (man) *habilis* (skillful or mentally able)] **lived in early pleistocene** about 2 - 1.75 million years ago.
  - Nut cracker fossil man, discovered by **Leakey**.
  - His **cranial capacity** was about **735 c.c**.
  - He was the **first fossil man** who **used tools** of chipped stones extensively.
- *Homo erectus* (**erect man**)
  - *H. erectus* is **considered a direct ancestor of modern man**.
  - *Homo erectus* evolved from *Homo habilis* about 1.7 million years ago in the **pleistocene**.
  - *Homo erectus* includes **three fossils** – java ape man, peking man, and heidelberg man.
  - **Java Ape man's** (*Homo erectus = Pithecanthropus erectus*) fossils (discovered by **E.Dubois from Java**) occurred in the pleistocene deposits some 1.5 million to 5,00,000 years ago (middle pleistocene).
  - He had **cranial capacity** about **940 c.c.**
  - He was **omnivorous**, **cannibal** and **had large protruding jaws**.
  - He was the **first prehistoric man** to **make use** of **fire for hunting, defence and cooking**.
  - **Peking man** (*Homo erectus pekinensis*) = *Pithecanthropus pekinensis sinanthropus pekinensis*) lived most probably about 1.5 to 5,00,000 years ago (**middle pleistocene**).
  - He had a **cranial capacity** about **850 - 1200 c.c.**
  - Peking man was **slightly shorter**, **lighter** and **weaker than Java man**.
  - **Heidelberg man** (*Homo erectus heidelbergensis*) had **cranial capacity** about **1300 c.c.** [(intermediate between those of erect man (*H.erectus*) and neanderthal man (*H. sapiens neanderthalensis*)].

True man including the living modern man

- **Neanderthal man** (*Homo sapiens neanderthalensis*)
  - Neanderthal man **existed in the late pleistocene period** and **its fossils were found in the neanderthal valley in Germany.**
  - The **cranial capacity** was about **1450 c.c.** roughly equal to that of modern man.
  - He had slightly **prognathous face** and were the lengendary **cave dwellers**.

- Neanderthals were **adapted** to a **cold environment** and were predatory and hunters.
- They **used clothings, utensils** and **fine tools**.
- In neanderthal society injured and dead were cared for, they even performed **elaborate burial rituals**. Neanderthals may had a religion.
- **Became extinct** 35, 000 years ago.

- **Cromagnon man** (*Homo sapiens fossil*)
  - Cromagnon man **emerged about 34000 years ago in holocene epoch**. Thus it is **regarded as most recent ancestor of today's man**.
  - It's fossils were **first discovered in 1868 from Cromagnon rocks of France by Mac Gregor**.
  - These succeeded neanderthals and **became extinct** about 20, 000 years ago.
  - They were **much more advanced than the neanderthals** and belonged to *Homo sapiens*.
  - Cromagnon has perfectly **orthognathous** face.
  - The **cranial capacity** was about **1650 c.c.** (thus believed cromagnon man was somewhat more intelligent and cultured than the man of today).
  - **Cro-magnon** man **first started cave painting** as well as **hunting** with domesticated dogs.
  - They were **omnivorous** and expressed themselves through painting and sculpture (cave paintings).
- **Modern man** (*Homo sapiens sapiens*) – First appeared about **10,000 years ago** in Asia near Caspian sea. Have **cranial capacity** of **1300 - 1600 c.c.** They have developed sound into words.
- **Characteristic features of man** are –
  - Large brain and cranial cavity.
  - Foramen magnum below the brain box.
  - Bipedal locomotion and release of forelimbs for other purposes.
  - Erect posture and free hands.
  - Opposable thumbs and grasping hands.
  - Sensitivity.
  - Reduced fertility.
  - Social organization.
  - Development of speech.
  - Ability to learn and transmit experiences.
  - Binocular and stereoscopic vision.
  - Weak brow ridges and shortening of jaws.

Dryopithecus africanus
[earliest fossil ape/proconsul]
↓
Ramapithecus
[earliest hominid fossil]
↓
Australopithecus afarensis
[the African ape man with cranial capacity 450 cc]
↓
Australopithecus africanus
[tuang baby with cranial capacity 350 - 450 cc]
↓
Homo habilis
[the stone tool maker with cranial capacity 735 cc]
↓
H. erectus
[the erect man with cranial capacity 800 - 1100 cc]
↓
H. erectus erectus / Pithecanthropus erectus
[Java man with cranial capacity 800 - 1000 cc]
↓
H. erectus pekinensis
[peking man with cranial capacity 850 - 1200 cc]
↓
Homo neanderthalensis
[neanderthal man with cranial capacity 1450 cc]
↓
Homo sapiens fossilis
[cromagnon man with capacity 1650 cc]
↓
Homo sapiens sapiens
[the living modern man with cranial capacity 1300 - 1600 cc]

Table : Cranial capacities of apes and man.

Primates	Cranial capacities (*in cubic centimetres*)
Chimpanzee and Gorilla	325-510 c.c.
Australopithecus	350-450 c.c.
Homo habilis	735 c.c.
Java ape man	940 c.c.
Peking man	850-1200 c.c.
Heidelberg man	1300 c.c.
Neanderthal man	1450 c.c.
Cro-magnon man	1650 c.c.
Living modern man	1300-1600 c.c.

- The continent where **maximum fossils** of prehistoric man have been found is **Africa.**
- **Cradle of human evolution** is South Africa.
- **Piltdown man** is hypothetical, developed on the

basis of artefact / hoax consisting of fragments of skull at Piltdown, England.

- **Heidelberg man, Sola man, Rhodesian man** and **Altarutic man** are believed to be variants of *Homo erectus*.
- The entire period through which man has improved the techniques of constructing instruments has been divided into **palaeolithic, mesolithic** and **neolithic ages.**
- **Paleolithic** age represents **age of tools of stones and bones**, **cave painting in later period.**
- **Mesolithic** age represents as the **age of animal husbandary, development of language, reading and writing.**
- **Neolithic** age represents **development of agriculture, manufacture of pottery and clothes etc.**
- Neolithic has continued with **bronze age** and then **iron age.**
- **Evolutionary explosion of mammals** occurred in **palaeocene period.**
- **First man like apes** appeared in **miocene.**
- In **pleistocene,** extinction of many large mammals occurred and also referred to as **age of man.**

Table : Taxonomic position of modern humans

Kingdom	–	Animalia	Intake of complex food, defaecation.
Phylum	–	Chordata	Notochord, dorsal hollow C.N.S.
Sub phylum	–	Vertebrata	Vertebral column
		Craniata	Cranium (brain box)
Section	–	Gnathostomata	Jaws
Superclass	–	Tetrapoda	Four limbs
Class	–	Mammalia	Mammary glands, hair, pinna
Infra class	–	Eutheria	True placenta
Order	–	Primates	Nails over the digits
Suborder	–	Anthropoidea	Facial muscles for emotional expression
Family	–	Hominidae	Erect posture, bipedal locomotion
Genus	–	*Homo*	Man
Species	–	*sapiens*	Wise
Subspecies	–	*sapiens*	

End of the Chapter

Chapter 28

Plant Taxonomy

- **Taxonomy** is the branch of botany which deals with identification, nomenclature and classification of plants.
- Taxonomy is also called **systemic botany**.
- The study of taxonomy has among its main objectives the learning of the kind of plants on earth and their names, of their distinctions, of their affinities, their distribution & characteristics and habitats, and the correlation of these facts of knowledge with pertinent scientific data.
- A secondary objective taxonomy is the assemblage of knowledge gained. Floras are published to account for the plant of a given area.
- They are essential to any study of the natural resources of an area, to studies of land potentials, to evaluation of resources of raw materials possible suited to man's needs.
- A third important and scientific objective is the demonstration of the tremendrous diversity of the plants & their relation to man's understanding of evolution.

TAXONOMIC DESCRIPTION OF FLOWERING/ANGIOSPERMIC PLANT

- Description of a flowering/angiospermic plant in semi-technical language is done using various morphological features.
- **Habit** – Herb, shrub, tree, twinner, trailer, creeper or climber.
- **Habitat** – Xerophyte, mesophyte, hydrophyte, halophyte or epiphyte.
- **Life span** – Annual, biennial or perennial.
- **Root**
  - Tap root or adventitious root.
  - Branched/unbranched.
  - Modification if any - fleshy/fibrous aerial/ nodulated/tuberous etc.
- **Stem**
  - Texture of stem - Herbaceous/woody.
  - Aerial / underground.
  - Habit of stem - Erect / prostrate / creeping / twinning / climbing.
  - Branching - Branched / unbranched, kind of branching.
  - Shape - Cylindrical / angular / flattened / square / ribbed / jointed.
  - Solid / fistular.
  - Surface - Glabrous / hairy / spring / prickly.
  - Modifications if any - Rhizome / bulb / tubers / corm / phylloclade / runner / stolon / offset / suckers, etc.
  - Colour - Green / grey / any other.
  - Any other special feature.
- **Leaf**
  - Insertion - Radicle / cauline / ramel.
  - Type - Simple / compound (palmately or pinnately compound).
  - Stipulate / exstipulate, nature of stipule - Free lateral / scaly / adnate / inter petiolar / intra petiolar / ochreate / foliaceous / spinous / tendrillar / convolute.
  - Petiolate / sessile / sub - Sessile.
  - Nature of leaf base.
  - Phyllotaxy - Alternate / opposite (decussate or superposed) / whorled.
  - Shape of leaf, leaf margin, leaf apex.
  - Venation - Reticulate / parallel, unicostate / multicostate (Convergent or divergent type).
  - Texture - Coriaceaceous / membranous / scarious / fleshy / succulent).
  - Modifications, if any.
  - Colour - Green, variegated.
- **Inflorescence**
  - Racemose / cymose / mixed / special.
  - If racemose - Typical raceme / spike / compound spike / spikelet / catkin / spadix / corymb/ umbel / capitulum.

- If cymose - Monochasial (scorpioid / helicoid / dichasial / polychasial.
- If special - Cyathium / verticillaster / hypanthodium.

- **Flower**
  - Pedicillate / sessile.
  - Bracteate / ebracteate, type of bract.
  - Bracteolate / ebracteolate.
  - Complete / incomplete.
  - Bisexual (hermaphrodite) unisexual (staminate / pistillate).
  - Actinomorphic / zygomorphic.
  - Cyclic / hemicyclic (spirocyclic) spiral.
  - Hypogynous / perigynous / epigynous / nude.
  - Number of floral parts - Dimerous / trimerous / tetramerous / pentamerous.
  - Any special feature - colour, size, anthophore, androphore, gynophore, gynandrophore, disc, nectaries.
- **Calyx**
  - Number of sepals.
  - Cohesion - Polysepalous / gamosepalous.
  - Sepaloid / petaloid.
  - Aestivation - Valvate / twisted / imbricate / quincuncial / others.
  - Coducous / persistent.
  - Modifications, if any.
- **Corolla**
  - Number of petals.
  - Cohesion - polypetalous / gamopetalous.
  - Shape of corolla - Cruciform / caryophyllaceous / rosaceaous / papilionaceous / campanulate (bell - shaped) tubular / infundibuliform (funnel - shaped) / rotate / bilabiate / ligulate.
  - Regular / irregular.
  - Aestivation - Valvate / twisted / imbricate / quincuncial / vexillary / others.
  - Appendages, if any - Spur / nectary / corona.
- **Perianth**
  - Number of tepals, number of whorls.
  - Cohesion - Polypetalous, gamopetalous.
  - Sepaloid / petaloid.
  - Aestivation - Valvate / twisted / imbricate / quincuncial.
  - Any special feature.
- **Androecium**
  - Number of stamens (write µ if more than 10), number of fertile, sterile (staminode) stamens.
  - Cohesion - Polyandrous / monadelphous / diadelphous / polyadelphous, syngenesious / synandrous.
  - Epipetalous / epitepalous / gynandrous.
  - Antipetalous / diplostemonous / obdiplostemonous.
  - Didynamous / tetradynamous.
  - Inserted / exerted.
  - Anthers - Dithecous (two celled) / monothecous (one celled).
  - Attachment of anthers - Basifixed / adnate / dorsifixed / versatile.
  - Dehiscence - Introse / extrose.
  - Any special feature.
- **Gynoecium**
  - Number of carpels - Monocarpellary / bicarpellary / tricarpellary / pentacarpellary / poly or multicarpellary.
  - Cohesion - Apocarpous / syncarpous.
  - Number of locules - Uni / bi- / tri- / tetra / penta / multilocular.
  - Ovary - Superior / semi - inferior / inferior.
  - Placentation - Marginal / axile / parietal / basal / free - central / superficial.
  - Style - Terminal / lateral / gynobasic / stylopodium.
  - Stigma - Number, shape, simple, lobed, capitate, branched.
  - Any other special feature.
- **Fruits**
  - Types of fruits - Simple, aggregate or composite.
  - Nature of fruit - Nut, achene, samara, etc.
- The diagrammatic representation of the transverse section of the flower in which all the floral parts are brought to the same level is **floral diagram**.

Fig. Floral diagram of *Brassica campestris* (Pili sarson)

- **From the floral diagram we can know about the**
  - No. of floral parts in each whorl.
  - Position of the floral parts.
  - Cohesion and adhesion of floral parts.
  - Aestivation of perianth parts.
  - Placentation.
  - Symmetry of the flower.
  - Sexuality of the flower.

- The symbolic representation of the flower just like a chemical formula is called **floral formula** (FF).
- **Symbols used to write floral formula**

Br.	–	Bracteate
Ebr.	–	Ebracteate
⊕	–	Actinomorphic or regular flower
% or + or ⦶	–	Zygomorphic or irregular flower
(⚥)	–	Bisexual flower
♀	–	Female flower
♂	–	Male flower
K	–	Calyx
C	–	Corolla
P	–	Perianth
A	–	Androecium
G	–	Gynoecium
G	–	Superior ovary
$\bar{G}$	–	Inferior ovary
1, 2, 3, 4, ... ∝	–	Number of sepals, petals, stamens or carpels.
()	–	Fused or united, e.g., C(5), *i.e.*, five petals of corolla fused
$\overset{\frown}{C\,A}$	–	Epipetalous condition, *i.e.*, stamens attached to petals,

- F.F. of *Solanum nigrum* (solanaceae) is Ebr. e.g., ⊕⚥ $K_{(5)}\overset{\frown}{C_{(5)}A_{(5)}}\underline{G}_{(2)}$.

SOME IMPORTANT FAMILIES

Family - Fabaceae (Papilionaceae or pea family)

Systematic position

Class	–	Dicotyledonae
Subclass	–	Polypetalae
Series	–	Calyciflorae
Order	–	Rosales
Family	–	Fabaceae

Distribution

- It is a large family having 420 genera & 7000 species. The family was previously considered subfamily papilionoiodeae or papilionatae of family leguminosae (the other subfamilies are caesalpiniaceae and mimosaceae). It is cosmopolitan and is economically highly important because of yield of pulses.

Vegetative characters

- **Habit** - Tree, herbs, shrubs, root with root nodules.
- **Habitat** - Halophytic, mesophytic, xerophytic & hydrophytic.
- **Life span** - Annual to perennial.
- **Stem** - Erect or climber.
- **Leaves** - Alternate, pinnately compound or simple, leaf base, pulvinus, stipulate, venation reticulate.

Floral characters

- **Inflorescence** - Raceme (Panicle in *Dalbergia*)
- **Flower** - Bisexual, zygomorphic bracteate, or ebracteate, pedicellate or sessile peri or hypogynous, pentamerous.
- **Calyx** - Sepals five, gamosepalous, imbricate.
- **Corolla** - Petals five, polypetalous, papilionaceous, consisting of a posterior standard, two lateral wings, two anterior ones forming a keel (enclosing stamens & pistil), vexillary aestivation.
- **Androecium** - Ten, diadelphous [(9) + 1], anther dithecous, introse.
- **Gynoecium** - Ovary superior, monocarpellary, unipolar with many ovules, style single marginal placentation.
- **Fruit** - Legume, seed, one to many, non-endospermic.
- **Floral formula** - % ⚥ $k_{(5\text{ or }(5)}\ C_{1+2+(2)}\ A_{(9)+1}G_1$.

Economic importance

- Many plants belonging to the family are sources of food, fodder, oils etc.
- **Food** (Pulse). A number of legumes or pulses are obtained from fabaceae. Eg, pea (*Pisum sativum*), gram (*Cicer arietinum*), lentils (*lens culinaris = L. esculenta*, vern. Masur), green gram (*Vigna radiata = Phaseolus radiatus = P. aureus*, vern. Mung), black gram (*Vigna* or *Phaseolus mungo*,vern. Urd), mat bean (*Vigna aconitifolia = Phaseolus aconitifolius*, vern. Moth), pigeon pea (*Cajanus cajan*, vern. Arhar)
- **Fodder.** Alfalfa (*Medicago sativa*, vern. Lusan), Indian clover (*Melilotus indica*, vern. Senji), guar (*Cyamopsis tetragonaloba*), Berseem (*Trifolium alexandrium*) and shaftal or shatala (*Trifolium resupinatum*).
- **Oils.** They are extracted from seeds of *Arachis hypogea* (groundnut or peanut) and *Glycine max* (soyabean). Roasted groundnut seeds are eaten.
- **Soil fertility.** Nodule bearing papilionaceous plants increase nitrogen content of the soil. Therefore, they are used in crop rotation and green manuring, *e.g.*, *Crotalaria*, *Sesbania*, *Cyamopsis*.
- **Fibres.** They are obtained from the stems of *Crotalaria juncea* (sunn hemp) and *Sesbania*

species. The fibres are used in making cordage, sacks, nets, tissue paper, etc.

- **Dyes.** Indigo was obtained from the leaves of *Indigofera tinctoria* and *I. suffruticosa*.
- **Gum.** *Cyamopsis tetragonaloba* yields guar gum which is employed in pharmaceuticals, explosives, ceramics, dyes, textiles, paper, plastics and photography. Gum is also obtained from *Butea monosperma* and *Astragalus gummifer* **(gum has medicinal use)**.
- **Medicines.** The roots of *Glycyrrhiza globra* (Liquorice, vern. Malatthi) are used as demulcent, expectorant and in treating gastric ulcers. The seeds of *Butea monosperma* (Flame of the Forest, vern. Dhak) have antifungal and anthelminthic properties. Seeds of *Psoralea corylifolia* are anthelminthic, diuretic and capable of curing skin diseases including leucoderma. Fresh leaf juice of *Abrus precatorius* (Jeweller's Weights, Ratti) is useful in treating leucoderma. Juice of flowers of *Sesbania grandiflora* improves evy sight.
- **Cork.** It is obtained from *Aeschynomene aspera* (Indian Cor, vern. Sola).
- **Jeweller's Weights.** The seeds of *Abrus precatorius* (a climber) are employed as weights by jewellers.
- **Timber.** *Dalbergia sisso* (Sisso), *Dalbergia latifolia* (Indian Rosewood) and other species, *Pterocarpus marsupium* (India Kino), *Butea monosperma* (vern. Dhak).
- **Ornamentals.** *Lathyrus ordoratus*, *Clitoria*, *Colutea*, *Lupinus*.

Family - Solanaceae (Potato family)

Systematic position

Class	–	Dicotyledonae
Subclass	–	Gamopetalae
Series	–	Bicarpellatae
Order	–	Polemoniales
Family	–	Solanaceae

Distribution

- It is a large family, commonly called as the "potato family". The family is represented by about 90 genera and 2800 species distributed in both tropical and temperature regions.

Vegetative characters

- **Habit** – Mostly herbs, a few shrubs, rarely soft woody trees (*S. grandifolium*) or climbers (e.g., *Solanum dulcamara*).
- **Root** – Tap root system
- **Stem** – Herbaceous rarely woody, aerial, erect, cylindrical, branched, solid or hollow, hairy or glabrous, underground stem in potato (*Solanum tuberosum*) climbing, (*S. pasminoides*), prostrate (*S. secratteuse*).
- **Leaves** – Alternate, simple, rarely pinnately compound, exstipulate, venation unicostate reticulate. Sessile or petiolate cauline and ramal.

Floral characters

- **Inflorescence** - Axillary or extra-axillary cyme, rarely solitary axillary (*Petunia*) as terminal (*Datura*).
- **Flower** – Bisexual, actinomorphic. Ebracteate or bracteate, pedicellate, hypogynous, pentamerous.
- **Calyx** – Sepals five, united, valvate aestivation persistent, accresent (*Physalis*) campanulate or tubular.
- **Corolla** – Petals five, variously shaped, infudibulum (*Petunia*) companulate, rotate (*Solanum*) bilabiate (*Schizanthus*) united, valvate aestivation.
- **Androecium** – Stamens fives, epipetalous free, anthers bithecous, basifixed or dorsifixed, longitudinal dehiscence.
- **Gynoecium** – Bicarpellary, syncarpous, ovary superior, bilocular, sometimes tetra locular due to false septum, placenta swollen with many ovules, axile placentation, carpels obliquely placed.
- **Fruits** – Berry or capsule.
- **Seeds** – Many, endospermous.
- **Floral formula** – Br $\oplus$ ⚥ $K_{(5)} \overparen{C_{(5)} A_{(5)}} G_{(2)}$.

Economic importance

- Many plants belonging to this family are sources of vegetables, fruits etc.
- **Vegatables.** Potato (*Solanum tuberosum*) and tomato (*Lycopersicon lycopersicum = Lycopersicum esculentum*) are the most common articles for cooking. Vegetables are also obtained from brinjal (*Solanum melongena*) and bell pepper (*Capsicum frutescens* var. *grossum*, vern. shimla mirch).
- **Fruits.** The fruits of some *Physalis* species (*e.g.*, *P. peruvina*, Gooseberry, vern. Rasbhari) are edible.
- **Tobacco.** It comes from the dried and curved leaves of *Nicotiana tabacum* and *N.rustica*.
- **Medicines.** *Atropa belladona* (Deadly Nightshade, vern. Suchi) and *A. acuminata* (vern. Angurshafa) yield belladona for relieving pain externally, cough and excessive perspiration internally and atropine

for dilating pupil. Henbane (*Hyoscyamus niger,* vern. Khurasani Ajjwain) yields a sedative while *Datura stramonium* (Jimson weed) gives an alkaloid called stramonium for relaxing bronchil muscles. Roots of *Withania somnifera* are used to cure rheumatism and general weakness. *Solanum surattense* (= *S. xanthocarpum*, vern. Kandiali, Mamoli) are used for curing cough, asthma, bronchitis, fever and leucoderma.

- **Ornamentals.** A number of plants are grown as ornamentals, *e.g.*, *Petunia*, *Schizanthus* (butterfly fower), *Cestrum nocturnum* (Night Jasmine), *Brunfelsia hopeana* (Yesterday-today-tomorrow), *Datura*, etc.

Family - Liliaceae

Systematic position

Class	–	Monocotyledonae
Series	–	Coronarieae
Family	–	Liliaceae

Distribution

- Commonly called the 'lily family' is a characteristic representative of monocotyledonous plants. It is distributed world wide.
- The family includes about 250 genera and 3700 species showing cosmopolitan distribution.

Vegetative characters

- **Habit** – Perennial herbs with underground bulbs/corms/rhizomes.
- **Stem** – Herbaceous or woody, sometimes reduced or modified. Aerial or underground, cladode (*Ruscus* and *Asparagus*).
- **Leaf** – Mostly basal, alternate, linear, exstipulate with parallel venation, reticulate in *Smilax*, cauline or radial, various phyllotaxy (alternate, opposite, or whorled), exstipulate, stipulate (in *Smilax*), scaly, leathery, spinous (*Asparagus*), modified into tendril (*Gloriosa*).

Floral characters

- **Inflorescence** – Solitary/cymose, racemose often umbellate clusters. (*Gloriosa*) scape present.
- **Flower** - bisexual, actinomorphic. Bracteate or ebracteate, pedicillate, zygomorphic in few cases, complete or incomplete, unisexual in *Ruscus* and *Smilax*, hypogynous, generally pentacyclic, trimerous.
- **Perianth** – Tepal six (3 + 3), often united into tube, may be polyphyllous valvate aestivation. Sepaloid or petalloid, distinguished into calyx and corolla in *Trifolium*.
- **Androecium** – Stamen six (3 + 3) free or monadelphores (eg *Ruscus*), antiphylous or epiphyllous, basifixed, dorsifixed, or versatile anther, longitudinal dehiscence.
- **Gynoecium** – Tricarpellary, syncarpous, ovary superior, trilocular with 2-many ovules, axile placentation rarely parietal, styles united or separate, stigma free or fused, trilobed.
- **Fruit** – Capsule, rarely berry (*Asparagus*).
- **Seed** – Endospermous.
- **Floral formula** – $\oplus ⚥ \overbrace{P_{(3+3)\text{ or }3+3}\,A_{3+3}}\,\underline{G}_{(3)}$.

Economic importance

- **Vegetables.** The young shoots and root tubers of *Asparagus* species are cooked. The bulbs of onion (*Allium cepa*) and garlic (*Allium sativum*) are also edible. They are added to vegetables as flavouring agents.
- **Perfume.** Perfume yielding plants are *Convallaria majalis* (Life-of-the Valley) and *Hyacinthus orientalis*.
- **Fibres.** They are obtained from the leaves of *Phormium tenax* (New Zealand Hemp), *Agave* (*e.g.*, *A. americana*, Centuary Plant), Yucca (*e.g.*, *Y. gloriosa*, daggar plant), *Sansevieria* (*e.g.*, *S.roxburghiana*, browstring hemp)
- **Resin.** It is obtained from *Xanthorrhoea* and *Dracaena* species. The resin is mostly used in varnishes and sealing waxes.
- **Poison.** Bulbs of *Urginea maritima* and *Scilla* yield raticide. Tuberous rhizomatous stems of *Gloriosa superba* are highly poisonous.
- **Medicines.** *Aloe barbadensis* gives a drug **aloin** which is laxative and is sometimes applied on boils and burns. The juice of garlic (*Allium sativum*) is useful against bronchitis, flatulence, blood pressure and gout. The poisonous underground stems of *Gloriosa superba* (glory lily, vern, kalihari) have properties to cure leprosy, piles, gonorrhoea, scorpion bites, etc. Leaf juice can kill lice. The dried corms of *Colchicum autumnale* yield **colchicine** which is used in cytology for doubling the number of chromosomes (polyploidy). Corms of *Colchicum luteum* are used in the treatment of rheumatism, gout, liver and spleen diseases. Roots of *Smilax zeylanica* (Vern. Ram Datun) yield sarsparilla-like drug for purifying blood (curing boils), piles, leprosy, gonorrhoea, etc.
- **Ornamentals.** *Asparagus, Hyacinthus, Gloriosa,* lily, tulip and *Smilax* are grown in the gardens.

End of the Chapter

Chapter 29

Morphology of Flowering Plants

- **Morphology** (Greek *morphe* - from, *logos*, Science) is the branch of biology which deals with the study of form, structure and relative position of different organs.
- Morphology is of two types - **external** and **internal**.
- **External morphology** is the study of external form like shape, size and colour, structure and relative position of different organs.
- **Internal morphology** studies the internal form and structure of organisms.
- Internal morphology has **two parts**: **anatomy** and **histology**.
- **Anatomy** (Greek - *ana*- again, *tommein* - to cut) is a branch of biology that deals with the study of internal structure which is exposed after dissection and opening of various parts.
- **Histology** (Greek - *histos* - wole, *logos* - Science) is the study of tissues, their composition and structure as observed with the help of microscope.
- **Importance of morphology are as follows** –
  - Gives a particular contour to the body of an organism.
  - Organisms are recognised by their external morphology.
  - Classification is based on the morphological traits of the organisms.
  - It gives information as to homology and analogy of organs.
  - With the help of external and internal morphology, structural simplicity and complexity can be known.
  - All breeding experiments are based on morphological data. It includes plants productivity.
  - It indicates the structural adaptations to habitat.
  - Difference between juvenile and mature phases are indicated by external morphology.
- **Flowering plants or angiosperms** are seeds bearing plants (**spermatophytes**, **phanerogams**) in which their seeds are always enclosed in a definite organ called the **ovary** inside the fruits, and the **sporophylls** are organised into **flowers**.
- The angiosperms are found in most diverse conditions and dominate the earth's vegetation today. **They provide us food**, **clothing, timber**, **spices**, **beverages**, **rubber**, **medicines and fuel**.
- There are about **3, 00, 000** species of flowering plants which have diverse habits, habitats, modes of nutrition, life span, shape and size.
- Angiosperms are divided into two groups – **dicots** and **monocots**.
- The **dicotyledons**, have leaves with a network of veins, vascular bundles in the stem in a circle, root with a definite number of vascular bundles and floral parts in multiples of five (sometimes four).
- The **monocotyledons** have vascular bundles in the stem, roots with several strands of vascular tissues and floral parts in multiples of three.
- Angiosperms are found in almost all places. The plants that grow on soil are called **terrestrial plants.** The plants found in water are **hydrophytes** and those growing in extremely dry habitats are specialised to grow in conditions intermediate between dry wet and very dry conditions, they are called as **mesophytes**.
- The flowering plants primarily consists of an **axis**, **root system** and **shoot system**.
- Shoot system **lies above the ground** and the root system **lies below**.

- Plant
  - Root system
    - Tap root
    - Lateral root
  - Shoot system
    - Vegetative shoot
      - Main stem
      - Lateral stem
    - Reproductive shoot → Inflorescence → Flower

- **Shoot system** bears branches, leaves, flowers and fruits.
- The root, leaves and branches **constitute the vegetative parts of the plants**.
- The **flowers, fruits** and **seeds form** the **reproductive parts of the plants**.

ROOT

- Root is an important **vegetative part** of the plant mainly **responsible for nutrition and support**.
- Root is the **descending, nongreen, underground part, lacking nodes, internodes, leaves and buds**. (**Except** sdventitious buds in *Ipomea batatus* which takes part in vegetative propagation).
- Root is **positively geotropic, positively hydrotropic and negatively phototropic**.
- Root consists of **4 major zones - root cap, meristematic zone, zone of cell elongation** and **maturation zone**.
- The cap like structure made up of thin walled cells that covers the root apex is the **root cap**.
- The root cap **made of dead cells, protects the young growing cells of the apical region**.
- **Mucilage** secreted by the cells of the root cap **help in easy penetration of root into soil**.
- Root cap is **also known as calyptra** as it originates from the calyptrogen.
- **Root caps are absent** in hydrophytes, epiphytes, parasites (haustoria) and mycorrhizae.
- **Multiple root cap** is present in *Pandanus* (screw pine).
- In hydrophytes **root pockets are present instead of root cap**, eg. *Pistia, Lemna*.
- Root cap and root pocket are structurally similar but **root pockets once damaged are not regenerated whereas root caps are regenerated**.
- **Meristematic zone** is present just above the root cap.
- Meristematic zone is **made up of compactly arranged small**, **thin walled isodiametric and meristematic cells having dense protoplasm and large nucleus**.
- The **meristematic initial cells of this region produce two types of cells** - one formed towards apex develops into **calyptrogen** & the second formed towards base develops into **histogen**.
- The **cells of meristematic region** are in **active state of divisions** and so this is the **main growing region of the root**.
- The region of **cell elongation** is present above the meristematic zone resulting in increase in the length of the root.
- The external cells of this region **possess the power of absorption of water and mineral salts** from the soil.
- Above the cell elongation zone, is present the **cell maturation zone**. Secondary growth takes place in this region.
- Region of maturation is the **area of origin of lateral root**.
- Unicellular and ephemeral root hairs are formed from the epidermal cells in this zone (maturation zone). **Root hair region** is called **piliferous zone**.
- The root hairs **help in absorption of water**.
- Root hairs are **absent** in all the plants **where there are no root caps**.

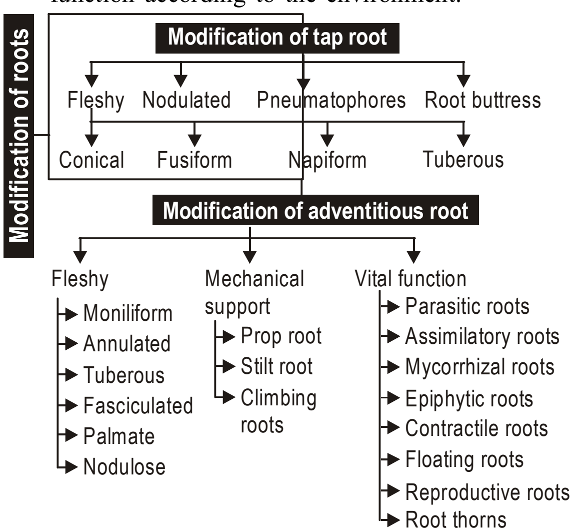
Types of root system

- There are **two types of root systems - tap root** and **fibrous roots** (or **adventitious roots**).
- The root that develops from **radicle** is **tap root** or **primary root**.
- It forms lateral branches called **secondary roots** which further divide to form **tertiary roots**.
- The tap root, with the secondary and tertiary roots forms the **tap root system**. Rootlets are the ultimate root branches that bear root hair.
- Tap root system is the **characteristic of dicot plants**.
- Tap root system is of **two types - deep feeder** and **surface feeder**.
- **Deep feeder tap root system** has elongated tap root which penetrates the deeper layers of soil.
- In **surface feeder tap root system**, the root does not elongate much but the secondary roots spread to a greater horizontal area.
- Roots developing from any part of the plant other than the radicle is called **adventitious roots**.

- In underground adventitious root system, the primary root is short lived and is replaced by a number of fine fibrous adventitious roots, developing from the base of the stem.
- Adventitious roots are mainly **found in monocots**.
- Adventitious roots can be grouped into **3 types on the basis of their appearance** –
  - Roots **arising from the base of the stem**, eg. *Triticum.*
  - Roots **arising from leaves**, eg. *Bryophyllum.*
  - Roots **developing from nodes and internodes of the stem**.
- In addition to the normal function of anchorage, absorption of water and minerals, roots perform some special function for which they get modified.

Modifications of roots systems

- **Modification** is a change from the normal structure of a plant organ to perform new or additional function according to the environment.



- **Tap root** are modified into – **fleshy**, **nodulated**, **pneumatophores** and **root buttress**.
- When the root becomes swollen and fleshy for storage, they are called **fleshy roots**. Fleshy root may be -
  - **Conical :** swollen at the base and narrow at the apex, eg. *Daucus carota* (carrot).
  - **Fusiform :** thicker in the middle and tapers at both ends for storage of food, eg. *Raphanus sativus* (radish).
  - **Napiform :** very thick upper portion and tapers in the lower end, eg. *Brassica napas*.
  - **Tuberous :** the roots get swollen at any portion and do not assume any definite shape, eg. *Mirabilis jalapa.*
- **Nodulated** : In leguminous plant, tubercles or nodules are formed on the secondary and tertiary branches of roots, where nitrogen fixing bacteria are present, Eg. *Glycine max.*
- **Respiratory roots or pneumatophore**s are erect root showing negatively geotropic, usually club shaped & protrudes some distance above substratum. They have minute pores called **pneumathodes for intake of oxygen**, eg. *Rhizophora.*
- Such roots are **common in many mangrove species** growing in water logged areas where soil aeration is extremely poor.
- **Root buttress** : Horizontal roots arise jointly from the bases of the tap root and the trunk. They provide extra support, eg. rubber tree.
- **Adventitious roots** can be **modified on the basis of their function** like, **fleshy** for food storage, **mechanical support** and **for vital functions**.
- **Fleshy adventitious roots** are of **following types**–
  - **Moniliform** (or beaded) : Roots are swollen at regular intervals and have bead like appearance, eg. *Momordica.*
  - **Annulated** : Roots possess a series of ring like outgrowths or swellings, eg. *Cephalis.*
  - **Tuberous** : The swollen root do not assume any definite shape, eg. *Ipomea batatas*.
  - **Fasciculated** : The swollen roots occur in clusters from lower nodes of stems, eg. *Asparagus* (monocot root), *Dahlia*.
  - **Palmate roots** : Fleshy roots are thickened like palm of human hand, eg. *Orchis*.
  - **Nodulose** : The apex or tip of the roots become swollen, eg. *Curcuma amada.*
- Some adventitious roots modify to **provide mechanical support** like prop root, stilt root & climber root.
  - **Prop roots :** Arise from branches of plants and enter the soil, to provide support in huge trees, eg. *Ficus benghalensis* (banyan).
  - **Stilt roots :** Aerial, obliquely growing roots formed from the nodes of lower most portion of the stem and fix firmly to the soil, eg. *Zea mays* (maize).
  - **Climbing root** or **clinging roots :** Formed from nodes of stem, eg. *Piper betel* (pan).

- Some adventitious roots are modified to perform several **vital functions** like parasitic, assimilatory, mycorrhizal, epiphytic etc.
- **Parasitic roots** : Parasitic plants develop sucking roots or **haustoria** which enters the host plant for drawing nutritions, eg. *Cuscuta*.
- The plants **which depend totally on host for food and water** are called **complete parasite**. The haustoria of these plants have connections with both xylem and phloem of host.
- Plants which **depend on hosts only for mineral and water** are called **partial parasite**. These are **chlorophyllous.** Haustoria of these plants have only connection with xylem only.

Partial stem parasite	–	*Viscum loranthus*
Partial root parasite	–	*Santatum album*
Total stem parasite	–	*Cuscuta*
Total root parasite	–	*Orobanche*

- **Assimilatory roots** : Green roots capable of photosynthesis, due to presence of chlorophyll, eg. *Tinospora*.
- **Mycorrhizal roots** bear fungal hyphae which function as root hair, eg. *Pinus*.
- **Epiphytic roots** have aerial roots which may be of **3 types** – **clinging** for fixation, **absorbing** (for absorption of mineral salts and moisture) and **hygroscopic aerial**.
- The **aerial roots do not have root caps** and **root hair**. They have a covering of dead spongy tissue known as **velamen**, eg. *Vanda*.
- **Contractile roots** : The apical portion of some thick roots of the underground stem contract and help the plant in fixation, eg. Corm of *Crocus*.
- **Floating roots** : In *Jussiaea* a number of adventitious roots arise from each node. Some of these roots became inflated, filled with air, come out of water and helps the plant in **floatation**.
- Floating roots **also help in gaseous exchange**. In floating plants of *Salvinia* one leaf of each node is modified into roots for balancing.
- **Reproductive roots** develop adventitious buds, that grow into new plant under favourable conditions, eg. sweet potato.
- The root that becomes stout and pointed and arises from stem are called **thorny roots**, eg. *Acanthorhiza*. Thorny roots give **protection to the plant**.
- **Leaf root** : In some adventitious roots are produced on margin of leaves, eg. *Bryophyllum*.
- The modified, aerial adventitious roots branched profusely to form a nest like structure that helps in the absorption of mineral water from the leaf pitcher are called **nest roots**, eg. *Dischidia, Neottia* (birds nests).

Functions of roots

- The **primary function of roots** are –
(i) Anchorage (ii) Absorption of water and minerals, (iii) Prevention of soil erosion, (iv) Transport.
- There are a numerous secondary or **accessory functions of roots** like – storage, mechanical support, nitrogen fixation, reproduction, floating, photosynthesis, respiration etc.
- Many plants growing in aquatic habitat **do not possess roots** (eg. *Wolffia*, *Utricularia*) and some **have roots only for balancing** (eg. *Lemna*, *Pistia*).

STEM

- Stem is the **aerial part** of the plant that bears leaves and flowers, have distinct nodes and internodes and **grows by means of terminal buds**.
- Stem **develops from the plumule**.
- The stem branches are **exogenous in origin**.
- It is **positively phototropic** and **negatively geotropic**.
- Stem **along with its leaves and branches forms** the **shoot system**.
- A **bud** is a condensed immature or embryonic shoot having a growing point surrounded by closely placed immature leaves.
- **Cabbage** or *Brassica oleracea* var *capitata* is the **largest bud**.
- **According to their nature**, buds are of **three types : vegetative** (form only leafy shoot); **floral** (reproductive buds that form flowers); and **mixed** (forming both vegetative & floral branches).
- **According to their positions**, buds are of **two types** – **terminal / apical** (present at the apical end and are **meant for increasing the plant height**) and **lateral** (develop on stem or on branches at any side).
- **Lateral buds** are of **four different types** – **axillary buds** (developing in the axil of leaves); **accessory buds** (occur on the lateral sides of axillary buds) **extra-axillary buds** (developing on the node by outside the leaf base), and **adventitious buds** which are of **three different types - foliar** (on leaves), **radical** (on roots), **cauline** (on stem).
- **Adventitious buds** can be **modified into thorns** (*Citrus*), **bulbils** (*Allium cepa*) or **tendrils** (*Passiflora*).

- **Unbranched stem** is called **caudex** or **columnar**, eg. palm, sugarcane, maize.
- **Branched stem** may be **dichotomous** or **lateral in nature**.
- **Lateral branching** are of **two types - racemose** and **cymose**.
- The terminal bud **continues to grow** in **racemose type**, and lateral branches are borne in **acropetal succession**.
- In **cymose branching** the **terminal bud stops growing** and gets **modified into flower, tendril, thorn** etc.
- **Cymose branching** may be of **three types** -
  - **Monochasial**, may be scorpioid (on both sides) or helicoid (on one side).
  - **Dichasial** in which two lateral axillary buds continue to grow, e.g. *Carissa.*
  - **Polychasial** in which growth takes place by whorl of axillary buds.
- **Aerial stem** may be **classified broadly into three types– upright (erect) stout stem**, **feeble weak stem** and **reduced stem**.
- **Erect stems** have sufficient mechanical strength to support themselves, e.g., common stems types.
- **Reduced stems** are small flat disc like, without distinguishable nodes and internodes.
- Reduced stem **helps in floating** in *Lemna* & *Wolffia*, **forms the base of bulb** in onion and **bears radical leaves** in carrot, turnip etc.
- **Feeble weak stems** are elongated, narrow and soft stems which cannot support themselves in upright position.
- Weak stem can be broadly classified into **two major types - twiners** and **climbers**.
- In **twiners** stem tip undergoes regular circular movements for support, the phenomenon known as **circumnutation**.
- **Climbers** are plants with **weak and flexible stems** which possess **clinging structures** for clasping support.

Tendril climbers	–	*Passiflora* (modified axillary branches), *Lathyrus* (whole leaf)
Root climbers	–	*Tecoma, Piper*
Scramblers	–	*Artabotrys*
Lianes	–	*Tinospora*
Adhesive disc climber	–	*Ampelopsis*

- **Trailers** are plants with weak stem, which are fixed to the soil at one point and branches spread along the ground.
- On the nature of spreading of branches they are:
  - **Procumbent** - when branches lie flat on ground, e.g., *Oxalis.*
  - **Decumbent** - prostrate branches bends to rise at apices, e.g. *Tridax.*
  - **Diffuse** - prostrate branches grow in all direction, e.g. *Euphorbia prostrata.*

Modification of stem

- **Modification of stem** are of **three types - underground, subaerial** and **aerial**.

Modifications of Stem

- Underground
  - Tuber
  - Rhizome
  - Bulb
  - Corm
- Aerial
  - Stem tendril
  - Phylloclade
  - Thorns
  - Cladodes
  - Thalamus
  - Hooks
- Subaerial
  - Runner
  - Stolon
  - Sucker
  - Offset

Underground stem

- Underground stems are **non-green stems** that may **take part in perennations**, **store food**, **or help in vegetative propagation**.

Why underground stems are not root ? Because,
Absence of root cap at the tip.
Presence of terminal buds.
Absence of root hairs near the apices.
Presence of distinct nodes and internodes.
Presence of scale leaves, axillary buds. .

- Modified underground stem are of **four types : stem tuber, rhizome, corm and bulb**.
- **Stem tuber** is the branch of main stem which possesses axillary buds or eyes, and swells due to food storage, e.g., *Solanum tuberosum.*
- **Rhizome** is fleshy stem with scaly leaves bearing buds in their axil. Adventitious roots arise from lower nodes, helps in perennation, e.g. *Zingiber officinale* (ginger).
- Rhizome rising obliquely in the soil, are called **root stalk**, e.g., *Alocasia.*
- **Corm** is subspherical, swollen, growing vertically in soil, adventitious roots at base of nodes, axillary buds in axil of scale leaves, e.g. *Colocasia, Gladiolus.*
- **Bulb** is highly reduced disc like stem with numerous

fleshy scaly leaves covering a central terminal bud, adventitious buds arising from under surface.

- **Tunicated bulbs** are covered with dry membranous sheaths called tunic, e.g. onion.
- In some the bulb consists of a number of bulblets arranged in two or more concentric rings, e.g. *Allium sativum.*

Characteristic smell of onion is due to sulphur allyl sulphide present in fleshy leaves.

Aerial stem

- **Aerial modification** are of following types – **stem tendril, phylloclades, cladodes, thorn, thalamus** and **hooks**.
- **Stem tendrils** are fine, sensitive thread like wiry structures which can coil around a support.
- **On the basis of their origin stem tendril** may be of **five different types -**
  - **Axillary tendril** - tendrils at axil of leaves, e.g. *Passiflora.*
  - **Extra-axillary** - from extra-axillary buds found over the nodes, e.g., *Cucurbita.*
  - **Apical bud tendril** - develops opposite the leaves from the apices of lower branches, e.g., *Vitis vinifera*.
  - **Tendrillar stem tip** - tip of stem branches get modified into tendril, e.g., *Gouniana.*
  - **Floral bud tendrils** - terminal part of inflorescence bears tendrils, e.g., *Antigonon*.
- **Phylloclades** are green, flat fleshy structure bearing nodes and internodes, perform photosynthesis instead of leaves. In some, the stem may store water, e.g., *Opuntia*.
- **Cladodes** are green stem of limited growth, generally one or two internodes long, that perform the function of photosynthesis, e.g. *Asparagus* (one internode long), *Ruscus* (2 internode long).
- Stem gets modified to stiff, hard pointed structures called **thorns** that **perform defensive functions and checks transpiration**, e.g., *Citrus, Duranta.*
- Thorn may sometimes have leaves and flowers (*Aegele marmelos*).

Thorns : modified stem with vascular cylinder
Spines : modified leaves with vascular strand
Prickles : superficial hard structures borne over surface stem and leaves, vascular cylinder is absent.
Bristles : modifications of hairs where deposition of silica or calcium carbonate has occurred.

- **Thalamus** is **condensed stem axis** which forms the base of the flower, containing reduced nodes and internodes, bearing sepals, petals, androecium and gynoecium.
- Sometimes some of the internodes may elongate between sepals and petals known as **anthophore**.
- Internodes between petals and stamens is called **androphore**.
- Internode between stamens and carpels is called **gynophore**.
- Pedicel or floral stalks of some plants produces a **curved hook** to help the plant in climbing, e.g., *Artabotrys.*

Subaerial stem

- **Sub aerial stems** are **feeble and weak** and aerial part of them grows horizontally on the ground while some parts remain underground and help in vegetative propagation.
- Subaerial modification are of **four types** – **runner, stolon, sucker** and **offset**.
- **Runner** is horizontal, green, devoid of leaves at nodes, aerial branches arising from axil of scaly leaves. Nodes bear adventitious roots and axillary buds, e.g. *Cynodon dactylon.*
- **Stolons** are prostrate branches that originate from the base of the crown and grow obliquely and the tip, after coming in contact with the soil grows to form a crown at the upper surface and adventitious roots in the lower surface.
- Nodes bear scaly leaves with adventitious buds. Eg. *Jasminum, Fragaria* (straw berry).
- **Sucker** is formed from the node of underground stem and runs obliquely upward inside the soil, comes out and forms new leafy shoot, The lower portion of nodes give rise to roots, e.g., *Mentha.*
- **Offset** is one internode long, short and thickened special horizontal branches, that develop from below a tuft or rosette of leaves, grows for some time and bears a new tuft of leaves. Adventitious roots develop from below the rosette, e.g. *Pistia.*

Functions of stem

- The stem performs both **primary** and **secondary** functions.
- The stem **conducts water and minerals from root to leaves** and **other organs through xylem**.

- It **conducts manufactured food from leaves to other parts of plants through phloem**.
- The **stem bears the aerial structures** like leaves, flowers and fruits.
- The leaves are borne in such a way to **provide maximum sunlight** and flowers are borne to **expose them to pollinating agent**.
- **Phylloclades** and **cladodes** perform photosynthetic functions.
- Various underground stem modifications are specialised to **store food**.
- In sugarcane the aerial stem **stores sugar** in itself.
- Fleshy stems of *Opuntia* and other cacti **store water** so that the plants can grow even when the soil remains dry for months together.
- The stem bears thorns and prickles for **protection against browsing animals** and **loss of water in transpiration**.
- Curved thorns, hooks and tendrils formed from stem structures help the plants in **climbing**.
- In *Neptunia* the stem bears a number of **air cavities** which make the stem light and **allow the plant to float over** the surface of water.
- All underground stems take part in **perennation** during unfavourable season.
- Underground stems, runners, stolon and offsets can take part in **vegetative propagation** of the plant.

LEAF

- Leaf (=**phyllopodium**) is the **main photosynthetic organ of the plant**.
- Leaf is green, thin flattened outgrowth of the plant **arising from the node of the stem and having a bud in its axil**.
- Leaves always **follow an acropetal order of developmet** and are **exogenous in origin**.
- A leaf is called **dorsiventral** if its dorsal surface differs in structure from its ventral surface, eg. dicot leaves.
- A leaf is called **isobilateral** when the two surfaces are similar, eg. monocot leaves.
- A **dorsiventral leaf is more strongly illuminated on upper surface** than on lower surface whereas in **isobilateral leaf there is equal illumination on both sides of the leaf**.
- Some cylindrical leaves have no distinction of the two surfaces (unifacial) and are called **centric**, eg. onion.
- In **peltate leaf**, the leaf blade and the petiole usually stand on one and the same plane, eg. lotus, water lily.
- When leaves are directly borne by the aerial parts of the stem and branches, it is called **cauline leaf**.
- In pineapple, *Agave* etc. a cluster of leaves arises from the short underground stem as if arouse from roots, then it is called **radical leaf**.
- In grasses, a membranous tongue like outgrowth is present at the junction of leaf base sheath and lamina and it is called **ligule**.
- **According to the origin** and **function of leaves** they may be grouped as–
  - **Cotyledonary leaves or seed leaves** : Are embryonic seed leaves.They become distinct in plant showing epigeal germination.
  - **Hypsophylls** or **bract leaves** : Are leaves that contain flower or an inflorescence in their axil. They perform the function of protection.
  - **Cataphylls or scale leaves** : Are non green present on aerial or underground parts, eg. rhizome, corm, phylloclade and cladode bearing plants and **perform the function of protection**.
  - **Sporophylls** or **fertile leaves** : Are the leaves which bear sporangia. These are **mainly found in gymnosperms and pteridophytes**.
  - **Foliage leaves** : Are the common leaves that are green in colour and **found on the main stem and branches that perform the function of photosynthesis**.
- Occurrence of dissimilar foliage leaves on a plant is called **heterophylly**. It is **commonly seen in emergent type of water plants**, for eg. *Limnophila heterophylla*, *Trapa* etc.
- Occurrence of dissimilar leaves on a node is called **anisophylly**, eg., *Boerhavia diffusa* etc.
- In **environmental heterophylly** heterophyllous leaves are produced in response to the surroundings or environment in which a plant is living. This types of heterophylly is found mostly in hydrophytes like, *Limnophila heterophylla, Ranunculus aquatiolous.*
- In **developmental heterophylly** plant produces different kinds of leaves at different developmental stages of its life. In *Acacia malanoxylon* the leaves

of the young plant (seedling) are pinnately bicompound. But in a mature plant, the leaf consists of only expanded petiole (phyllode) without lamina.

- In **habitual heterophylly**, the plant produces different types of leaves at every node throughout its life, eg. *Selaginella.*

Parts of leaf

- A leaf consists of **three parts** *i.e.,* **leaf base**, **petiole** and **lamina**.

Leaf base

- **Leaf base** (**= hypopodium**) is the basal part by which leaf is attached to stem or branch.
- **Different type of leaf bases** are– **pulvinus**, **sheathing**, **decurrent**, and **amplexicaul**.
- In **pulvinus leaf base** (for eg. in leguminosae plants, mango, banyan) the leaf base is swollen.
- In **sheathing leaf base** (for eg. in monocots like maize, sugarcane, banana) the leaf base **expands forming flat sheath which encloses the stem portion above the node**.
- In banana (*Musa paradisiaca*) leaf bases **forms a pseudostem or false stem** while the actual stem is below the ground.
- In **decurrent leaf base** (for eg. in *Crotolaria, Laggera* etc.) the leaf base becomes flat broad and winged covering the upper part of the node.
- In **amplexicaul leaf base** (for eg. in *Polygonum*) the sheathing leaf base **encloses the stem completely**.
- In many dicots, leaf base **bears two lateral outgrowths** called **stipules** (which **generally protect the young leaves**) and **axillary buds**.
- Small stipule like outgrowths called **stipels** are **found at the base of leaflets of a compound leaf**.
- The leaves having stipules are termed as **stipulate** while the leaves without stipules are called **exstipulate**.
- The **stipules are of three types according to the time period of their attachment** -
  – **Caducous**, eg. *Michelia champaca*,
  – **Deciduous**, eg. *Cassia, Dilenia* etc;
  – **Persistent**, eg. rose, *Hibiscus rosa sinensis*.
- According to the **structure and location**, stipules may be of following types– (a) **free lateral stipules**, (eg. cotton, *Hibiscus rosa sinensis*), (b) **adnate stipules** (eg. *Rosa indica*), (c) **ochreate stipules** (eg. *Rumex*, *Polygonum*), (d) **interpetiolar stipules** (eg. *Ixora, Anthocephalus* etc), (e) **foliaceous stipules** (eg. *Lathyrus*), (f) **tendrillar stipules** (eg. *Smilax*), (g) **bud scales** (eg. banyan, *Artocarpus* etc), (h) **spiny stipules** (eg. *Mimosa, Acacia, Zizyphus*).

Petiole

- **Petiole** (= Mesopodium) is the stalk of the leaf, that connects the lamina with the stem and is generally cylindrical, being terete or grooved.
- When **petiole is present**, the leaf is said to be **petiolate or stalked** and when **it is absent**, the leaf is said to be **sessile**.
- Petioles show certain pecularities which are of different types namely **winged petiole**, **tendrillar petiole**, **phyllode** and **floating petiole**.
- In **winged petiole**, the petiole is modified into flattened, winged leaf like structure. For eg., in *Citrus* (orange, pummelo, lemon etc), *Feronia* etc.
- In **tendrillar petiole**, petiole is tendrillar in nature and helps the plant to climb up, eg. in *Clematis, Nepenthes*.
- In some plants like Australian acacia (*Acacia auriculaeformis*), *Parkinsonia* etc. the petiole performs the function of leaf by modifying into leaf like structure called **phyllode**.
- In **floating or bulbous petioles**, the petiole become spongy bulb (pseudobulb) which contains many air cavities and thus help the plant in floating, for eg. *Eichhornia, Trapa*.

Lamina

- **Lamina** (**= epipodium**) or leaf blade is green and expanded portion of the leaf. (*For division of lamina refer flow chart on page no. 253*)
- In the middle of the lamina, a strong vein called **midrib** is present which extends from its base to the apex.
- The midrib produces thinner lateral veins, which in turn, give rise to still thinner veins or veinlets and as a result a net like structure is visible in the lamina.

Venation, Vernation and Ptyxis

- Distribution of veins (vascular bundles) and the

Lamina of leaf

Shapes of lamina

- Acicular – long & pointed, eg., *Allium cepa*
- Lanceolate – narrow at ends, broad at middle, eg., *Nerium*
- Linear – long, narrow, parallel margins, eg., *Triticum*
- Ovate – egg shaped, broad base, narrow top, eg., *China rose*
- Obovate – narrow base, broad apex, eg., *Prunus amygdalus*
- Cordate – broad base, bilobed, eg. *Bauhinia*
- Reniform – kidney shaped, eg., *Hydrocotyle*
- Lunate – semicircle eg., *Passiflora*
- Oblong – long and broad lamina, round apex, eg., banana
- Oval – broad middle, narrow ends, eg., *Psidium*
- Sagitate – triangular, eg., *Saggitaria*
- Spathulate – spoon shaped, eg., *Lipia*
- Tunicate – narrow base, wide apex e.g., *Pistia*
- Rofund – spherical, eg., *Nelumbo*
- Lyrate – large terminal lobes, smaller lower bases eg., *Raphanus.*

Apex of lamina

- Acute – pointed, eg. *Mangifera indica*
- Obtuse – round apex, eg. banyan
- Caudate – tail like, eg., *Ficus religiosa*
- Cuspidate – spiny, eg., *Agave*
- Mucronate – broad apex, with pointed end, eg., *Ixora*
- Tendrillar – modified into tendril, eg., *Gloriosa*
- Cirrhose – short thin apex, eg., *Pistia*
- Retuse – broad apex with a notch, eg., *Oxalis*
- Truncate – sharply cut margin, eg., *Paris polyphylla*
- Emarginate – deep notch divides the apex, eg., *Opuntia*

Margin of lamina

- Entire – smooth, eg., *Mangifera indica*
- Sinuate – wavy, eg., *Saraca*
- Serrate – cut like teeth of saw, directing upward, eg., *Hibiscus*
- Biserrate – incision further incised
- Dentate – incision make right angles with margin
- Bidentate – incised
- Crenate – incised margin, round, eg., *Hydrocotyle*
- Bicrenate – incised round teeth, further incised
- Retroserrate – incised margin downward teeth
- Spiny – eg., *Argemone*
- Lobed – eg., *Raphanus*

veinlets in a leaf blade is called **venation**. It is of **two types** - **reticulate** and **parallel**.

- In **reticulate venation** the main vein of leaf forms numerous irregular branches and as a result a net like arrangement is formed, eg., dicots.
- Reticulate venation is of **two types** - **unicostate** (or **pinnate type**) and **multicostate** (or **palmate type**).
- In **unicostate venation** only one midrib is present which gives out lateral veins running parallel to each other either towards the apex or margins, eg. mango, peepal etc.
- In **multicostate venation** there are more than one main veins arising from petiole and extend towards apex. It is subdivided into **two categories** - **convergent type** and **divergent type**.
- In **convergent type** a number of main veins arising from the petiole spread upward and converge at the apex, eg. *Zizyphus* (ber), *Cinnamomum camphora* (kapoor).
- In **divergent type** different main veins arising from the tip of petiole diverge towards the periphery, eg. *Ricinus* (castor), cucumber.
- In **parallel venation**, veins are arranged parallel to each other. On the basis of number of midribs, it is subdivided into two types - **unicostate or pinnate type** and **multicostate or palmate type**.

- In **unicostate parallel venation** only one midrib is present which gives out lateral veins running parallel to each other, either towards the apex or margins, eg. *Canna*, banana etc.
- In **multicostate parallel venation**, many midribs are formed from the petiole. It is of two types - **convergent type** and **divergent type**.
- In **convergent type** different midribs running parallel to each other converge at the apex, eg. wheat, bamboo, grasses etc.
- In **divergent type** a number of midribs extend towards the margins, eg. palms etc.
- The function of venation is **conduction of food material, distribution of mineral**, **water** and **to provide shape** and **mechanical strength to the lamina**.
- The **arrangement of leaves in relation to each other in the bud** is called **vernation**.
- The way in which young leaves are folded or rolled in the bud is called **ptyxis**.

Phyllotaxy

- **Phyllotaxy** means the **arrangement of leaves on both main stem and branches**.
- Arrangement of phyllotaxy is **made to facilitate the leaves to obtain maximum light for photosynthesis**.
- The **three types of phyllotaxy** are - **alternate**, **opposite** and **whorled arrangement**.
- In **alternate** (or **spiral**) form of arrangement, one leaf is borne at a node and leaves are arranged alternately giving a spiral form, eg., mango, mustard, tobacco etc.
- In **opposite arrangement** each node gives rise to two leaves, arranged opposite to each other.
- Opposite phyllotaxy are of **two types** – **opposite superposed** (each pair parallel to the next pair, eg., *Ixora* etc); and **opposite decussate** (one pair of right angle to the next pair, eg., *Ocimum* etc).
- In **whorled arrangement** more than two leaves are formed from each node, eg. *Nerium, Alstonia* etc.
- Both alternate phyllotaxy (in vegetative parts) and opposite phyllotaxy (at the floral region) are found in *Datura*.

Simple and compound leaves

- **Simple leaf** is a leaf having a single blade which may be entire or incised, eg. mango, guava, papaya etc.
- In **pinnate simple leaf** the incisions are pointed towards the midrib, eg. radish.
- In **palmate simple leaf** the incisions are pointed towards the petiole, eg. *Ricinus.*
- In **compound leaf**, the incision of the leaf blade goes down to the midrib (rachis) or to the petiole so the leaf is broken up into a number of segments called leaflets. It is of two types - **pinnately compound leaf** and **palmately compound leaf**.
- In **pinnate compound leaf** the rachis is the original midrib and the leaflets are arranged along its two sides as a feather. It is of four types - (a) **unipinnate**, (b) **bipinnate**, (c) **tripinnate**, and (d) **decompound**.
- In **unipinnate type**, leaflets are directly associated with the rachis. It is of **two types** - **paripinnate** (rachis terminated by even number of leaflets) eg. tamarind, asoka etc. and **imparipinnate** (rachis terminated by an odd number of leaflets), eg. rose, *Clitoria* etc.
- In **bipinnate type**, rachis is subdivided *i.e.*, the secondary leaflets are formed on both sides of the primary leaflets, eg. *Mimosa pudica, Acacia* etc.
- In **tripinnate compound leaf** the rachis divides to form primary leaflets which give rise to secondary leaflets which inturn form tertiary leaflets, *i.e.*, divides thrice, eg. *Moringa* etc.
- In **decompound type**, the division of rachis occurs more than three times, eg. corriander, carrot etc.
- In **palmately compound leaf** the incisions of lamina are pointed towards the base and are connected to the petiole tip.
- **Types of palmately compound leaf** are –
  - **Unifoliate** (single leaflet), eg. *Citrus*.
  - **Bifoliate** (two leaflets) are attached at the tip of petiole), eg. *Balanites, Bignonia*.
  - **Trifoliate** (three leaflets), eg. *Oxalis.*
  - **Quadrifoliate** (four leaflets), eg. *Paris quadrifolia,* in pteridophytes *Marsilia.*
  - **Multifoliate** (more than four leaflets), eg. *Cleome, Bombax* etc.
- Leaves perform various functions beside photosynthesis and thus they are modified into different forms like
  (a) **leaf tendrils** (help in climbing), eg. sweet pea,
  (b) **leaf spines** (protection of plants, reduce transpiration), eg., *Argemone, Acacia,*

(c) **leaf hooks** (help in climbing), eg. *Bignonia*,
(d) **scale or protective leaf**, eg. *Ficus, Artocarpus*. etc.,
(e) **leaf roots** (a leaf transformed into roots for balancing on water), eg., *Salvinia*,
(f) **leaf bladders** (part of leaf segment is modified into bladder), eg., *Utricularia*,
(g) **leaf pitchers** (leaf is modified into pitcher), eg., *Nepenthes* (insectivorous), *Dischidia* (non-insectivorous),
(h) **leaf tentacles**, eg., *Drosera*,
(i) **phyllode** (petioles modify into leaf like structure), eg. *Parkinsonia*, *Acacia auriculiformis*.

Parts of leaf modified into spines
– Stipules - eg. *Zizyphus*
– Leaf margins - eg. *Argemone*
– Leaf apex - eg. *Yucca*
– Entire leaf - eg. *Barberis*.

Parts of leaf modified into tendril
– Stipules - eg., *Smilax*
– Petiole - eg., *Clematis*
– Leaf apex - eg., *Gloriosa*
– Leaflets - eg., *Pisum*.
– Whole leaf - *Lathyrus*

Table : Exceptions is leaf morphology

	Character	**Examples**
1.	Monocots with reticulate	*Smilax Dioscorea, Alocasia*.
2.	Dicots with parallel venation	*Eryngium, Calophyllum inophyllum*.
3.	Dichotomous venation	*Gingko biloba*
4.	Dicots with xerophytic leaves show isobilateral symmetry	*Eucalyptus*
5.	Reproductive leaves	*Bryophyllum*
6.	Epiphyllous buds occur in the notches of leaf margins	*Bryophyllum*
7.	Root like structures to absorb mineral water	*Utricularia* and *Limnophila*
8.	Terrestrial plant with longest leaves	*Rapbia teedigera*
9.	Largest leaves	*Victoria regia*

INFLORESCENCE

- The **arrangement of flowers on the floral axis** (peduncle) is known as inflorescence.
- **Cauliflory** is the development of flowers on old stems, eg *Artocarpus*.
- The main axis of the inflorescence together with the lateral axes, if present, is known as **peduncle**.
- The **floral axis may** be **simple** (*i.e.* unbranched) or **compound** (*i.e.* branched).
- In **unbranched condition** the flowers are borne on the simple axis called **rachis**.
- In **branched axis** the flowers are borne only on the branches which are called **rachises**.
- The flowers that arise singly at the axil of vegetative leaf are **solitary flower**, eg., china rose, *Datura*.
- Inflorescence may be of following types –
  – **Terminal** - Single flower present on floral axis.
  – **Axillary infloresence** - When flower is found in the axil of a leaf.
  – **Intercalary** - Single flower present in between the floral axis.
- Axillary inflorescence are of the following types –
  – **Racemose** or indefinite inflorescence
  – **Cymose** or definite inflorescence
  – **Mixed** inflorescence
  – **Special type** of inflorescence

Racemose inflorescence

- In **racemose type** main axis of inflorescence with indefinite (indeterminate) growth gives rise to (lateral or axillary) flowers in an acropetal order.
- In racemose type the rachis and peduncle donot terminate by flowers but their apices are provided with buds.
- In acropetal order the youngest flower is at the apex while the oldest is at the base.
- In racemose inflorescence **opening of flower is centripetal** *i.e.* the basal or outer flowers open first and the apical or inner flowers open last.
- When the flower of the racemose inflorescence are borne on an unbranched peduncle, the inflorescence is called **simple racemose inflorescence.**
- In **compound racemose inflorescence** the peduncle is branched and branches are borne over the mother peduncle in acropetal order.
- The various forms of racemose inflorescence can be described under–

- those in which the main axis is elongated, e.g. **raceme**, **spike**, **spikelets**, **catkin**, **spadix**.
- those in which the main **axis is shortened**, e.g., **corymb**, **umbel**.
- those in which the main axis **becomes flattened**, **concave or convex**, e.g. head.

- In **raceme inflorescence**, pedicillate flowers are borne acropetally on an **elongated inflorescence** axis, e.g. *Brassica, Cassia*.
- When the main axis of the raceme is branched and the lateral branches bear the flowers then the inflorescence is **compound raceme or panicle**,eg. *Delonix*, litchi, mango.
- **Spike** is the type of inflorescence where sessile flowers are borne acropetally on an elongated inflorescence.
- In **compound spike** the inflorescence axis of a spike is branched and the branches bear sessile flowers (flowers are arranged like that in spike). For example *Amaranthus spinosus*.
- **Spikelet** is the compound inflorescence or secondary spike which is common in **grasses** and hedges, eg wheat.
- **Catkin** (**amentum**) is a special type of spike with a long, thin and pendulous axis which **bears unisexual deciduous acropetally arranged sessile flowers**. For example oak, willow, mulberry (*Morus*) etc.
- The axis of the spikelet (ultimate branch) is called **rachilla**.
- Each spikelet (locusta) bears two **glumes** (minute bracts) at its base and inflorescence bears one to many sessile flowers on a reduced stem. It bears **lemma** and **palea also**. Above palea there are two scale like **lodicules** (*i.e.* perianth)
- The **rice inflorescence** is described as panicle of spikelets and each spikelet is composed of one flower only.
- In wheat the **spikelets are multiflowered** and are borne on an unbranched axis appearing as a compounds spike.
- **Strobile** is a type of spike in which the sessile flowers are borne in the axils of persistent membranous bracts, e.g. hop (*Humulus lupulus*).
- **Spadix** is a spike with a fleshy axis that is enclosed by one or more large, often brightly coloured bracts called **spathes**. For example in banana, *Colocasia* etc.
- The spadix is **found in monocots only**.
- In coconut, palm, *Pandanus*, **compound spadix** is present where the main axis of the spadix is branched and the flowers are borne on the branches.

Largest spadix inflorescence is present in *Amophophallus*.
Smallest spadix is present in lemnaciae.
Woody spadix is found in *Cocos nucifera.*

- **Corymb** is similar to raceme but axis is short at the top. As the lower flowers are long stalked and the upper ones have a short stalked thus all the flowers appear almost at the same level, eg. *Iberis, Cassia* sp. etc.
- In **umbel inflorescence** due to condensation of the axis, the flowers appear to be arising from one point in a centripetal manner (outer flowers are more mature).
- The inflorescence in umbel is subtended by an involucre, e.g., *Hydrocotyl, Centella asiatica.*
- The flowers in an umbel type of inflorescence **usually have stalks of equal length**.
- When the axis of an umbel inflorescence is branched and each branch bears equally pedicellate flowers it is called **compound umbel**, e.g., fennel, corriander, carrot. The involucres of the secondary umbels are called **involucels**.
- In **capitate inflorescence** the axis is suppressed to form a globose head and large number of sessile flowers grow on it to give it a globose appearance. eg., babul *(Acacia),* siris *(Albazzia)*.
- **Head or capitulum** or anthodium inflorescence consists of mono - or di-morphic florets borne on a condensed axis called **receptacle**.
- Although the whole inflorescence looks like a single flower in head, it really consists of a clustered mass of small sessile flowers called **florets**.
- Florets are usually of **two kinds - ray florets** (marginal) and **disc florets** (central tubular ones).

Mixed panicle $\rightarrow$ e.g. *Ligustrum vulgare.*
Panicle of spikelets $\rightarrow$ e.g. rice
Cymose Umbel $\rightarrow$ e.g. *Allium cepa, Calotropis.*
Cymose Corymb $\rightarrow$ e.g. *Ixora*
Mixed Spadix $\rightarrow$ e.g. banana
Thyrsus (a number of cymose clusters are borne acropetally on an axis with unlimited growth), e.g., Grapevine.
Corymb of capitula $\rightarrow$ *Agerantum*

- The **ray florets** are neutral in sunflower and pistillate in *Tridex*. The **disc florets** are generally bisexual. Each floret has individual scaly bract.

- The florets in head are **borne in acropetal manner but they appear centripetal due to condensations of the axis**. The entire inflorescence is subtended by an involucre of bracts at the base.
- The head are of **two types - homogamous head** and **heterogamous head**.
- In **homogamous head** monomorphic florets are present. Only ray florets occur in *Sonchus*, *Launea* etc. and disc florets in *Ageratum, Vernonia* etc.
- In **heterogamous head** dimorphic florets are present. The ray florets are peripheral and bisexual disc florets are central in position, eg. *Dahlia, Helianthus* etc.
- **Compound capitulum** is formed when the main inflorescence axis is branched and several capitula are included within a common involucre.
- In compound capitulum **each head has a single floret subtended by its own involucre**, eg. *Echinops echinatus*.

Cymose inflorescence

- In **cymose inflorescence** the growth of the main axis is limited and the rachis or peduncle apices are terminated by flower (no further elongation of the axis).
- In cymose inflorescence the **flowers are arranged on the rachis laterally in basipetal succession** *i.e.* the apical or uppermost flowers are older than the basal (lower) flowers.
- On the basis of arrangement of flowers cymose inflorescence are of different types as **uniparous** (**or monochasial cyme**), **biparous (or dichasial cyme), multiparous (or polychasial cyme).**
- In **uniparous cyme** the main axis ends in a flower and it produces only one lateral branch at its base which also ends in a flower. The process is repeated.
- **Two types of uniparous cymes** are - **helicoid** and **scorpioid**.
- In **helicoid uniparous cyme** the lateral axis develop successively on the same side (either on the left or right side) of the main axis forming a helix, eg. sundew (*Drosera*), *Bigonia*, *Heliotropium* etc.
- Helicoid uniparous cyme are of **two types** - **drepanium** (when the lateral branches are in the same plane), and **bostryx** (when the lateral branches are in different plane).
- In **scorpioid monochasial cyme** the successive lateral branches develop alternately on the opposite sides (to the right or left) of the main axis, evidently forming a zigzag, e.g. *Ranunculus, Heliotropium* etc.
- Scorpioid monochasial cyme are of **two types** – **rhipidium** (when the lateral branches are in the same plane, eg. *Solanum nigrum*) and **cincinus** (when the lateral branches are in the different plane).
- In **biparous cyme or dichasium type** the main axis ends in a flower and at the same time it produces two lateral branches which terminates in flowers. The latter branches may again branch similarly, eg. jasmine, *Ixora, Dianthus* etc.
- In **multiparous cyme** or **polychasium type** the main axis ends in a flower and at the same time produces more than two lateral branches which also end in flowers. This process is repeated again, e.g., *Calotropis*.
- In **cymose head**, sessile/subsessile flowers are borne centrifugally around a receptacle, eg., *Anthocephalaus cadamba.*

Mixed inflorescence

- **Mixed inflorescence** have both the characters of racemes and cymose type of inflorescence.

Special types of inflorescence

- Special type of inflorescence are **basically cymose but ultimately** it is **modified to form a special appearance**.
- **Different types of special inflorescence** are - cyathium, coenanthium, hypanthodium and verticillaster.
- In **cyathium** the whole inflorescence is covered by a cupshaped green involucre formed by the fusion of bracts. Here extremely reduced florets are present on a convex receptacle.
- In cyathium, the central, largest, single female flower with a single pistil is surrounded by a number of young male flowers (each reduced to a solitary stamen) seated on short stalks.
- Each male flower in cyathium has a stalk and a scaly bract at the base. The flower follow centrifugal order of development *i.e.* the female flower at the centre mature first and then the male flowers surrounding it.
- Cyathium is **found in** *Euphorbia*, *Pedilanthus* (jew's slipper) etc. Nectar secreting glands are often present in cyathium.

- **Coenanthium** is a saucer shaped inflorescence with margins curved upward, e.g. *Dorstenia*.
- **Hypanthodium** has a fleshy receptacle which forms a hollow cavity more or less pear shaped with an apical opening or ostiole.
- The **ostiole** of hypanthodium is **guarded by scales** and **flowers are borne on the inner side of the cavity**.
- The receptacle of hypanthodium is formed by the condensation of the rachis of three cymes.
- In hypanthodium the female flowers are present at the base and male flowers higher up towards the mouth. Sterile or gall flowers are present in between the male and female flowers. Example of hypanthodium is *Ficus*.
- **Verticillaster** is **condensed dichasial cyme**.
- On the main axis there are two opposite bract at the node. A large flower arises in the axil of each bract and two small flower are borne on the side of such a flower.
- All the three flowers are sessile or subsessile. Each dichasial cyme changes into monochasial cyme of scorpioid type. Thus there are 7 flowers in a cluster, e.g., *Ocimum*.

Inflorescence

- **Terminal e.g., *Crotolaria***
- **Axillary**
  - Racemose (Indefinite)
    - Raceme e.g., Cruciferae
    - Panicle e.g., *Delonix*
    - Spike e.g., Lilly
    - Catkin e.g., *Casuarina*
    - Spikelet eg, wheat
    - Spadix e.g., *Alocasia*
    - Corymb *Iberis*
    - Umbel e.g., *Coriander*
    - Capitate eg. *Acacia*
    - Head or capitulum
  - Cymose (Definite)
    - Solitary e.g., *Gossypium*
    - Simple e.g., *Bougainvillaea*
    - Monochasial
      - Helicoid e.g., *Hamolia*
      - Scorpioid e.g., Brinjal
    - Dichasial e.g., *Clesodendron*
    - Polychasial e.g., *Calotropis*
    - Cymose head eg, *Anthocepholus*
  - Mixed Thyrus
  - Special
    - Cyathium e.g., *Euphorbia*
    - Coenanthium e.g., *Dorstemia*
    - Hypanthodium e.g., *Ficus*
    - Vesticillaster e.g., *Ocimum*
- **Intercalary e.g., *Callistemon***

FLOWER

- Flower is a specialised branch of limited growth which bears floral leaves that **carry on sexual reproduction and give rise to seeds and fruits**.
- The **study of flowers** is called **anthology**.
- Plants which **flower only once in their life time** are called **monocarpic**, eg : *Bambusa arundinacea, Agave americana* (century plant), annual crop plants.
- Plants **which flower many times in their life time** are called **polycarpic**, eg : all perennial trees.
- Flowers are regarded as **modified shoots for sexual reproduction**.
- **Pedicel** is the **stalk** of the flower.
- Flowers with stalk are **pedicillate flowers** and without stalk are **sessile flowers**.
- In case of solitary flower, its stalk is termed as **peduncle**.
- The tip of the pedicel is called **thalamus** or **torus** or **receptacle**.
- Thalamus is formed by the condensation of internodes of the **floral axis**.
- In case of underground modified stem, flowering shoot that come out annually above ground is termed **scape**, e.g. tuberose.
- The floral buds usually develop at the axils of small specialised green leaves called **bracts**.
- A flower with bract at its base is called a **bracteate flower**, e.g. *Adhatoda* and one without bract is called as **ebracteate** flower, *e.g.* mustard.
- A bract may fall off early (**deciduous**) or may be present even after fertilisation (**persistent**).
- When additional bract like structures are borne on the peduncle or the pedicel between the flower and the bract they are termed as **bracteoles**, e.g. *Leonurus*.
- In **scaly bracts**, the bracts are **scale like** appendages, e.g. cruciferae.
- In leafy or **foliaceous bracts**, the bracts resemble green foliage leaves, e.g. *Cleome viscosa, Adhatoda vasica*.
- In **petalloid bract**, the bracts are brightly coloured *e.g. Bougainvillea*.
- **Spathe** is a large, thick, boat shaped bract that covers a spadix inflorescence, e.g., *Colocacia*.
- **Involucre** (or **involucel**) is a **whorl of bracts subtending an inflorescence**, e.g., umbel and capitulum inflorescence.

- There are two lower whorls of **accessory or non essential organs** (calyx and corolla) and two upper whorls of **reproductive or essential organs** (androecium and gynoecium).
- **Complete flower** has all the four floral whorls.
- In **incomplete flower** any one of the floral whorl is absent.
- When both **non-essential whorls are present**, the **flower is described as dichlamydeous** and when only one **non-essential whorl is present, the flower** is **called as monochlamydeous**, e.g., *Polygonum.*
- When **both the nonessential whorls are absent** then the flower is said to be **achlamydeous** or naked, e.g., betel.
- When **both the essential whorls are present** then the flower is described as **bisexual or hermaphrodite**.
- When **only one essential whorl is present**, then the flower is describe as **unisexual or diclinous** either **staminate (male flower - androecium) or pistillate (female flower - gynoecium)**.
- In **heterochlamydeous flower** the two non-essential whorls possess different colours, eg. *Hibiscus*.
- In **homochlamydeous** flower the two non-essential whorls possess same colour, eg. *Artabotrys*, **majority of the monocots**.
- When **both the essential whorls are absent**, the flower is designated as **neutral or aclinous**, e.g., in inflorescence of *Hydrangea*.
- The four whorls develop in an ascending order from the swollen, supressed end (**thalamus**) of the floral axis or stalk (**pedicel**).
- The **androecium** is the **male whorl** and each of its stamen differentiates into a **filament**, **anther** and **connective**.
- **Gynoecium or pistil** is the **female whorl** that is differentiated into the **ovary**, **style** and **stigma**.
- A plant **bearing both male and female flowers** is said to be **monoecious**, e.g., gourd.
- A plant **bearing either male flowers or female flowers** is called **dioecious**, e.g. mulberry, papaw etc.
- In **trioecious plants** male, female and bisexual flowers are present on separate plants, eg. *Silene.*
- In **andromonoecious plants** male and bisexual flowers are present on the same plant, eg : *Veratrum.*
- In **gynomonoecious plants** female and bisexual flowers are present on the same plant, eg. asteraceae plants with heterogamous head inflorescence.
- In **gynodioecious plants** female and bisexual flowers are present on different plants, eg. *Thymus.*
- A **plant bearing bisexual, unisexual and even neuter flowers is** said to be **polygamous**, e.g., *Polygonum*, mango.
- In **cyclic flowers** (whorled) sepals, petals, stamens and carpels are arranged in circles or whorls round the thalamus.
- In **acyclic flowers** (spiral) sepals, petals, stamens and carpels are spirally arranged, e.g., *Magnolia*, custard apple.
- The flower may be **hemicyclic** when some parts are cyclic and others acyclic as in rose.
- When the floral parts are different in number in each whorl it is called **anisomerous flower**, eg. *Achras sapota.*
- In **isomerous flower** floral parts are uniform in number or multiple in number in all whorls.
- When all the floral organs are similar in their size, structure and order of disposition, the flower is said to be **regular or actinomorphic**, e.g., in carrot, rose, sunflower.
- Flower is said to be **irregular** or **zygomorphic** if any series show dissimilarity in its parts regarding any of their traits.
- **Assymetric flower** cannot be cut into two equal parts in any plane.
- **According to the position of gynoecium**, the flowers are of **three kinds** as **hypogynous**, **perigynous** and **epigynous**.
- When the calyx, corolla and androecium arise below the ovary, the flower is described as **hypogynous**. The ovary is superior, e.g., cruciferae, liliaceae.
- When the calyx, corolla and androecium arise from the around of ovary, the flower is described as **perigynous**. In these flowers the ovary is semi inferior, e.g., *Saxifraga.*
- When the calyx, corolla and androecium arise from the top of the ovary, the flower is described as **epigynous** and the ovary is inferior, eg. myrtaceae, umbelliferae, compositae etc.
- **Depending upon the number of floral parts**, flowers of different types as –
  - **dimerous**, e.g. *Papaver* etc. (floral parts in the multiple of 2)
  - **trimerous**, e.g. monocots (floral parts in the multiple of 3).
  - **tetramerous**, e.g. cruciferae (floral parts in the multiple of 4).

- **pentamerous**, e.g. malvaceae, solanaceae (floral parts in the multiple of 5)
- **hexamerous**, e.g. *Argemone* (floral parts in the multiple of 6).

Parts of flower

- A typical flower has **four main parts – calyx**, **corolla**, **androecium** and **gynoecium**.
- The **individual units of a calyx** are **sepals**, of **a corolla** are **petals**, **of an androecium** are **stamens or microsporophylls** and **of a gynoecium** are **carpels** or **megasporophylls**.
- **Calyx** and **corolla** are **helping or accessory whorls** because they attract insects during pollination and protect the essential parts before the flower bud has opened.
- **Androecium** and **gynoecium** are **essential or reproductive whorls** as they are necessary for sexual reproduction and seed formation.

Calyx

- Calyx is the outermost, lowermost, non essential but protective whorl of the flower.
- Calyx or sepal is composed of green leaf like structure.
- When sepals are coloured other than green, they are called **petaloid**.
- When the **sepals are free from one another**, the calyx is said to be **polysepalous**, e.g., mustard, water lily etc.
- When the sepals are wholly or partially united with one another by their margins, then the calyx is said to be **gamosepalous**, e.g., brinjal, chilli.
- Calyx may **show various shapes** like **campanulate** (bell like, eg., *Petunia*), **cupulate** (cup like, eg. *Gossypium*), **urceolate** (urn shaped, eg. silene) **infundibulum** (funnel shaped, eg., *Atropa*), **globose** (inflated, eg., *Physalis*), **tubular** (eg., *Verbena*), **bilabiate** (2-lipped, e.g., *Salvia*), **spurred** (beak like, e.g., *Larkspur*), **hooded** (one sepal enlarged to form a hood, e.g., *Aconitum*), **spinous** (modified into spines, e.g., *Trapa*), **pappus** (hairy, e.g., *Sonchus*), **saccate** (pouched, e.g., mustard), **reflexed** (bent backwardly, *Cassia*), **gland dotted** (e.g., *Citrus*).
- Calyx can be **differentiated on the basis of their duration** as **caducous**, **deciduous** and **persistent**.
- In **caducous type**, the calyx fall off just after opening the bud, e.g. *Argemone, Papaver* etc.
- In **deciduous type** , sepals fall off along with petals just after fertilisation, e.g. mustard.
- In **persistent type**, sepals remains attached with the ripe fruit, e.g. *Pisum*, *Ocimum*, solanaceae.
- Persistent calyx growing in size along with fruit (e.g., *Physalis*) is called **accrescent calyx**.
- **Epicalyx** is an extra series of green sepal like floral organ which lies on the outside of calyx, e.g., malvaceae.

Corolla

- The inner non essential attractive whorl, proceeding towards the centre is called **corolla**.
- Corolla are **brightly coloured** and **attract insect for pollination** and **protect the inner essential whorls from injury**.
- When a petal looks like a sepal it is called **sepaloid petal**, e.g., *Anona, Polyalthia.*
- The petals may be differentiated into a **limb (expanded part)** and a **claw (narrow part) or unguis**.
- When stalked, the petals are described as **clawed or unguidculate**, e.g., cruciferae and when the claw is absent the petals are sessile, e.g., rosaceae.
- When the petals within the corolla remain free from one another then corolla is said to be **polypetalous**, e.g., mustard etc.
- When the petals are united by their lateral margins then the corolla is said to be **gamopetalous**, e.g., *Datura*, gourd etc.
- In a gamopetalous corolla, the **petals unite to form a lower tubular** portion known as **corolla tube** and **the upper free portion** is known as **corolla lobes**.
- Shape of polypetalous corolla are **cruciform**, **caryophyllaceous**, **rosaceous** and **papilionaceous**.
- In **cruciform type** four free petals are diagonally arranged in relation to floral axis, e.g., *Brassica.*
- In **caryophyllaceous type** five or more free petals with long claws are present, e.g., *Dianthus.*
- In **rosaceous type** five or more free petals with short claws are present, e.g., *Rosa.*
- **Papilionaceous corolla** has butterfly shaped corolla. It consists of five free dissimilar petals of which the **outermost one is the biggest** and is called the **standard or vexillum**, two postero- lateral petals called **alae** and two antero - lateral petals (**smallest**) fused to form the **carina or keel**, eg., pea, bean, gram.

- Gamopetalous corolla are of **different shapes** like **campanulate** (eg. *Cucurbita*), **hypocrateriform** or **salvar shaped** (tubular with spreading lobes, e.g., *Clerodendron*), **infundibulum** (e.g., *Petunia*), **urceolate** (e.g., *Bryophyllum*), **tubular** (e.g., sunflower), **ligulate** (strap shaped, e.g., **ray florets** of sunflower), **rotate** (short tube with spreading lobes e.g., *Solanum nigram*), **spurred** (*Delphinium*), **bilabiate** (*Salvinia*).
- When a pouch like outgrowth arises at the base of the corolla then such type of corolla is described as **gibbous**, e.g., *Antirrhinum*.
- In **monochlamydeous flower** when single accessory whorl is present (no distinction between sepal and petal), the whorl is described as **perianth**.
- **Unit of perianth or individual member of perianth** is known as **tepal**.
- When the members of perianth are free the perianth is termed as **polyphyllous**, e.g., *Polygonum*, *Asparagus* etc.
- When the members of perianth are united the perianth is termed as **gamophyllous**, e.g., *Polyanthes*.
- When the perianth is bright like petals it is called **petaloid perianth** as in glory lily, water hyacinth etc.
- If the perianth is sepal like it is called **sepaloid perianth** as in *Acalypha indica*, *Phyllanthus niruri*.
- In grasses the perianth is scale like and is called **lodicule**.

Androecium

- Androecium is the outer essential whorl consisting of **stamens**.
- Each stamen is distinguishable into **anther** and **filament**.
- Each anther consists of two anther lobes attached at the back by a sterile band called **connective** and each lobe contains two **microsporangia**.
- Sterile and undeveloped stamens are called **staminodes**.
- All stamens are with filaments but in some special cases stamens are without filaments (sessile condition) as in *Arum maculatum*.
- The number of stamens present within a flower varies from one to many. Based upon this the condition is called **monandrous** (when number is one), e.g., ginger; **diandrous** (two), e.g., *Adhatoda*; **triandrous** (three), e.g., wheat; **tetrandrous** (four) e.g., *Ocimum*; **pentandrous** (five), e.g., *Datura*; **hexandrous** (six), e.g., paddy, polyandrous (many), e.g., rose.
- When the stamen number is equal to the petals or sepals, they are described as **isostemonous** or **haplostemonous**, e.g., brinjal.
- When the stamens differ in size or mode of dehiscence, they are called **heterostemonous**.
- Stamens may be **alternipetalous** (alternating with petals, e.g., *Petunia*), **antipetalous** (opposite to petals, e.g., corriander), **alterniphyllous** (alternate to sepals) and **antiphyllous** (opposite to sepals).
- When the number of stamen is double the petals (arranged in two whorls) and outer whorl lies opposite the sepals, they are described as **diplostemonous**, e.g., *Geranium*.
- When the number of stamens is double the petals and the outer whorl lies opposite the petals, the stamens are described as **obdiplostemonous**, e.g., *Oxalis*.
- When the stamens are in more than two whorls, the condition is described as **polystemonous**, e.g., *Delphinium*, *Aquilegia* etc.
- In *Delphinium*, stamens are spirally arranged and they are described as **spirocyclic**.
- The union of stamens may take place either among themselves (**cohesion**) or with other floral members (**adhesion**).
- In **syngenesious condition** fusion of anther occur only and filaments remain free, e.g., sunflower.
- In **synandrous condition** both anthers and filaments remain fused, e.g., cucurbitaceae.
- When there is no fusion, the androecium is described as **polyandrous**, e.g., cruciferae.
- In **adelphous condition** stamens are united only by their filaments forming one to several bundles but the anthers remain free.
- Different terms are used to describe the fusion of filaments in different plants as **monadelphous** (fusion in one bundle e.g., china rose), **diadelphous** (fusion in two bundles, e.g., papilionaceae), **polyadelphous** (fusion in more than two bundles e.g., *Citrus*).
- Condition in which filament of stamens are attached to corolla or petals and anthers are free is called **epipetalous**, e.g., brinjal, potato etc.
- In **episepalous condition** stamens are attached to the sepals, e.g., *Quisqualis*.

- When the stamens are fused with tepals they are described as **epiphyllous**, e.g., liliaceae.
- When the stamens are fused with carpels they are described as **gynandrous**, e.g., *Calotropis*.
- When the union between stamens and carpels is complete *i.e.* throughout then condition is called **gynostegium** (*Calotropis*) or only by apex it is called **gynostemium** (orchid).
- When two stamens are long and two are short as in labiatae, acanthaceae, the condition is said to be **didynamous**.
- In **tetradynamous** condition four stamens are long and two are short, e.g., cruciferae.
- When the connective is very narrow, so that the two anther lobes lie in close proximity as in *Adhatoda*, *Euphorbia* sp, it is called **discrete**.
- When the connective is broad and the two anther lobes are separated as in *Tilia* sp, it is called **divaricate**.
- When the connective is elongated long stalk like present at right angle to the filament and subtending one fertile anther lobe at one end and one sterile anther lobe on the other end as in *Salvia* sp, it is called **distractile**.
- In **adnate anther**, filament is attached to the complete length of the anther *i.e.* from base to apex of anther.
- When the filaments appear to be attached to the base of the anthers, then the condition is **basifixed**, or innate, e.g., *Raphanus*.
- When the filaments appear to be attached to the anthers abaxially, they are described as **dorsifixed** e.g., malvaceae, *Sesbania*.
- When the filament is attached at one point and the anther hangs over it showing seesaw movement, they are described as **versatile**, e.g., grass.
- The anthers are generally linear elongated structure but in some flowers they have other shapes also like reniform *i.e.* kidney shaped (*Hibiscus*), sagittate *i.e.* arrow shaped (apocyanaceae), sinuous *i.e.* lobed in S-like manner (cucurbitaceae).
- A one celled or lobed anther having only two microsporangia or pollen chambers as in malvaceae is called **monothecous anther**.
- A two celled or lobed anther having four microsporangia or pollen chambers is called **dithecous anther**, e.g., cruciferae.
- **Dehiscence of anthers** may be **longitudinal** (lengthwise slits, e.g., *Datura*, mustard), **transverse** (breadthwise slits, e.g., *Malva*), **valvular** (anther lobe breaks at places by lifting of surface layers, e.g., barberry), **porous** (by pores, e.g., *Solanum*), **irregular** (e.g., *Najas*).
- The anther dehiscing towards periphery of flower as in malvaceae is called **extrose anther**.
- The anther dehiscing towards the centre of flower is called **introse anther**.
- Appendages of the stamens are called **staminal corona**.

Gynoecium

- Gynoecium **constitutes the inner essential whorl of flower comprising carpels**.
- **Carpel** is the **unit of gynoecium** and it is distinguishable into basal ovule bearing region (**ovary**), a terminal pollen receiving region (**stigma**), joined by stalk like structure (**style**).
- A sterile pistil or gynoecium or ovary is known as **pistillode**, e.g., male flowers of hypanthodium.
- The word pistil is derived from the latin term *Pistillum*, "pestle".
- The **number of carpels is usually fixed for a plant species** and it is described as **monocarpellary** (single carpel), **bicarpellary** (two carpels), **tricarpellary** (three carpels), **tetracarpellary** (four carpels), **pentacarpellary** (five carpels) to **multicarpellary** (usually having more than five carpels).
- In **compound gynoecium** if the carpels remain completely free from one another it is termed **apocarpous**, e.g., lotus, rose; but if carpels are fused with each other then it is called **syncarpous**, e.g., cruciferae.
- The term **locule** refers to the intraovarian chamber or compartments of ovary.
- **Depending upon the number of locule**, the **ovary is** termed as **unilocular** (1 locule), **bilocular** (2 locules), **trilocular** (3 locules), **tetralocular** (4 locules), **pentalocular** (5 locules), or **multilocular** (more than 5 locules).
- Generally number of ovary corresponds with the number of carpels but in *Datura* etc., number of chambers increases due to **false partition or septum** called **replum** *i.e.*, bicarpellate pistil having two chambered ovary becomes four chambered.
- The swollen place of the ovary where the ovules are attached is called **placenta**.

- **Arrangement of ovules** inside the ovary on placenta is called **placentation**.
- Main types of placentation are **axile**, **marginal**, **parietal**, **free central**, **basal** and **superficial**.
- **Axile placentation** is found in bi- to multi-carpellary, bi- to multilocular ovary and **ovules are borne on central axile column** mound on axis, e.g., in malvaceae, solanaceae.
- **Marginal placentation** is found in monocarpellary (unilocular) ovary and **ovules are borne on margin** e.g., in family fabaceae.
- **Free central placentation** is found in bi- to multicarpellary, unilocular ovary and **ovules are borne on central mound** axile column not connected to the ovary wall by any septum, e.g., in caryophyllaceae (*Stellaria*).
- **Parietal placentation** is found in bi- to multicarpellary, unilocular ovary and **ovules are borne on periphery**, e.g., *Papaver, Argemone*.
- **Basal placentation** is found in mono to tricarpellary, unilocular ovary. Ovules may be few or reduced to one which are **borne at the base of ovary**, e.g., sunflower (compositae).
- **Superficial or laminar placentation** is found in multilocular ovary and ovules are **borne on inner surface or partition walls**, e.g., in waterlily (*Nymphea*).
- The **stalk of ovule** is called **funicle**.
- Funicle is **useful for the attachment of ovule to the placenta**.
- Style may be **terminal**, **lateral** or **gynobasic** based on the position on the ovary.
- Style is **terminal** in position when it arises from the top of the ovary, e.g., chinarose, mustard.
- Style is **lateral** in position when it arises from one side of the ovary as in mango.
- **Gynobasic style** is **characteristic feature of family labiatae** (*Ocimum*) were style arises from the depression or cavity in the centre of ovary or directly from thalamus.
- When base of the style is swollen to form a pad like structure, it is called **stylopodium**, e.g., in umbelliferae (corriander).
- The styles are **generally deciduous** *i.e.*, they fall off after fertilisation but in *Clematis* they are persistent and feathery.
- **Depending upon their shapes**, the **stigmas** have been variously described. They may be **bifid** (compositae), **dome shaped** (*Brassica*), **funnel shaped** (*Crocus*), **striate** (*Papaver*).
- Feather like stigma is called **plumose stigma** as in grasses (gramineae).

Table : Some important definitions

Term	Character	Eg
Resupination	Turning or twisting of ovary or flower through 180º, *i.e.*, upside down	Orchids
Phyllody or chloranthy	Transition from sepals to stamens through petals	*Nymphea*
Anthesis	Opening of flower	
Anthophore	The elongated internode between calyx and corolla	*Silene*
Androphore	The elongated internode between corolla and androecium	*Passiflora*
Gynophore	The elongated internode between androecium and gynoecium	*Capparis*
Zynandrophore or androgynophore	When androphore and gynophore both are present in the same flower.	*Cleome gynandra*
Carpophore	The prolongation of thalamus beyond carpels	*Coriandrum*

Aestivation

- The **mode of arrangement of the sepals or petals** with respect to one another in the floral bud is termed as **aestivation**.
- Aestivation is of the **different types** as – valvate, twisted or contorted, imbricate, quincuncial, vexillary, convolute, and plicate.
- In **valvate aestivation**, sepals or petals or tepals just touch without any overlapping, e.g., *Brassica*.
- In **twisted** or **contorted type**, one margin of each petal overlaps the margin of an adjacent petal and the other margin being overlapped by margin of another adjacent petal, e.g., china rose.

- **Imbricate** is aestivation of five parts, where one is exterior, one is interior and rest three are having one margin exterior and other interior.
- **Vexillary** is **characteristic aestivation of corolla of pea** where posterior petal is outermost.
- **Quincuncial** is aestivation of 5 parts, where two are exterior, two interior and the fifth is having one margin exterior and the other interior.
- **Convolute type** is a **modified form of contorted aestivation** and applied when the entire petals are involved in twisting, e.g.*Phlox.*
- When each petal is folded like a fan along its midrib and with margins fused then the condition is called as **plicate**, e.g., *Datura.*

FRUIT

- Fruit is the **matured ovary or ovaries**, with or without seeds together with any accessory structures closely associated with them.
- **Pomology** is the **study of fruit**s.
- After fertilization **ovary forms fruits** and **ovules form the seeds**.
- Fruits are **classified on the basis of the**
  - **floral parts** that participate in the fruit development,
  - **nature of pericarp**,
  - **union of carpels**,
  - **type of dehiscence**.
- **On the basis of the formation of fruits**, they are classified into – (a) **true fruits** and (b) **false fruits** (or **spurious fruits or pseudocarps**).
- The fruits which are **developed only from the ovary** and in which no other floral parts take part in its development are called **true fruit**s.
- The fruits in which **addition to ovary other floral parts also contribute for its development** are called **false fruits**, e.g, aggregate fruits.
- A **fruit that is formed without fertilization** and thus without seed is called **seedless fruit or parthenocarpic fruit**, e.g., banana.
- **Noll** defined parthenocarpy as the development of fruit without any stimulus by other factors.
- Modified definition of **parthenocarpy is formation of fruit without fertilization**.
- The fruits that develops out of fertilization and possess seed is termed **seeded fruits**.
- The mature wall of the ovary after ripening in the fruit is called **pericarp** (*peri* - around, *karpos* - fruit)

Pericarp
- Outermost layer — **Epicarp** (skin of the fruit)
- Middle region — **Mesocarp** (may be thin and membranous in orange, hard and stony in palms, fleshy and juicy in mango etc.)
- Innermost layer — **Endocarp** (thin and membranous)

Types of fruits

- There are three main types of true fruits - (a) **simple fruits** (b) **aggregate fruits**, (c) **composite fruits**.
- **Simple fruits** develop from **monocarpellary or multicarpellary syncarpous ovary**.
- **Aggregate fruits** develop from the **multicarpellary apocarpous ovary**. A single part of fruit is called as **fruitlet**.
- **Composite fruit develops from entire inflorescence** with its flowers and peduncle etc.

Fruits
- **Simple fruits**
  - Simple dry
    - Indehiscent: Achene, Nut, Cypsella, Caryopsis, Samara
    - dehiscent: Legume, Follicle, Siliqua, Siliqula, Capsule
    - Schizocarpic: Lomentum, Cremocarp, Double Samara, Regma, Carcerulus
  - Simple fleshy: drupe, pome, berry, pepo, hesperidrum, amphisarca, balausta
- **Aggregate fruits**
  - etaerios of follicles
  - etaerios of achenes
  - etaerios of drupe
  - etaerios of berry
- **Composite fruits**
  - Sorosis
  - Syconus

Simple fruits

- Simple fruits is **divided into two groups** – **dry** and **fleshy fruits**.
- The **simple dry fruits** are with dry membranous, leathery or woody pericarp.
- The **dry fruits on the basis of dehiscence** is again **divided into three groups - indehiscent**, **dehiscent** and **schizocarpic**.
- The fruits that **do not burst or split open** at maturity are called **indehiscent fruit**. These fruits are single seeded as in **achene**, **caryopsis**, **cypsella**, **nut** and **samara**.
- **Achene** is **developed from a monocarpellary superior one chambered ovary**. The fruit is dry one seeded where pericarp (fruit wall) and testa (seed coat) are free from each other as in *Mirabilis jalapa, Clematis* etc.
- **Caryopsis** is a small, dry, indehiscent one seeded fruit **developing from monocarpellary simple pistil** where the pericarp is fused with testa as in rice, wheat, maize, grass etc.
- Caryopsis is **commonly known as grains**.
- **Cypsella** is a dry, indehiscent, one seeded fruit **developing from a bicarpellary syncarpous inferior ovary** with the pericarp and the testa free as in sunflower, marigold, cosmos etc.
- **Nut** is a dry indehiscent, one seeded fruit, **developing from a superior bi or multicarpellary syncarpous pistil**, where the pericarp is either hard woody or leathery at maturity, e.g., hard woody pericarp as in oak, or soft leathery pericarp as in litchi.
- **Samara** is one seeded fruits **developing from superior, bi or tricarpellary ovary**. Pericarp becomes flat like wings, e.g., elm, chilbil.
- In the sal tree, wood oil tree etc., fruit is winged but here wings are the dry, persistent sepals. This type of winged fruits are called **samaroids**.
- The fruits in which **pericarp rupture automatically on ripening and discharge their seeds** are called **dehiscent fruits**.
- **Different types of dehiscent fruits** are **legume or pod, follicle, siliqua, silicula** and **capsule.**
- **Legume or pod** is a dry monocarpellary fruit **developing from a superior, one chambered ovary** and **dehiscing by both the sutures** as in pea, bean, pulse.
- **Follicle** is a dry dehiscent fruit **developing from monocarpellary**, **superior**, **one chambered ovary** but **dehiscence by one suture only**.
- Single follicle is rare, sometimes seen in *Calotropis.* Follicle usually develop in an aggregate of two, three or many fruits, e.g., *Michelia, Vinca* etc.
- **Siliqua** is a dry, dehiscent fruit **developing from a bicarpellary falsely two chambered**, **superior pistil** and dehiscing from below upwards by both the margins while the seeds remain attached to the false septum, the **replum**, as in mustard, radish.
- **Silicula** is a **short**, **broad and flat siliqua** found in some members of cruciferae like candytuft (*Iberis*), shepherds purse (*Capsella*) etc.
- **Capsule** is a many seeded, uni or multilocular fruit **developing from a superior** (or sometimes inferior), bi or **polycarpellary ovary** and dehiscing in many ways, e.g., poppy, cotton etc.
- **Schizocarpic fruits split up at maturity into one seeded parts** in such a manner that a portion of the pericarp always surrounds seed.
- **Different types of schizocarpic fruits** are– **lomentum**, **cremocarp**, **double samara**, **regma**, **carcerulus**.
- **Lomentum** is a type of dry, indehiscent legume **constricted** or **partitioned between the seeds into a number of one seeded compartments** (mericarps), e.g., *Acacia, Arachis hypogea* etc.
- **Cremocarp** is a dry, indehiscent, two chambered fruit **developing from an inferior, bicarpellary ovary**. On maturation it divides into one seeded pieces called mericarps.
- Number of mericarp is equal to the number of carpels and the mericarps in cremocarp remain attached to the prolonged end (**carpophore**) of the axis.
- Cremocarp is the **characteristic fruit of umbelliferae**, e.g., corriander, cumin, fennel etc.
- The **double samara** fruits develop from **bicarpellary, syncarpous, superior ovary**. Pericarp develop into two wings. On maturation divides into two seeded samara, e.g., *Acer.*
- In **regma**, fruits develop from **multicarpellary pistil** and **on maturation split** and **divide into as many parts equal to the number of carpels**.
- Each one seeded part in regma is known as **coccus** e.g., castor has 3 cocci.

- **Carcerule** is small, dry indehiscent, four chambered fruit **developing from a superior, bicarpellary pistil**. This is a fruit **characteristic of labiatae**, e.g., *Ocimum*.
- **Fleshy fruit** are **indehiscent** and usually remain succulent and juicy at maturity.
- The main types of fleshy fruits are **drupe, pome, berry, pepo, hesperidium, amphisarca, balausta**.
- **Drupe** is a fleshy one or more chambered and one or more seeded fruit **developing from a monocarpellary or multicarpellary, syncarpous, superior ovary**.
- In drupe pericarp is differentiated into **epicarp** which forms skin of the fruit, the **mesocarp** which is fleshy and the **endocarp** which is hard and stony. Hence **drupe is also known as stone fruit**.
- **Examples of drupe** are – mango, coconut, peach, cherry, almond, etc. In mango, mesocarp is fleshy and juicy whereas it is dry and fibrous in coconut.
- **Berry or Bacca** develops from **mono or multicarpellary superior or inferior syncarpous** ovary with axile and parietal placentation.
- **Epicarp of berry** forms the rind of the fruit, mesocarp is fleshy and endocarp is thin membranous, e.g., tomato, banana, brinjal, guava etc.
- Berry that develops from a superior ovary is called **superior berry** and which develops from inferior ovary it is called **inferior berry**.
- The **only hard part in berry** is **seed**.
- **Pome** is an **inferior**, **two or more celled, fleshy, syncarpous fruit surrounded by thalamus**. Pome is a **false fruit**.
- In pome, **fleshy edible part is composed of the thalamus**, while the **actual fruit lies within**, e.g., apple, pear, rose apple etc.
- **Pepo** is a fleshy many seeded fruit that develops from an **inferior tricarpellary ovary with parietal placentation**. It is **characteristic fruit of family cucurbitaceae**, e.g., cucumber, water melon etc.
- **Hesperidium** is a superior many celled fleshy fruit **developing from a syncarpous pistil with axile placentation**, e.g., citrus fruits.
- In hesperidium, **epicarp becomes thick and leathery with oil gland, mesocarp is white, fibrous** and **fused with epicarp** whereas **endocarp is membranous from which unicellular, juicy hairs arise which form the edible part**.
- In **balausta**, fruits develop from **multilocular syncarpous inferior ovary**. **Testa is fleshy** and **fruit has persistent calyx**, e.g., pomegranate.
- In pomegranate the pericarp of the fruit is tough and leathery and the chambers are made of thin walls of carpels. The **edible portion** is the **succulent testa**.
- **Amphisarca** develops from **multicarpellary, syncarpous, multichambered superior ovary**. Fruit is **many seeded** with woody pericarp. Mesocarp, endocarp and swollen placenta are eaten as in wood apple (*Aegle marmelos*).
- All fruits with no hard parts excepting the seeds are called **baccate or berry like fruit** and it includes berry, pepo, hesperidium, amphisarca and balausta.

Aggregate fruits

- **Aggregate fruits develops from a single flower** with many **free carpels and ovary** (multicarpellary apocarpous ovary). They make aggregate of fruitlets

Table : Methods of fruit dehiscence

Method	Feature	Eg.
Sutural	Fruit dehisce by one suture	In follicle (*Calotropis*) or by two sutures (legumes-pea and bean)
Porous	Found in capsule fruit. Pores are formed on the upper side of the fruit, through which seeds are dispersed.	*Papaver*
Transverse	Pericarp dehisces transversely into two portions. The cap like portion is blown away by wind.	*Celosia* (Cock's comb), *Ecalyptus*, *Psidium guajava*
Loculicidal	Pericarp splits through the middle of locules along with division of placenta.	*Gossypium*, *Hibiscus*
Septicidal	Septa gets ruptured and locules are separated. Pericarp also gets separated in the forms of valves	Linseed, Castor, mustard.
Septrifragal	Placenta remains attached in the centre of fruit and pericarp segments get separated	Datura, *Cedrela*

known as **etaerio of fruitlets**.

- Aggregate fruits are of following types –
  (a) **Etaerio of follicles** (b) **Etaerio of berries**
  (c) **Etaerio of drupes** (d) **Etaerio of achenes**.
- In **etaerio of follicles**, each separate carpel develops into a fruitlet called follicle. Many follicles form on etaerio as in *Calotropis*, *Catharanthus, Michelia.*
- In **etaerio of berries** aggregate of small berries are present where apical parts of the berries fuse with each other to form a common rind, e.g., custard apple.
- In **eaterio of drupes** many small drupes developed from different carpels are arranged in groups on the fleshy thalamus, e.g., *Rubus idaeus*.
- **Eaterio of achenes** are found in *Ranunculus scleratus, Clematis gouriana* etc.

Composite fruits

- **Multiple or composite fruits** develop from an inflorescence in which the flowers are crowded together and often fused with one another to form a single structure.
- Composite fruits are of **two types** – **sorosis** and **syconus**.
- **Sorosis** is a multiple fruit **developing from a spike** or **spadix**. The flowers fuse together by their succulent sepals and at the same time, the axis bearing them grows and becomes fleshy and woody, thus forming a compact mass in pine apple, jackfruit, mulberry etc.
- **Syconus** develops from **hypanthodium inflorescence**. The hollow pear shaped fleshy receptacle encloses a number of minute male and female flowers, it becomes fleshy and forms the fruit, e.g., *Ficus* (banyan, peepal, fig etc.)

SEED

- A fertilized and **ripened ovule** is known as **seed**.
- Seeds are characteristic of **spermatophytes** (gymnosperms and angiosperms).

Table : Types of fruits & their edible part.

	Name	Scientific Name	Type	Fleshy part
1.	Wheat	*Triticum aestivum*	Caryopsis	Endosperm & Embryo
2.	Maize	*Zea mays*	Caryopsis	Endosperm. & Embryo
3.	Rice	*Oryza sativa*	Caryopsis	Endosperm & Embryo
4.	Litchi	*Litchi (= Nephalium) chinensis*	Nut	Aril
5.	Cashewnut	*Anacardium occidentale*	Nut	Seed (cotyledons) and Thalamus (Peduncle)
6.	Tomato	*Lycopersicum esculentum*	Berry	Pericarp and placentae
7.	Grape	*Vitis vinifera*	Berry	Pericarp and placentae
8.	Guava	*Psidium guajava*	Berry (inferior)	Thalamus, pericarp and Placentae
9.	Banana	*Musa paradisica*	Parthenocarpic berry	Mesocarp and Endocarp
10.	Orange	*Citrus reticulata*	Hesperidium	Placental hair
11.	Date palm	*Phoenix dactylifera*	Berry	Pericarp
12.	Mango	*Mangifera indica*	Drupe	Mesocarp
13.	Coconut	*Cocos nucifera*	Drupe	Endosperm and Embryo
14.	Apple	*Pyrus malus*	Pome	Fleshy thalamus
15.	Pear	*Pyrus communis*	Pome	Fleshy thalamus
16.	Custard apple	*Annona squamosa*	Etaerio of berries	Pericarp (mesocarp)
17.	Jackfruit	*Artocarpus heterophyllus*	Sorosis	Bracts, Perianth, Seeds
18.	Pineapple	*Ananas camosus*	Sorosis	Outer part of receptacle (peduncle)
19.	Fig	*Ficus carica*	Syconus	Fleshy receptacle

- Seed is a **dormant structure** containing **protective coverings, reserve food** and **embryo** (2n).
- **Outer protective covering** of the seed is called **seed coat**, which develops from integuments of ovule.
- In seeds developing from **bitegmic ovules**, there are **two distinct layers in seed coat**. The **outer layer** is thick, hard and leathery (developing from outer integument), called **testa**, whereas **inner layer** is thin and papery (developing from inner integument), called **tegmen.**
- Seed coat is membrarous, generally fused with fruit wall.
- In seeds developing from **unitegmic ovules** there is **single layered seed coat**.
- The seed is attached to the fruit wall or pericarp by means of a stalk called **funicle** or **funiculus**.
- The point of attachment of funiculus to the body of mature seed is called **hilum.**
- A small opening or pore called **micropyle** is **present just below the hilum, which is the way of entry of water into the seed**.
- Seeds may also show marking of **chalaza** for the area where the integuments of ovule originate.
- The seeds having endosperm are called **endospermic** or **albuminous** seeds, e.g., cereals, castor, etc.
- Seeds in which **endosperm is fully consumed** by embryo and no endosperm is left, are called **non-endospermic or ex-albuminous seeds**, e.g., gram, pea, sea cucumber, tamarind etc.
- Monocotyledonous seeds are endospermic but some as in orchids are non-endospermic.
- The endosperm is bulky and stores food.
- Outer covering of endosperm separates the embryo by a proteinous layer called **aleurone layer**.
- The embryo is small and situated in a groove at one end of the endosperm.
  - **Endospermic dicot seeds :** e.g., castor, papaya, cotton.
  - **Non-endospermic dicot seeds :** e.g., gram, bean, pea, cucumber, tamarind.
  - **Endospermic monocot seeds :** e.g., maize, rice, wheat.
  - **Non-endospermic monocot seeds :** *Pothos* (money plant), *Vallisneria, Alisma, Amorphophallus.*
- **Embryo** is the future plant and its origin is from **fertilized eggs or zygote**.
- The embryo is having an **embryonal axis** or **main axis called tigellum**.
- To the tigellum **one** (in case of monocot) or **two** (in case of dicot) **cotyledons are attached**.
- The portion of embryonal axis or tigellum **below the point of attachment of cotyledons**, is called **hypocotyl,** which **bears radicle or future root at its tip**.
- Portion of embryonal axis or tigellum **above the point of attachment of cotyledons**, is called **epicotyl**, which **bears plumule (future shoot) at its tip**.
- Plumule occurs on the side of the single cotyledon.
- The epithelial layer is present for absorption of nourishment from the stored food.
- Radicle is often covered by root cap and a special protective sheath called **coleorhiza**.
- Plumule is surrounded by a protective sheath of **coleoptile**.

DISPERSAL OF SEEDS AND FRUITS

- **Dispersal** is the process of carrying over of the fruits and seeds to distant places (away from the mother plant) by various external agents.
- Dispersal is **essential to avoid struggle for existence**, **for colonization of new areas** and **production of mixed population**.
- Dispersal is facilitated by various agents like wind (**anemochory**), water (**hydrochory**), animals (**zoochory**) and by explosion (**autochory**).
- **Anemochory** is the mode of dispersal of fruits and seeds by wind, eg *Calotropis*.
- **Hydrochory** is the mode of dispersal of fruits and seeds by **water of aquatic or near water plants**, eg *Nymphaea*.
- Some fruits and seeds are dispersed by animals, the method termed as zoochory, eg *Xanthium*.
- The fruits burst due to compression or release of pressure to throw or scatter the seeds to a distance away from the mother plant. This process is termed **autochory**, eg *Impatiens*.

Table : Fruit and seed dispersal

Mode of dispersal and adaptations	Examples of plants	Mode of dispersal and adaptations	Examples of plants
Wind		**Water**	
Wings (i) Winged seeds	*Tecoma, Cinchona, Moringa, Oroxylon Lagerstroemia*	Spongy outer coat Spongy seed coat Spongy thalamus Air cavity seed	Coconut *Nymphaea*, lotus *Mucuna* (in seeds) *Entada* (embryo)
(ii) Winged fruits (pericarp forms wings)	*Hiptage, Shorea, Acer, Dioscorea, Dodonaea*	**Animals**	
Parachute		Hooked fruits and seeds (hooks, barbs, spines, bristles, stiff hairs etc.)	*Xanthium* (curved hooks), *Pupalia* (stellate hooked bristles), *Aristida* (stiff hairs), *Martynia* (Tiger's nail), *Tribulus* (rigid spines)
(i) Pappus (modified calyx) (ii) Coma (tufts of hair) (iii) Persistent hairy style (iv) Balloon like appendages (fruits inflated)	*Sonchus, Taraxacum* *Calotropis, Alstonia* *Clematis, Narvelia* *Physalis* (calyx) *Colutea* (ovary)	Sticky fruits and seeds (sticky glands)	*Boerhaavia, Plumago* *Rafflesia* (by elephants)
Censor (seeds scattered after dehiscence)	*Papaver, Argemone, Aristolochia.*	Fleshy fruits	*Solanum nigrum, Citrullus*
		Edible fruits	Guava, brinjal, tomato etc.
Dust seeds/light seeds (very small and dry)	Grasses, orchids	Mimicry	*Biserula* and *Scorpiurus* (resemble caterpillar)
Propellar fruits (fruits flattened and twisted)	*Ailanthus*	**Explosion of fruits**	
Tumble weeds (plants get uprooted)	*Carthamus, Salsola, Argemone*	Jaculator mechanism	*Andrographis, Barleria, Ruellia*
		5 valved opening 2 valves (burst in contact with water)	*Impatiens,* *Ruellia tuberosa*
			Ecballium, Entada, Bauhinia (camel's foot climber)

End of the Chapter

Chapter 30

Anatomy of Flowering Plants

- Study of internal structure exposed after dissection and opening of various parts is called **anatomy**. (Greek, *ana* - again, *tommein* - to cut).
- In common usage anatomy is studied with naked eyes. However, naked eye is unable to study much internal structure in plants.
- Plants possess cells organised into tissues and tissues organised into tissue systems which can be studied only with the help of microscope.
- **Histology** (Greek *hostos* - web, *logos* - science) is the study of tissues, their composition, structure and organisation as observed with the help of microscope. For plants, the terms, anatomy and histology are synonymous interchangeable.
- **Importance of anatomy** are –
  - It gives information about internal structure of different parts of an organism.
  - Simplicity or complexity of structure is known only through the study of internal structure.
  - It is important for the study of phylogeny and evolution.
  - It has been used in resolving taxonomic problems.
  - On the basis of anatomical studies, wood is used variously for cabinet work, musical instrument, furniture, paper, match box, pencils, sports articles etc.
  - Forensic science studies plant anatomy in order to identify plant remnants.
- Anatomical details indicate the structural modifications in response to environmental condition.
- A group of cells having similar origin, same method of development and same function constitute **tissue**.
- The term tissue in plant anatomy was coined by **N. Greew (1682)**.
- A tissue is **formed in response to a basic division of labour**.
- Based on the capacity to divide, **plant tissues are classified into two main groups** : **meristematic** and **permanent**.
- A tissue is called **simple tissue** if it consist of only one type of cells, eg., meristem, parenchyma.
- A **complex tissue** has two or more types of cells which of course have a common origin & common function, e.g., xylem & phloem.

MERISTEMATIC TISSUE

- **Meristematic tissues** (Greek *meristos*-divisible) is a simple plant tissue of thin walled embryonic cells which undergo mitosis forming new cells & tissues.
- Term meristematic was introduced by **Nageli (1858)**.
- Cells of meristematic tissue are **isodiametric** in shape (with **prominent nuclei** and **dense cytoplasm)**.
- Cells are of **various shapes like oval, spherical, rounded or rectangular** and **lacks intercellular spaces**.
- **Protoplast** is **present** but **ergastic substance** are **absent**, **ER small**, **mitochondria simple**.
- Meristematic cells of **vascular cambium** are fusiform in shape, contain ergastic substances like starch grains and tannins.
- Meristematic cells **form two types of cells** : **initiating cells** and **permanent cells**.
- The meristematic cells which retain their capacity of division throughout their life are called **initiating cells**.
- Cells which loose their power of cell division and become mature are called **permanent cells**.
- The meristem which forms the new tissue or organ is called **promeristem** or **embryonic** or **primordial meristem**.

- Promeristems are **usually found in root apex or shoot apex**.
- **On the basis of the plane of division** meristem can be **classified** as **mass**, **plate** and **rib meristem**.
- **Mass meristem** divides in all planes, eg., endosperm.
- The **plate meristem** divides in two planes; right angle to each other, eg. - epidermis.
- **Rib meristem** divides in one plane only, eg. - certain cells of pith and cortex.
- **Based on mode of origin** meristem are **classified** into **two types - primary** and **secondary**.
- Meristem that originate from the embryonic meristem is called **primary meristem**.
- These are **located at the tip of stem**, **roots** and **appendages**.
- Meristem that originate from permanent cells are called **secondary meristem**.
- Secondary meristem is **formed at lateral position of the axis and parallel to surface**.
- **Example of secondary meristem** are cork cambium, interfascicular cambium & cambium in roots.
- **On the basis of the position** meristem can be **classified as** – **apical**, **intercalary** and **lateral meristem**.
- **Apical meristem** are usually **found at the apical region of stem, root and lateral appendages**.
- Apical meristem is **terminal in position** and are **responsible for terminal growth of the plant apices**.
- **Intercalary meristem** get detached from the mother meristem and **present in between the permanent cells**.
- Intercalary meristem is **present in grasses at the basal regions of internodes** and in **leaf sheath of monocots**.
- Intercalary meristem are **short lived**. On loosing their power of division they merge with permanent tissue.
- **Lateral meristem** are **responsible for increase in thickness of the axis**, eg. vascular cambium or cork cambium.
- **On the basis of function** meristem can be **classified into three types** – **protoderm**, **procambium** and **ground meristem**.
- **Protoderm** is the **outermost layer of apical meristem** from which rises epidermis of stem and epiblema of root.
- Meristem which develops into primary vascular tissue is called **procambium**.
- The derivatives of procambium is differentiated into **phloem** and **xylem**.
- Meristem which develops into ground or fundamental tissue is called **ground meristem**.
- **Shoot apex** is portion of shoot above youngest primordium.
- **Plastochron** is the time gap between two successive primodia.
- **Hanstein gave the histogen concept** which shows 3 groups of initials in the shoot apex as **dermatogen** (gives rise to epidermis), **periblem** (gives rise to cortex), and **plerome** (gives rise to vascular tissue).
- **Schmidt** proposed the **Tunica-Corpus concept** showing two portions in the shoot apex as **tunica** (divide anticlinally) and **corpus** (divides anticlinally and periclinally).
- Similar to shoot-apex, **histogen concept was also proposed for root apex**.
- **Quiscent centre** is an **inactive centre in the root apex** having low DNA, RNA and proteins and **it acts as reservoirs of active initials**.
- **Calyptrogen** is a distinct meristem in many monocots that gives rise to root cap.
- **According to Korper-Kappe theory** the root apex has two parts – **keppe or cap** and **korpe or body** showing T-type divisions.
- **Functions of meristem** are –
  - Meristem is responsible for growth or addition of new cells in various regions of the plants.
  - Stem apical tissue produces new leaves and branches.
  - Reproductive shoot apex forms flowers.
  - Intercalary meristem adjusts internodal length & protects the plants from lodging.
  - Root apices continously add new structures (root hairs) to the roots.
  - Vascular cambium adds new vascular tissues as the older ones becomes non - functional.
  - Cork cambium forms protective covering around stems & roots.

PERMANENT TISSUE

- Permanent tissue are those tissue which have **lost the power of cell division**.
- Cells of permanent tissue are matured, assume a definite shape, size and function.

- The permanent tissues which developed from apical meristem are called **primary permanent tissue**.
- The permanent tissues which developed from lateral meristem are called **secondary permanent tissue**.
- **On the basis of constituents cell** permanent tissues are classified into **three types** : **simple tissues**, **complex tissues** and **special tissues**.

Simple permanent tissue

- Simple tissue consists of a group of uniform cells which are **similar in structure** and **carry out same function**.
- Simple tissues are of **three types : parenchyma**, **collenchyma** and **sclerenchyma**.

Parenchyma

- Parenchyma is the **commonest simple tissue**.
- These are the most primitive tissues from which other tissues are evolved and hence also called as **fundamental tissue**.
- Parenchyma consist of **oval, round, polygonal, elongated, star shaped** or **irregular cells**.
- Cells of parenchyma are **living** and **arranged loosely with intercellular spaces**.
- The cells usually have **thin cellulose cell walls** but **parenchyma cells of secondary xylem are thick due to the presence of lignified secondary wall**.
- The parenchyma cells **shows a thin layer of cytoplasm**, a **peripherally located nucleus** and a **large central vacuole**.
- Parenchyma facilitates transfer of materials especially solutes, by transfer cells and retention of small quantity of food & water in all plants.
- Parenchyma cells **which have large intercellular spaces filled with air** are called **aerenchyma**.
- Aerenchyma **gives aeration** and **buoyancy to aquatic plants**.
- Fibre like elongated parenchyma are called **prosenchyma** which **provide strength and rigidity**.
- In fruits, stem tubers, tuberous roots etc., parenchyma store food material, so are known as **storage parenchyma**.
- In succulent xerophytes like *Agave*, these cells store water, so are called **water storage tissue**.
- Parenchyma cells of epidermis having cutinised cell walls are **protective in function** and **prevent evaporation of water**.
- The parenchyma cells also **store waste products** like tannins, gums, resins, calcium oxalate crystal etc.
- **Chlorenchyma** are those parenchyma cells **which contain a large number of chloroplast**.
- Chlorenchyma are **present in young stems and leaves**.
- Chlorenchyma **carry out the process of photosynthesis** and **synthesis of food materials**.

Collenchyma

- Collenchyma are **living, simple, mechanical tissue**.
- These are **present beneath the epidermis of young stem, petioles** and **midrib of leaves etc**.
- Collenchyma are **absent in underground tissues and leaves & stem of monocots**.
- The shape of collenchyma cell can be variable. It may be **oval** or **polygonal**.
- Intercellular space may be **present** or **absent**.
- Cell wall of these cells are made up of **cellulose** and **pectin**.
- Thickening of cells are confined only to the **corners of cells**.
- **Chloroplast is present** in these cells.
- **Primary pit fields** are present in both parenchyma and collenchyma.
- On the **basis of thickening of the cell wall at the corners** collenchyma can be divided into three types *viz*. **angular**, **lacunar** and **lamellar collenchyma**.
- **Angular collenchyma** are the most common one. Thickening is confined at the corners only, eg. stem of *Cucurbita*.
- **Intercellular spaces are absent** in them.
- The **lumen appears circular** due to continued deposition of wall materials.
- In **lacunar collenchyma** the thickening is confined to the walls of the regions bordering intercellular spaces.
- Lacunar collenchyma are **present in aerial roots** of *Monstera*, **stems** of *Malva* etc.
- **Lamellar collenchyma** have thickening confined to tangential walls, eg. stem of *Clerodendron*.
- Lamellar collenchyma are **also called plate collenchyma** as they appear like plate or bands due to tangential wall thickening.
- **Collenchyma has various functions as**
  – It provides elasticity and support to growing organs.
  – The tissue is able to grow along with the growth of the plant organ.

- The cells undergo dedifferentiation to form phellogen.
- It provides support to delicate leaf margins & prevents their tearing.
- The cells contain chloroplasts & perform photosynthesis.
- They store small quantity of food.

Sclerenchyma

- Sclerenchyma are **simple dead mechanical tissues occurring in mature organs of plant body**.
- These are chiefly **distributed in cortex**, **pericycle**, **xylem** and **phloem region**.
- Cells of sclerenchyma have **lignified secondary cell walls**.
- Due to presence of **highly thickened cell walls**, the lumen of these cells are highly reduced.
- **Based on size and shape** sclerenchyma cells are of **two types** *viz*. **fibres** and **sclereids**.
- **Fibres** are **elongated sclerenchyma cells with pointed needle like cells**.
- Fibres are **longest cell in higher plants** reaching a length of **1-3 mm in angiosperm** and **2-8 mm in gymnosperms**.
- Walls of fibres are **lignified**, **hard** and **uniformly thickened**.
- Small round or **slit like pits** are **present** and **intercellular spaces** are **absent**.
- The **secondary walls of fibres of flax are made up of cellulose**.
- Fibres are further classified as **intraxylary** and **extraxylary fibres**.
- **Intraxylary fibres** are fibres **occurring in xylem**.
- **Libriform fibres** (true fibres having simple pits) and **fibre tracheids** (reduced tracheids having bordered pits) are **two types of intraxylary fibres**.
- Fibres **occurring outside the xylem** are called **extraxylary fibres**.
- These are known as **cortical fibres**, **pericyclic fibres** and **phloem or bast fibre** when present in cortex, pericycle and phloem respectively.
- **Sclereids** are **short sclerenchyma cells which are isodiametric or irregular in shape**.
- Their walls are **hard**, **highly thickened with lignin with simple pits**.
- Sclereids are **most abundant in soft tissues** like cortex, phloem, medulla, fleshy fruits, seed coats and fruit walls.
- Sclereids are classified into the following **six categories** – **brachysclereids, macrosclereids, osteosclereids, astrosclereids, trichosclereids and idioblast**.
- **Brachysclereids or stone cells** are short and isodiametric sclereids resembling parenchyma cell in their shapes.
- Stone cells are **found in cortex, medulla** (*Nicotiana*) and **pulp of fleshy fruits** (*Annona*).
- **Macrosclereids** (also called **malpighian cells**) are **elongated rod like sclereids**.
- Malpighian cells form palisade like layer in the outer seed coat of legumes.
- **Osteosclereids** are bone like sclereids with rounded ends found in **leaves** and **seed coats**.
- **Astrosclereids** are star shaped sclereids found in leaves and petioles, eg. *Nymphaea*.
- **Trichosclereids** are elongated and hair like sclereids found in aerial roots of *Monstera* and leaves of *Olea*.
- **Filiform sclereids** are fibre like, sparingly branched.
- **Idioblasts** are the sclereids which occur singly.
- The **important functions of sclerenchyma** are –
  - Sclerenchyma fibres provide mechanical strength to various plant organs.
  - The fibres are specialised to tolerate stress of bending, sheering, compression and pull.
  - Sclerenchyma provides for elastic stretching and compression.
  - It prevents collapsing of soft plant organs under conditions of temporary wilting.
  - Sclereids form protective covering of testa in many legume seeds.

Complex permanent tissue

- A tissue **made up of more than one type of cells** functioning as a unit is called **complex tissue**.
- **Xylem** and **phloem** are the complex tissues **found in all vascular plants**.
- Xylem and phloem are together called **conducting tissues** and are organised into **vascular bundles**.

Xylem

- Xylem, known as **water conducting tissues**, is also called **hadrome** (except xylem parenchyma).
- The **term xylem** was **coined by Nageli**.
- Xylem besides conduction **also provide mechanical strength**.
- Xylem **increases with secondary growth**.
- Xylem is of **two types** depending upon the time and origin of it.

- **Protoxylem** is **first formed xylem** and **metaxylem** is **later formed xylem**.
- **Protoxylem vessels** have **annular** or **spiral thickenings on their secondary walls**.
- **Metaxylem vessels** have **scalariform** (like rungs of ladder), **reticulated** (like net), **pitted** (leaving the thin areas) **thickening on their walls**.
- Xylem may be **primary** (**develops from procambium**) and **secondary (develops from cambium)**.
- Xylem consists of **four different types of elements** – **tracheids**, **vessels, xylem parenchyma** and **xylem fibres**.
- A tracheid is an **elongated cell with tapering ends**.
- Their walls are **highly thickened by the deposition of lignin**, except at certain points called as **pits**.
- **Tracheids** are **dead** and **lignified cells**.
- Through bordered pits **movement of water and mineral salts** takes place from one cell to other.
- Tracheids are **commonly found in pteridophytes, gymnosperms** and **xylem of dicotyledons**.
- The **term tracheid** was **coined by Sanio**.
- The **occurrence of tracheids** in the primary xylem is considered as a primitive feature.
- Tracheids possess **annular, spiral, scalariform, reticulate** and **border pitted thickening on their walls**.
- Tracheids **not only conduct water and dissolved salts but also give mechanical support**.
- **Xylem vessel** resembles the trachea of insect hence it is called **trachea**.
- Vessels are **present in angiosperms**.
- Certain **vesselless angiosperms** are *Drimys Dagenaria*. Vesselless angiosperms belong to families **winteraceae, trochodendraceae** and **tetracentracae**.
- Vessels are **absent in pteridophytes & gymnosperms**.
- The gymnosperms like *Gnetum*, *Ephedra*, *Welwitchia* contain **vessels in their xylem**.
- **Lumen of the vessel is wider** than that of tracheid.
- The **vessels** are **made up of vessel elements**.
- Walls of xylem vessels are **lignified with annular**, **spiral**, **reticulate**, **scalariform and pitted thickening**.
- The end walls of vessel elements are called **perforation plates**.
- The perforation plates are of **two types** – **simple** (having one opening only) and **multiple** (having several openings at the end walls) and the latter one are of three types - namely **scalariform**, **reticulate** and **foraminate**.
- Vessels **help in conduction of water and dissolved salts** from roots to the different parts of the shoot and **provides mechanical support**.
- Parenchyma associated with xylem is called **xylem parenchyma** or **wood parenchyma**.
- Primary xylem contains only **axial parenchyma**.
- Xylem parenchyma is a **living component of xylem**.
- Xylem parenchyma is **made up of small thin or thick walled parenchymatous cell having simple pits**.
- It helps in **lateral conduction of water or sap and stores food**.
- **Xylem fibres** are sclerenchyma (dead cells) fibres associated with xylem.
- **Xylem fibres** occur abundantly in woody dicotyledons and add to the mechanical strength of xylem and of the plant body.
- Xylem fibres are of **two types** – **libriform fibres** (typical fibre with simple pits) and **fibre tracheids**. (Intermediate between fibres and tracheids having thin walls and pits with reduced borders).

Phloem

- Phloem is called **bast or leptome**.
- Phloem is **food conducting tissue** (*i.e.* transport food from green and storage organs of the plants to the other organ of plant) and **also provides** some mechanical support.
- **First formed phloem** is called **protophloem** and **later formed phloem** is called **metaphloem**.
- Phloem **formed from procambium is called primary phloem** and that **from cambium is called secondary phloem**.
- The bulk of phloem does not increase because as soon as new phloem becomes functional, the older one gets crushed.
- **Different kinds of elements** of phloem are : **sieve elements** (sieve cells and sieve tubes), **companion cells, phloem parenchyma** and **phloem fibres**.
- **Sieve cells** are elongated with tapering end arranged in parallel groups.
- These are **primitive type** of sieve elements.
- The perforated end walls are called **sieve plates**.
- A sieve plate with many sieve pores is called **compound sieve plate**.

- **Gymnosperms** have **albuminous cells** and **sieve cells** and **pteridophytes have only sieve cells**.
- **Sieve tube** consists of rows of cells arranged one above other to form long pipes.
- Sieve tube occurs in angiosperms.
- During unfavourable conditions the cytoplasmic strand is ensheathed by the **callose material** in the sieve area and transport of food material is **stopped**.
- During favourable conditions (spring season) the **callose material dissolves** and translocation of food material is restored.
- Mature sieve tubes always remain closed by **callose**.
- **Callose** is a carbohydrate (polysaccharide), it stains blue with aniline and forms glucose on hydrolysis.
- The food materials are conducted through sieve tubes **downwards** from leaves to storage regions and **upwards** to the growing regions **(bidirectional)**.
- Companion cell and sieve tube are the sister cells *i.e.* they are **formed from the same mother cell**.
- Companion cells are **living parenchymatous cells**.
- **Companion cell** contains both **nucleus** and **cytoplasm** and show **abundance of proteins**. There are **cytoplasmic connections** between sieve tube and companion cell.
- Companion cells are **present only in angiosperms** and are **absent in pteridophytes & gymnosperms**.
- The special parenchymatous cells present in the phloem of protein rich cells are called **albuminous cells**, eg. *Pinus*.
- The **living parenchyma cells** associated with phloem are called **phloem parenchyma**.
- Phloem parenchyma are **thin walled cells**, **present in pteridophytes**, **gymnosperms and dicot angiosperms except** *Ranunculus* (monocots generally do not have phloem parenchyma).
- Only **axial parenchyma** is present in primary phloem.
- **Axial & ray parenchyma** is present in secondary phloem .
- Ray parenchyma is **useful for radial conduction of food materials**.
- Phloem parenchyma cells in general **store up food materials and help in conduction**.
- **Phloem fibres** may be **living** or **nonliving**.
- Living phloem fibres are useful for **storage of food materials**, while non-living fibres give **mechanical strength**.

Special tissues / Secretory tissues

- **Secretory tissues** are responsible for secretion of **resin, tannins, gums, alkaloids, volatile oil, nectar latex, etc**.
- External glands are present on epidermis.
- **Glandular hair** is found in *Urtica dioca*.
- **Nectar secreting glands** are present in flower parts and leaves.
- **Digestive glands** are present in insectivorous plants.
- Internal glands are of many types as oil glands in citrus, resin glands in *Pinus* and hydathodes in *Colocasia*.
- Tissues which contain milky latex are called **lactiferous tissues**.
- These tissues also contain organic substances like **alkaloid enzymes, tannins** etc.
- Latex cells are made up of individual cells, eg. *Calotropis vinea*.
- Latex vessel are made up of number of cells joined together, eg., *Papaver*.

TISSUE SYSTEM

- One to many tissues performing some common function irrespective of their position in the body is called **tissue system**.
- **According to function**, tissue system are of **five types - protective**, **mechanical**, **photosynthetic**, **fundamental** and **vascular**.
- **Sachs classified** the tissue systems **into three types** namely **epidermal tissue system**, **ground tissue system** and **vascular tissue system.**
- **Epidermal tissue system** is derived from **protoderm**, **ground tissue system** from **ground meristem** and **vascular tissue system** from **procambium**.

Epidermal tissue system

- **Epidermal tissue system** consists of **epidermis** and **epidermal outgrowths**.
- Epidermis is the superficial layer covering the entire surface of the primary plant body.
- Mostly epidermis is **uniseriate** (single layered) but multiple epidermis is also seen in the leaves of *Nerium, Ficus* sp. etc.
- All the **epidermal cells are living** (parenchymatous) and **contain vacuolated protoplasms**.
- Epidermal cells except guard cells are colourless.
- Large water filled epidermal cells present in the

Types of tissue based on stages of developments

- **Meristematic**
  - Capable of active cell division
  - Thin walled & living
  - Variable shaped
  - Compactly arranged
  - Found in root & shoot apices
  - **Division on the basis of**
    - **Origin**
      - Primary meristem
      - Secondary meristem
    - **Function**
      - Protoderm (Epidermis)
      - Procambium (Pericycle, phloem, xylem, cambium)
      - Ground meristem (Hypodermis, cortex, endodermis, pith)
    - **Position or location**
      - Apical
      - Intercalary
      - Lateral
    - **Histogen**
      - Dermatogen (Epidermis)
      - Periblem (Hypodermis, cortex, endodermis)
      - Plerome (Stele, pericycle, phloem, xylem, cambium, pith)
    - **Plane of division**
      - Mass meristem (Young, in all planes)
      - Plate meristem (Anticlinal division in two plane)
      - Rib meristem (Perpendicular / anticlinal division in one plane, occasional periclinal division)
- **Permanent**
  - Growth is ceased temporarily
  - Have definite shape, size & form
  - **Divisions on the basis of constitution**
    - **Simple** (one type of cells, homogenous)
      - **Parenchyma**
        - Thin wall, isodiametric, compactly arranged
        - Provide protection, storage area, growth & perform photosynthesis
        - Three types – **aerenchyma, chlorenchyma, prosenchyma**
      - **Chlorenchyma**
        - Absent in secondary tissue
        - Occupies hypodermal position
        - Polygonal & living cells
        - Provide mechanical strength
      - **Sclerenchyma**
        - Cell dead & empty
        - Lignified, divide into
          - **Fibres**
          - **Sclereids**
            - **Macrosclereids** (columnar, rod shaped)
            - **Osteosclereids** (bone shaped)
            - **Astrosclereids** (star shaped)
            - **Brachysclereid** (isodiametric, also called stone cell)
            - **Trichosclereids** (hair like)
            - **Filiform** (fibre like)
    - **Complex** (more than one type of cells, heterogenous)
      - **Xylem** (Water conducting part)
        - **Tracheids** (Dead elongated cells with tapering ends)
        - **Vessels** (Made of row of dead cells)
        - **Xylem fibres** (Lignified & sclerenchymatous)
        - **Xylem parenchyma** (Living & cellulose)
      - **Phloem** (Solute conducting parts)
        - **Sieve tubes** (Tube like elongated cells with large lumen)
        - **Companion cells** (Form only in angiosperm)
        - **Phloem parenchyma** (Living parenchymatous cells, absent in monocot & herbaceous direct)
        - **Phloem fibres** (Thick walled sclerenchymatous cells, mechanical in function)

epidermis of monocot leaves (grasses) are called **bulliform** or **motor cells**.

- These are **hygroscopic** and **help in rolling and unrolling of the leaves**.
- The epidermis is **covered with a cutin layer** called **cuticle** on its outer surface.
- The **thickness of cuticle depends upon the adaptation of plant**. It is **thick in xerophytes**, **thin in mesophytes** and **absent in hydrophytes**.
- Root epidermis is also called **rhizodermis** or **epiblema** or **piliferous layer**.
- In **epiphytic root** (*Vanda*) the epidermis is made of

a **dead tissue** called **velamen tissue** (multilayered epidermis).

- Epidermis **consists of two types of structures - stomata** and **out growths** (appendages).
- **Stomata** are mostly present in epidermal layers of leaves and in other aerial parts like young stems floral parts etc.
- The specialised green epidermal cells present around the stoma are called **guard cells**.
- Guard cells **in dicots** are **kidney (bean) shaped** and **in monocots** (grasses) are **dumb bell shaped**.
- Outer wall of guard cell is **thin** but innerwall is **thick and inelastic**.
- **Contents of guard cell** are nucleus, chloroplasts, mitochondria, sphaerosomes, ribosomes, endoplasmic reticulum, nucleic acids and starch.
- Leaves with stomata in upper epidermis are **epistomatic** (eg. *Nympheae*), in lower epidermis is **hypostomatic** (e.g. apple), on both surface is **amphistomatic** (e.g. potato) and without stomata are **astomatic** (e.g. potamogeton).
- Stomata in which guard cells and subsidiary cells are formed from the same mother cell are called **syndetochelic stomata**.
- In **haplochelic type of stomata** guard cells and subsidiary cells are formed from two different mother cells.
- Stomata are **classified into various types** by various scientists **on the basis of their origin**, **development**, **arrangement** and **number of the subsidiary cells**.
- Three dissimilar subsidiary cells are present in **anisocytic type** of stomata, e.g. family *Brassicaceae*.
- The **movement of stomata depends on the turgidity and the flaccidity of guard cells**.
- In majority of the plants stomata **open** during **day time** and remain **closed during night**.
- **Epidermal outgrowths** are of two kinds - **trichomes** and **emergences.**
- Outgrowths formed from epidermis only are called **trichomes**.
- Outgrowths formed from both epidermis and outer most cortical cells are called **emergences**.
- Prickles in *Rosa* are **emergences**.
- **Trichomes** are ephemeral or persistent, their cell wall is made up of cellulose.
- The trichomes are of two types - **glandular** (secretory) and **non-glandular**.
- Trichomes **minimise the transpiration and give protection to the inner parts**.
- **Root hairs** do not come under the category of trichomes, they are the **tubular prolongations of epidermal cells of root** (also termed **trichoblast**).

Functions of epidermis

- Epidermis is a layer of the plant part which **gives protection to the internal tissue from mechanical injuries, attack of pathogens and fluctuations of temperature**.
- **Root epidermis** helps in the absorption of water and mineral salts.
- Having stomata epidermis helps in **interchange of gases** and **transpiration**.
- When necessary the epidermis of the dicot stem gives rise to **cork cambium**.

Ground tissue system

- Ground tissue system, also known as **fundamental tissues**, contain various types of tissues excluding epidermis and vascular tissues.
- Ground tissue system is **derived partly from periblem** and **partly from plerome**.
- Ground tissue system is of **two types - extrastelar ground tissue system** and **intrastelar ground tissue system**.
- **Extrastelar ground tissue system** is **also called cortex**.
- **Cortex** is the zone which **lies between the epidermis** and **the pericycle**.
- Cortex is **divisible** in **three parts only in dicot stem** (as in the monocot stem vascular bundle are scattered in ground tissue) and **all roots** from outer to inner.
- Three subdivisions of cortex from outer to inner are **hypodermis**, **middle cortex** and **endodermis** respectively.
- The **hypodermis** in stems and leaves in **dicot is collenchymatous** while it is **sclerenchymatous in monocots**.
- In stems and leaves hypodermis **gives mechanical support**.
- In dicot stem hypodermis **performs photosynthesis** (when it contains chloroplasts) and **gives rise to cork cambium**.
- **Exodermis** is formed in mature roots when epidermis disorganises.
- **Middle cortex** of dicot stem is parenchymatous. It is completely or partially chlorenchymatous.

- Middle cortex in dicot stem **helps in temporary storage of food materials and sometimes produces cork cambium or secondary meristem**.
- **Endodermis** is the **innermost layer of cortex**.
- Endodermal cells are **living** and **contain abundant protoplasm and large nuclei**.
- Endodermal cells of root are **characterised by casparian bands** (thickening of lignin, suberin and cutin).
- **Casparian bands** are present on the radial and inner tangential walls of endodermal cells.
- The thin walled endodermal cells present opposite to the protoxylem are called **passage cells** or **transfusion cells**.
- Endodermis **acts as waterdam (water tight jacket)** and **prevents the movement of water from the stele to cortex**.
- Endodermis **also acts as airdam** preventing the diffusion of air into the vessels.
- The layer which is **useful to maintain pressure in the root** is endodermis.
- The **innermost layer** of cortex in dicot stem helps in storage of starch materials hence called **starch sheath**.
- The poorly developed endodermis present in the dicot stem is called **endodermoid**.
- **Pericycle**, **pith**, **medullary rays** (**dicot stem**) and **conjunctive tissue of roots** are the **parts of intrastelar ground tissue system**.
- The pericycle of root is always **parenchymatous**.
- Pericycle is **absent in the stems of monocots**, **hydrophytes** and **parasites**.
- Pericycle of root is the **seat of origin of lateral roots in dicots**.
- In dicot stem the **adventitious roots are formed from parenchymatous pericycle**.
- The central portion of the axis (dicot stem and all roots) is called **pith** or **medulla**.
- **Pith** is **mostly parenchymatous and stores water & food materials**.
- Parenchymatous or sclerenchymatous tissue present between the xylem and phloem of all roots is called **conjunctive tissue**.
- Parenchymatous extensions of pith in dicots stem in between the vascular bundles are called **medullary rays**.
- Medullary rays **help in radial conduction of water and food materials**.
- Parenchyma of primary medullary ray produces the interfascicular cambium strip. This strip joins with intrafascicular cambium to form a vascular cambial ring.

Vascular tissue system

- Central column of axis (root and stem) is **called stele** which is made up of **number of vascular bundles**, **which constitute vascular** (or **fascicular**) **tissue system**.
- Each vascular bundle **comprises of xylem and phloem and cambium (if present)**.
- **Phloem elements are formed earlier** than the xylem elements.
- Primary phloem shows **centripetal growth**.
- Primary xylem **shows 3 types of growth**–
  - **centripetal differentiation** – protoxylem towards outside is called **exarch**.
  - **centrifugal differentiation** – protoxylem facing the centre is called **endarch**.
  - **centripetal as well as centrifugal differentiation** – protoxylem surrounded by metaxylem is called **mesarch**.
- Depending upon the number of protoxylem group, **root can be differentiated** as **monarch** (single protoxylem group), **diarch**, **triarch**, **tetrarch**, **pentarch**, **hexarch**, **polyarch** (more than 6 protoxylem group).
- The dicot root show **mono to hexarch condition** whereas monocot root are **hexarch to polyarch**.
- **Exarch xylem** is seen in all roots, **mesarch** in rachis and leaflets of *Cycas* and **endarch** in stems of angiosperms and gymnosperms.
- Usually **procambium towards outside differentiates into phloem** and the **procambium present inside differentiates into xylem**.
- Undifferentiated procambium present between primary phloem and primary xylem is called **intrafascicular cambium** or **fascicular cambium**.
- A special conducting tissue present in addition to primary phloem and primary xylem in the leaves of gymnosperms (*Cycas*, *Pinus*) is called **transfusion tissue**.
- **Depending on the arrangement of phloem & xylem**, **vascular bundles** are of **four kinds** - **collateral**, **bicollateral**, **concentric** and **radial (separate)**.
- **When the phloem and xylem are present side by**

side on the same radius, the vascular bundles are called **collateral vascular bundles**.

- Collateral vascular bundles are **present in stems and leaves of angiosperms and gymnosperms**.
- If **cambium is present** in a collateral bundle then it is called **open vascular bundle**.
- If **cambium is absent** between phloem and xylem then the vascular bundle is called **closed vascular bundle**.
- **Open vascular bundles** are present in the **stems of dicots and gymnosperms.**
- **Closed vascular bundles** are present in **stems of monocots (also in leaves)**.
- A vascular bundle containing phloem on either side of xylem is called **bicollateral vascular bundle**.
- Bicollateral vascular bundle consists of **outer phloem**, **outer cambium**, **xylem**, **inner cambium** and **inner phloem**, e.g. cucurbitaceae and solanaceae (stems).
- Collateral bundles of stems and bicollateral bundles show endarch xylem.
- Collateral and bicollateral vascular bundles are **conjoint vascular bundles** (vascular tissues are arranged on the same radius).
- When one type of vascular tissue is surrounded by another type, the vascular bundle is called **concentric vascular bundle**.
- Concentric vascular bundles are of **two types- amphicribal** (or **hadrocentric**) and **amphivasal** (or **leptocentric**).
- When xylem is surrounded by phloem, such concentric vascular bundles are called **amphicribal** or **hadrocentric**, eg ferns.
- When phloem is surrounded by xylem the vascular bundle is called **amphivasal** or **leptocentric**, eg *Dracaena*.
- Concentric vascular bundles are of **closed type**.
- When **xylem and phloem are arranged alternately on different radii** the vascular bundles are called **radial** and **separate vascular bundles**.
- **Radial vascular bundles** are **always closed and present in all roots**.
- Stele in which **pith is absent** is called **protostele**, e.g *Selaginella*, *Lycopodium*.
- A medullated stele having cylindrically arranged vascular tissues, is called **siphonostele**, e.g. *Marsilea* (stele with pith).
- Highly dissected stele is called **dictyostele**.
- A branch of dictyostele is called **meristele**, e.g. ferns (*Adiantum*).
- Stele with **circular arrangement of vascular bundles** is called **eustele**, e.g. dicot stem.
- Stele containing irregularly scattered vascular bundles is called **atactostele**, e.g. monocot stem.
- First plants possessing stele are **pteridophytes**.

ANATOMY OF DICOT AND MONOCOT PLANTS

Anatomy of dicot root

- Dicot root **consists of a single layer of epiblema or piliferous cells which bears unicellular root hairs**.
- **Cuticle or stomata** is **absent in root**.
- Endodermis is **made up of single layer of barrel shaped cells without intercellular spaces**.
- **Casparian strips** are present along the tangential and radial walls of endodermis.
- Endodermis is **followed by one** (sunflower) or **more** (mulberry) **layers of pericycles**. Pericycle is **absent in the roots of some aquatic plants and parasites**.
- A part of vascular cambium is formed from pericycle.
- Inner to pericycle lies **radially arranged vascular bundles** (2 - 6).
- Radial arrangement of vascular bundles is a mechanism to keep the xylem bundles in direct contact with the outer tissues of the root which conduct water absorbed by root hairs to the inside.
- Xylem is **exarch**.
- **Conjuctive tissue** is present which **later becomes meristematic to form vascular cambium**.
- Generally **pith is absent in root** or if present is very small.

Anatomy of monocot root

- **Monocot root** is similar to dicot roots in having epiblema, cortex, endodermis and vascular tissues.
- The **number of radial vascular** bundles are **more** than in dicot roots. Eg. 20-30 in maize and 100 or more in *Pandanus* and palms.
- **Xylem** is **exarch** and **polyarch**.
- The **conjuctive tissue** present in between xylem and phloem, **store food and provide mechanical strength but do not form cambium**.
- The centre of the monocot root is **occupied by large pith**.

Anatomy of dicot stem

- **Epidermis of dicot stem** is made up of compactly arranged elongated **parenchymatous cells**, having distinct cuticle, stomata and trichomes (sunflower).
- Inner to epidermis is present **3-4 layers of collenchymatous hypodermis**.
- Inner to hypodermis is **cortex**.
- In sunflower **cortex contains oil ducts**.
- **Endodermis** lies at the innermost boundary of cortex. **Casparian strips are absent** in stem.
- Inner to endodermis is present a few layers of **heterogenous pericycle** (parenchyma and sclerenchyma).
- Bundle caps are **sclerenchymatous** pericycle.
- **Eustelic type of vascular bundle** (VBs arranged in ring, also present in gymnosperms) is seen here.
- Vascular bundles are **conjoint, collateral and open**.
- Cambium **helps in secondary growth**.
- Xylem is **endarch** and **fascicular cambium** is **present**.
- **Medullary rays** are **present** in **between vascular bundles**.
- The central portion is **occupied by pith**.

Anatomy of monocot stem

- Monocot stem is characterised **by epidermis,** (2 - 3 layered) **hypodermis and undifferentiated ground tissue stem**.
- Vascular strand is **atactostele** (numerous and scattered).
- Vascular bundles are **conjoint, collateral and closed**. Phloem lies on outer side.
- Xylem is **endarch**.

Anatomy of dicot leaf (dorsiventral)

- Dicot leaf is characterised by **upper and lower epidermis**, **cuticle, mesophyll cells and vascular bundles**.
- Epidermis is generally single layered (multilayered in *Ficus*) with cuticle and stomata in only lower epidermis (in upper epidermis only in floating leaves).
- Epidermal cells may have some outgrowth called **papillae**, eg. *Gladiolus*.
- **Mesophyll** is **present in between upper and lower epidermis**.
- Mesophyll are of two types **- palisade parenchyma** and **spongy parenchyma**.
- **Palisade parenchyma** are **made up of elongated, columnar cells without intercellular spaces**, have chloroplast.
- **Spongy parenchyma made up of oval** or **spherical cells with intercellular spaces** is present below palisade parenchyma.
- **Vascular bundles** (VBs) are **scattered in spongy parenchyma** and the **vascular bundle in midrib region is largest**.
- VBs are **conjoint, collateral and closed**.
- Each vascular bundle is surrounded by a bundle **sheath of parenchymatous cells**.
- Xylem is present towards the upper epidermis and phloem towards the lower epidermis.
- Above and below the largest vascular bundle are present parenchymatous or collenchymatous mass of cells, devoid of chloroplast.

Anatomy of monocot leaf (isobilateral)

- Isobilateral leaf is somewhat similar to dorsiventral leaf having epidermis, cuticle and mesophyll cells.
- Stomata are present on both the surfaces of epidermis.
- **Bulliform cells** or motor cells are present.
- Mesophyll cells are **undifferentiated into palisade and spongy parenchyma**.
- Vascular bundles are **conjoint, collateral, closed** with **phloem towards lower side** and **xylem towards upper side**.
- Above and below larger vascular bundles are present patches of sclerenchymatous cells.

SECONDARY GROWTH

- The **formation of secondary tissue** which **leads to increase in girth** is called **secondary growth**.
- **Secondary tissues** are **formed by two types of lateral meristems - vascular cambium** (formed from conjunctive parenchyma and pericycle) and **cork cambium** or **phellogen** (formed from pericycle).
- **Vascular cambium produces secondary vascular tissues**.
- **Cork cambium or phellogen produces phellem** (cork cells) **on the outer side and phelloderm on the inner side**.
- **Phellem**, **phellogen and phelloderm together constitutes** the **periderm**.
- The **fascicular cambium and the interfascicular cambium** together constitutes the **vascular cambium**.

- The cambial ring cuts of secondary xylem towards the centre and secondary phloem towards the periphery.
- Secondary xylem consists of vessels, xylem parenchyma and few fibres and secondary phloem consists of sieve tubes, companion cells, phloem parenchyma and fibres.
- Amount of s**econdary xylem** is **more than secondary phloem** and so **stem increases in girth**.
- Cambial cells are of **two types** – **fusiform initials** and **ray initials**.
- Fusiform initials **give rise to vessels and tracheids**.
- Ray initials **give rise to rays in secondary tissue**.
- The wood formed in a single year is called **annual ring**.
- **Spring wood** is the secondary xylem **formed during spring when the cambial activity is more**.
- Wood elements are **larger in size and have wider lumen**.
- **Autumn wood (or late wood)** is the wood element formed during **winter when cambial activity is less**.
- Wood formed is lesser in amount and have narrow lumen.
- The age of tree can be determined by counting annual rings, the process is known as **dendrochronology**.
- In perennial woody trees, the **central portion is dark, hard** and **tough due to deposition of resins, tannins, gums and formation of tyloses**.
- This region **consists of dead elements and do not conduct water but provides mechanical support.**
- This central region is called **heartwood** (duramen).
- The outer or peripheral portion is soft and lighter in colour consisting of living cells.
- It is called **sap wood** (**alburnum**) and **helps in conduction of water and minerals**.
- **Wood of gymnosperm** is called **non-porous or soft wood** (absence of vessels and fibres) and that of **dicots is called porous or hard wood**.
- Porous wood may be **ring porous** (large size vessel in early wood) or **diffuse porous** (vessels throughout).
- **Tyloses** are balloon like structures, produced due to ingrowth of xylem parenchyma into the lumen of xylem vessels through pits.
- **Bark** is all the **tissues outside vascular cambium**.
- All the dead cells outside the innermost layer of cork cambium constitute **rhytidome**.
- There are certain loosely arranged areas in the periderm formed due to rapid activity of phellogen, called **lenticels**.
- Lenticels **help in gaseous exchange and transpiration**.
- In dicot root, **vascular cambium is completely secondary in origin**.
- Secondary growth takes place by extra stellar cambium which cuts phellem and phelloderm as in stems.
- **Abnormal type of secondary growth** or **increase in thickness are found in some arborescent monocots** like *Dracaena*, *Yucca*, *Agave*, etc.

End of the Chapter

Chapter 31

Animal Tissue

- **Tissue** means similar cells having common origin and functions.
- Cells of a tissue are often held together by cell junctions.
- The word tissue was used by **Bichat** (1972) and histology by **Mayer** (1819).
- The study of microscopic structures of tissues and organs are called **histology**.
- **Marcello Malpighii** is regarded as **father of animal histology**.
- The formation of tissues from germinal layers is called **histogenesis**.

Table : Types of animal tissues according to their origin and functions.

Type	Origin	Function
Epithelial tissue	Ectoderm (skin epidermis); endoderm (gut epithelium); mesoderm (coelomic epithelium)	Protection, secretion, absorption, excretion, reproduction
Connective tissue	Mesoderm	Attachment, support, storage, protection & transport
Muscular tissue	Mesoderm	Movement of body parts & locomotion and support
Nervous tissue	Ectoderm	Control and coordination by nerve impulse.

EPITHELIAL TISSUE

- **Epithelial tissue** (the first tissue to be formed) is arranged in single or multilayered sheets and **covers the internal and external surface of the body of an organism**.
- The cells in epithelial tissues are very closely packed together and joined with little space between them.
- **Origin of epithelial tissue** is **ectoderm** (skin epidermis), **endodermis** (gut epithelium), and **mesoderm** (coelomic epithelium).
- Epithelial tissue helps in **protection, secretion, absorption**, **excretion**, **transcellular transport**, **sensation detection**, **selective permeablity** and **reproduction**.
- The term **'epithelium'** was coined by **"Ruysch".**
- Epithelium is **subjected to wear, tear and injury**, its cells divides and produce new cells to replace those that are destroyed.
- Epithelium is **polarized** *i.e.,* it has a free surface (the apical surface) exposed to outside and **an attached surface** (the basal surface) resting on the underlying connective tissue.
- **Depending on the nature**, epithelial tissue can be classified as – (i) **covering and lining epithelium or true epithelium**, and (ii) **glandular epithelium**.
- **True epithelium** can be classified into **simple** and **compound epithelium**.

True epithelium
- **Simple** (one cell thick)
  - Squamous
  - Cuboidal (cubical)
  - Columnar
  - Ciliated
  - Pseudostratified
- **Compound** (more than one cell thick)
  - Stratified
  - Transitional

- Common structures present in epithelial membrane are **intercellular junctions** (which provide structural integrity of the epithelium), **basement membrane** and **structures on the free surfaces of cells** like microvilli, stereocilia, cilia, flagella and endocytic, exocytic and pinocytic vesicles.
- The bottom layer cells rest on a **basement membrane.**
- **Basement membrane** is composed of a network of fibres which include **collagen** (in a **matrix**) and **proteoglycans** and **serves a selective filter** determining which molecule diffuse from the undergoing connective tissue**.**
- **Glandular epithelium** are invaginated epithelia into the connective tissue which differentiate into secretory units. It can be classified on the basis of their features.

Glandular epithelium
Division according to
- **Presence or absence of ducts**
  - Exocrine (With ducts)
  - Endocrine (Without ducts)
- **Mode of secretion**
  - Holocrine
  - Apocrine
  - Merocrine
- **Number of cells**
  - Unicellular (One celled)
  - Multicellular (Many celled)
    - Depending on the shape of secretory units
      - **Tubular**
        - Simple
        - Simple branched
        - Simple compound
      - **Alveolar (saccular)**
        - Simple
        - Simple branched
        - Simple compound
      - **Tubulo-alveolar**
- **Nature of secretion**
  - Serous
  - Mixed

- Epithelium lining the lumen of blood vessels is called **endothelium** and lining the body cavity **mesothelium.**
- Epithelial cells are **not supplied with blood vessels.**
- **Nerve ending** may occur in epithelium.
- Cilia are fine fibres having **9+2 internal structure**. They are also known as **kinocilia**. They are motile, occur in cells of respiratory and reproductive tract.
- **Stereocilia** are non-motile and cylindrical. They are **found in epididymis, vas deferens and organ of corti**.
- **Cilia** is associated with flow of materials in a particular direction, **stereocilia** (long microvilli) is associated with the movement of sperms and **microvilli** increase the absorptive area where they are present.
- In **simple epithelium**, cells are single layered, thin and flattened and all have direct contact with basement membrane.
- **Squamous epithelium** is also called **pavement epithelium** because the cells look like tiles of floor. It occurs in renal capsules of kidney, alveoli of lungs, wall of blood capillary and heart, lining of eye etc.
- The one cell of simple squamous epithelium is a minimal barrier to diffusion.
- **Cuboidal epithelium** is the least specialized of all epithelia having roughly cube-shaped cells with centrally placed nucleus. It is often with microvilli hence, called **brush bordered cuboidal epithelium.**
- Cuboidal epithelium is found in **surface of ovary, kidney tubules etc.**
- **Cells of columnar epithelium** are tall and quite narrow, thus providing more cytoplasm per unit area of epithelium.
- **Nucleus is present at the basal end** in columnar epithelium**.**
- Columnar epithelium is **ciliated in bronchioles and fallopian tube**.
- Columnar epithelium is **secretary in nature** in gastric glands of stomach, intestinal glands, pancreatic lobules and gall bladder.
- **Sensory epithelium** (modified columnar cells) bear sensory hairs on their free surface and are connected with nerve fibres. These are **found in retina, nasal cavity** (Schneiderian membrane) and **tongue** (gustatory cells), brain etc.
- In **pseudostratified epithelium**, a single layer of cells is present but they are all at different levels thus appearing **multilayered.**
- Pseudostratified epithelium is found **lining the urinary tract** and the **respiratory passages** (trachea, bronchi, bronchioles).
- **Compound (stratified) epithelium** is made of more than one layer (multilayered) of cells.
- Stratified epithelium is **thicker than simple epithelium** and forms a relatively tough impervious barrier.

Table : Summary chart of epithelial tissues.

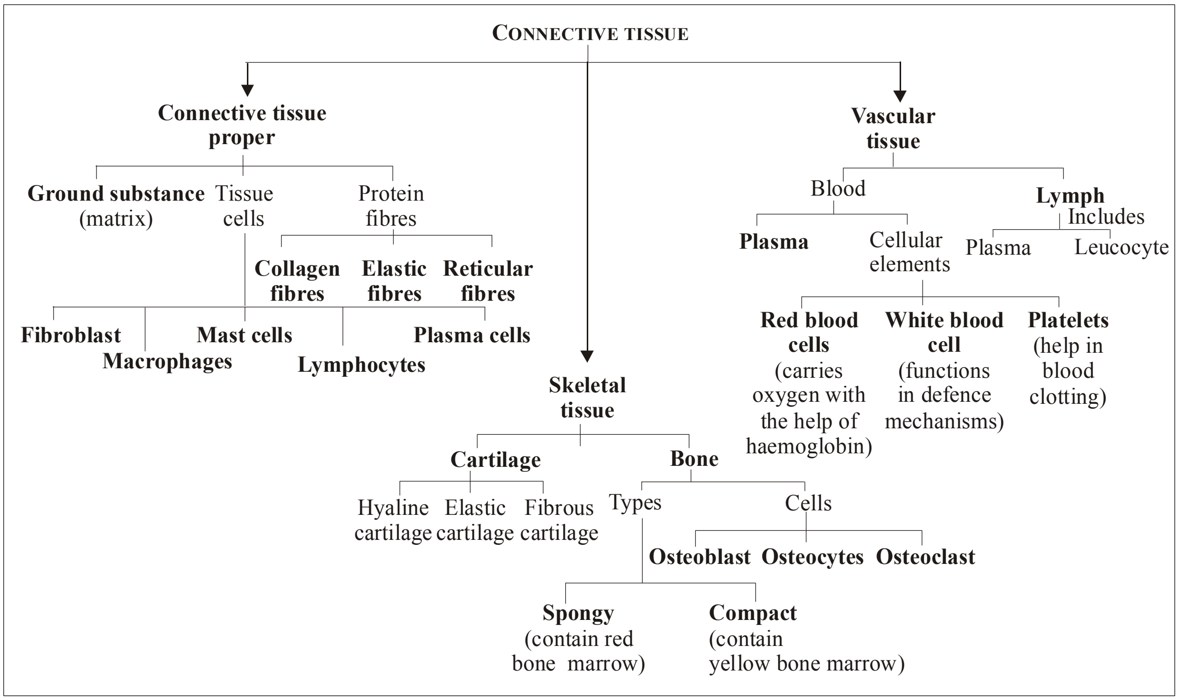
Structure	Location	Function
Simple Squamous Single layer of flat scale-like cells, large centrally located nucleus.	Alveoli, Bowman's capsule, blood vessel (endothelium) heart, visceral and peritoneal lining of coelom (mesothelium)	Filtration, absorption and secretion
Simple Cuboidal Single layer of cube-shaped cells, centrally located nucleus	Surface of ovary, inner surface of cornea and lens of eye, kidney tubules, salivary and pancreatic ducts and thyroid vesicles	Secretion and absorption
Simple Columnar (Nonciliated) Single layer of non-ciliated rectangular cells, contains goblet cells, nuclei at bases of cells	Lines stomach, small and large intestine, digestive glands and gallbladder	Secretion and absorption
Simple Columnar (Ciliated) Single layer of ciliated rectangular cells, contain goblet cells, nuclei at bases of cells	Oviduct, fallopian tube, neurocoel of CNS, few portions of upper respiratory tract	Movement of gametes, cerebrospinal fluid and mucus by ciliary action
Stratified Squamous Several layers of cells, deep layers are cuboidal to columnar, surface layers flat and scale-like	**Nonkeratinizing** Mouth, oesophagus, part of epiglottis and vagina **Keratinizing** Dry surface of skin	Protection
Stratified Cuboidal Two or more layers of cube-shaped cells	Duct of adult sweat gland	Protection
Stratified Columnar Several layers of polyhedral cells, only superficial layer is columnar	Male urethra (only part)	Protection and secretion
Transitional Resembles stratified squamous non-keratinizing tissue, except superficial cells are larger and more rounded	Urinary bladder and ureters	Permits distention
Pseudostratified Basically it is single layered, but few basal cells are present, smaller in size and do not reach upto free surface.	Trachea, bronchi, olfactory epithelium, eustachian tube	Secretion and movement of mucus by ciliary action

- The first formed cells are cuboid in shape, but as they pushed outwards towards the free surface of the tissue, they become flattened. In this condition the cells are called **squamous.**
- **Stratified squamous epithelium** may be **keratinized** (epithelium of skin, hard palate, gingiva) and **non-keratinized** (buccal cavity, pharynx, oesophagous etc).
- **Keratinized epithelium** contains **keratin** a highly insoluble fibrous protein with water proofing qualities and is also **resistance to friction and bacterial invasion**.

- **Non-keratinized epithelium** is found on wet surface that are **subjected to considerable wear and tear and do not perform the function of absorption**.
- **Transitional epithelium** is often **regarded as a modified type of stratified epithelium**.
- **No basement membrane** is present in transitional epithelium as it would impede stretchabilitiy.
- Transitional epithelium **lines the inner surface of renal calyces, urinary bladder, ureter**. Because of its distribution, it is also called **urothelium.**
- Since the cells in transitional epithelium, can slide over each other, the appearence of this epithelium depends on whether the organ is distended or contracted, if distended it appears as if there are only a few layers and when contracted, it appears as if there are several layers.
- **Endocrine glands (ductless)** manufactures hormones and secretes them directly into the bloodstream to act at distant sites in the body (known as **target organs** or **cells**), e.g., pituitary, thyroid etc.
- **Exocrine glands** pour their secretion through ducts at the site of action, e.g., salivary gland, gastric gland etc.
- **Goblet cell**, found in the lining of respiratory tract and alimemtary canal, secrete mucous and is the **example of unicellular gland.**
- Sweat glands, intestinal glands, crypts of Liberkuhn are **simple tubular gland.** The gland is elongated and tube like.
- Gastric glands, Brunner's glands, Bartholin's glands are **simple branched tubular.** It has simple duct with branched tubes.
- Bulbourethral gland and liver are **compound tubular**. Duct is branched aggregation of tubules.
- Mucous and poison gland in amphibian skin are **simple (acinar) alveolar.** This gland has single flask shaped duct with sac.
- Sebaceous, meibomian glands are **simple branched alveolar.** Duct branched but with many sac (flasked shaped).
- **Salivary glands like submandibular and sublingual glands** are **compound alveolar glands** whose secretory portion is flask shaped.
- Mammary glands, pancreas, lacrimal gland are **compound tubulo-alveolar**.In them tube ends in a sac like dilation.
- In **apocrine glands** apical portion (where secretory products accumulates) of cell goes with secretion, example - mammary glands.
- In **holocrine glands** secretory cell comes out with the secretion, example - sebaceous glands. Sometimes holocrine glands are described as those endocrine glands which secrete only hormones. Example - Thyroid, PTH, adrenals, etc.
- In **merocrine glands** only secretion is secreted without any loss of cells or their parts. Example - most of the glands such as salivary glands, sweat glands etc.

CONNECTIVE TISSUE

- **Connective tissue** is the **major supporting tissue** of the body.
- About **30% of body mass** is formed of connective tissue.
- Connective tissue fulfils many functions other than **packing** and **binding** other structures together, such as
  - providing **protection** against wounding or bacterial invasion (areolar tissue),
  - **insulation of the body** against heat loss (adipose tissue),
  - providing a **supportive frame work** for the body (cartilage and bone) which plays an important role in locomotion, and keeps all the organs avoiding **ptosis** (prolapse of an organ or part); and
  - **producing blood cells**.
- Connective tissue is divided into **three categories- connective tissue proper** (including matrix, cells and protein fibres), **skeletal tissue** (containing cartilage and bone) which plays an important role in locomotion and **vascular tissue** (including blood and lymph).
- **Connective tissue proper** is a **composite material** made up of a variety of cells. It contains several **types of fibre** which are **non-living products of the cells** and a fluid or semifluid background material or **matrix** in between the cells.
- The **cells of connective tissue are living** and responsible for secreting the large amounts of intercellular ground substance (matrix).
- **Ground substance** or **matrix** occupies the space between the cells and fibres of connective tissues.
- Matrix consists of mainly water and sulfated **mucopolysaccharide**.



- The matrix is a **non living material** which may be **liquid** (e.g. blood), **semisolid** (e.g. connective tissue) or **solid** (e.g. bone).
- **Types of connective tissue cells** are -
  - **fibroblasts** secreting fibres and some matrix.
  - **macrophages** (histiocyte) which are modified monocytes cells and having the capacity to phagocytose.
  - **mast cells** storing histamine (vasodilator), serotonin (vasoconstrictor) and heparin (anticoagulant).
  - **lymphocytes** which are migrating cells and transport antibodies.
  - **plasma cell** producing antibodies.
- Connective tissue is composed of several protein fibres such as **collagen fibres** (having protein **collagen**), **elastic fibres** (having protein **elastin**) and **reticular fibres** (having protein **reticulin**).
- **Collagen** is the **most abundant protein** in the human body.
- **Disease caused by abnormal collagen structure** are –
  - **Marfan's syndrome** (causing abnormal fibrillin and results in abnormally long and distensible extremities etc.);
  - **Scurvy** (due to vitamin C deficiency as vitamin C is required for collagen cross linking), and
  - **Ehlers Danlos syndrome** (causing progressive deterioration of collagen).
- **Elastic fibres** are **prominent** in parts of the body that expand and contract regularly like blood vessel walls.
- **On the basis of cells and fibres present** connective tissue proper is further divided into – **areolar tissue, adipose tissue, dense connective tissue** (fibrous and elastic), **reticular connective tissue**, **mucous and pigmented connective tissue**.
- **Loose or areolar connective tissue** has abundant matrix, thin and sparse fibres and almost all cell types.
- Found beneath the epithelia, hollow visceral organs and on the walls of arteries and veins, areolar tissue **helps in packing, protecting, nourishing** etc. It is also important in inflammation.
- **Adipose tissue** contain **adipocytes**, used for **cushioning, insulation, lubrication** (primarily in the pericardium) and **energy storage**.
- Adipose tissue are **found beneath the skin in mesentries, bone marrow, kidney, liver** etc.
- **White fat** and **brown fat** are two **types of adipose tissue**.

- White fat contains **primarily unilocular adipocytes** (one large fat vacuole) and brown fat contains **multilocular adipocytes** (many small fat vacuoles).
- **Brown fat** (whose brown colour is due to iron containing cytochrome pigments in fats) is **found in hibernating animals** such as rats and also in **new born babies**.
- Adipose tissue is a **poor conductor of heat**, it reduces heat loss through skin.
- **Prominent adipose tissue sites** are – subcutaneous fat (**panniculus adiposes**), **blubber** of whales, **humps** of camel.
- In **white fibrous tissue**, collagen is dominant and cells are mainly **fibroblasts**. It makes the joints immovable.
- Fibroblast **facilitate wound healing** by filling the gaps in the tissue by proliferating and migrating towards the wound. Fibroblasts **form the scar that closes the wound**.
- White fibrous tissue is **found in skull bones** and **dermis of higher mammals**.
- A **tendon,** which connects skeletal muscle to a bone is a **modification of white fibrous tissue**. It is being tough and inelastic.
- **Yellow elastic tissue** is mainly composed of **elastic fibres**. They are mostly **present** in **ligaments, wall of blood vessels**, **bronchioles and lung**.
- **Ligaments** attach one bone to another. They contain both collagen and the protein elastin (which permits ligaments to be stretched).
- **Reticular connective tissue** is a network of reticular fibres (fine collagen with a rich coat of glycoproteins) that form a soft skeleton to support the lymphoid organs (lymph nodes, bone marrow and spleen).
- **Mucous connective tissue** is composed of a gelatinous substance (called **Wharton's jelly**), few fibroblasts and collagen.
- It is **found in vitreous humor** and **umbilical cord**.
- **Cartilage** and **bone are specialized connective skeletal tissues** that provide the body with mechanical support and protection.
- Cartilage is usually **found in close association with bone** in the body.
- Cartilage is composed of cells called **chondrocytes** which are dispersed in a firm gel like ground substance called **matrix**.
- **Chondrocytes lie in a cavity** called a **lacuna**.
- Cartilage is **avascular** (contains no blood vessels) and nutrients are diffused through the matrix.
- The matrix of cartilage consists mainly of glycoprotein material, **chondroitin sulfate** and keratan sulfate.
- Cartilage is **found** in the joints, ribcage, the ear, the nose, in the throat and between intervertebral discs.
- The cartilage in the ear and nose **do begin to grow with age as the production of sex hormones lowers.**
- The margin of a piece of cartilage is enclosed by a dense layer of cells and fibrils known as **perichondrium**.
- There are **three main types of cartilage** – hyaline, elastic and fibrocartilage.
- **Hyaline** (means glassy or shiny) **cartilage** is an elastic, compressible tissue located at the ends of bones, on nose, bronchi, larynx etc.
- Inside the bone, hyaline cartilage **serving as a centre of ossification or bone growth.**
- **C shaped rings** of hyaline cartilage keep open the air passages of the respiratory system (trachea, bronchi and larger bronchioles).
- Hyaline cartilage also forms the skeleton of **cartilaginous fish** (e.g. shark) and forms the embryonic skeleton in bony vertebrates.
- **Calcified cartilage** is **formed by the calcification of hyaline cartilage**. It is **found in suprascapula and pubis in frog**.
- **Yellow elastic cartilage** is found in external ear and epiglottis.
- Elastic cartilage **helps to maintain the shape and flexibility of the organ** and also strengthens and supports these structures.
- **Fibrous (also called white cartilage) cartilage** is the **strongest cartilage** due to **presence of collagen fibres.**
- It occurs in the **pubic symphysis** of man and **intervertebral disc**.
- Fibrocartilage **lacks a perichondrium**.
- The **matrix of cartilage** acts as a barrier, preventing the entry of lymphocytes or diffusion of immunoglobulins. This property allows for the transplantation of cartilage from one individual to another without fear of tissue rejection.

- Cartilage cells can **give rise to benign** (chondroma) or **malignant** (chondrosarcoma) **tumors**.
- **Bone**, also called **osseous tissue**, is a type of hard endoskeletal connective tissue found in many vertebrate animals.
- Bone **supports** body structures, **protect** internal organs, and (in conjuction with muscles) **facilitate** movement; and are also **involved with cell formation**, **calcium metabolism** and **mineral storage.**
- **Osteoblasts form bones** and its formation is called **osteogenesis**.
- About 30% of **bone matrix** is **composed of organic material (ossein protein)**, whilst 70% is **inorganic bone salts** [such as hydroxyapatite, $Ca_{10}(PO_4)_6(OH)_2$, a form of calcium phosphate]. Sodium, magnesium, potassium, chloride, fluoride, hydrogen carbonate and citrate ions are also present.
- **Bone resorption** and **reconstruction** processes enable a particular bone to adapt its structure to meet any change in the mechanical requirement of the animal during its development.
- **Calcium and phosphate may be released into the blood** as needed, **under the control of two hormones parathormone** and **calcitonin**.
- Bone is surrounded by a sheath of collagen fibres, **periosteum** which is richly supplied with blood vessel, whereas the bone marrow cavity is surrounded by **endosteum**.
- A compact mammalian bone has several concentric lamellae through which blood vessels, lymphatics and nerves pass, this is called **haversian canal**.
- Main function of haversian canal is **transportation of nutrients** and **oxygen through blood**.
- Haversial canals run parallel to the marrow cavity and contain all the structures similar to marrow cavity except the lymph vessels which are absent.
- In the solid matrix of bone, flat irregular space, **lacunae** are present in which a single **osteocytes (inactive bone cells)** is present.
- Radiating from each lacuna are many fine channels called **canaliculi** containing cytoplasm which may link up with the central Haversian canal with other lacunae or pass from one lamelle to other.
- Bone cells are of three kinds - **osteoblasts** (bone forming cells), **osteocytes** (bone maintaining cells) and **osteoclasts** (bone cleaning cells).
- **Osteoblasts** are located near to the surface of bone and their functions are to make osteoid and manufacture hormones such as prostaglandin which act on bone itself.
- Osteoblasts **secrete bone extracellular matrix**.
- When an osteoblast is completely surrounded by matrix, it is called **osteocyte**.
- Osteocytes **respond to parathormone to help regulate blood calcium and can secrete new bone extracellular matrix**.
- **Osteoclasts** are syncytial cells and formed by the fusion of monocytes and **destroy bone matrix**.
- Osteoclasts release lysosomes, organic acids and hydrolytic enzymes to break down bone matrix.
- Osteoclast respond to parathormone and calcitonin to help regulate serum calcium levels.
- Bone marrow cavity is filled with a soft and sinusoidal fatty neurovascular tissue, called **bone marrow**.
- Bone marrow will **indicate blood related diseases like leukemia**.
- Bone marrow contains **two types of stem cells – haemopoietic** (which can produce blood cells) and **stromal** (which can produce fat, cartilage and bone).
- **Haematopoietic stem cells** give rise to the three classes of blood cell that are found in the circulation - leucocyte, red blood cells (erythrocytes) and platelets (thrombocytes).
- The tissue of bone marrow where pluripotential haemopoietic stem cells form is called **myeloid tissue**.
- **Stromal stem cells** have the capability to differentiate into many kinds of tissues, such as nervous tissue.
- Bone marrow has **haematogenic** and **osteogenic** potentials.
- **Bone marrow** are of **two types - red bone marrow** and **yellow bone marrow.**
- **Red bone marrow** are **active vascular tissue in the long bone** and **produces red blood cells**.
- **During foetal life and at birth** red bone marrow **occurs throughout the skeleton**.
- **Yellow bone marrow** are **inactive vascular tissue in** the long bones.
- Yellow colour is **due to predominance of adipocytes.**
- At birth**, all bone marrow cavities are** haematopoiesis**. As the individual ages, the loci of haematopoiesis shift.**

- **Spongy bone** (also known as **cancellous bone**) carries no haversian system and consists of a meshwork of thin, interconnecting bony struts called **trabeculae**.
- The space in between the trabeculae contain **red bone marrow**.
- Spongy bone **occurs in the embryo, growing organisms,** and **the swollen ends of long bones**.
- The matrix of spongy bone **contains a rather smaller proportion of inorganic material** than does the matrix of compact bone.
- **Compact bone** form shaft (diaphysis) of long bones and consists of yellow bone marrow.
- **Foetal sites of haematopoiesis** are blood islands (group of mesenchymal cells in the yolk sac)**,** liver, spleen and bone marrow**.**
- **Dried bone** is a **bone without living cells**. Dried bone possesses matrix, lacunae, canaliculi, marrow cavity etc.
- **Cartilage bone** is formed by ossification of cartilage. It is **also known as replacing bones**.
- **Investing bone** is formed by transformation of connective tissue. It is also known as **membrane bone**.
- **Visceral bone** (heterotypic bone) is a bone separated from the remaining skeleton, *e.g.* **os cordis** (interventricular septum of heart in deer), **os penis** (penis in rodents, bats etc), **os palpebrae** (eye lids of crocodile) etc.
- **Sesamoid bone** is a bone formed within a tendon near a joint.
- **Dibolic bone** is bone with compact surfaces and cancellous middle, *e.g.* skull bone, vertebrae.
- Bone can also be either **woven** or **lamellar**.
- **Woven bone** is put down rapidly during growth or repair. It is so called because its fibres are aligned at random and as a result has low strength.
- **Lamellar bone** has parallel fibres and is much stronger.
- Woven bone is **often replaced by lamellar bone as growth continues**.
- **Blood** (derived from mesoderm) is a **highly specialised fluid connective tissue** constituting approximately 8% of the body weight or 5.6 1ts in a 70 kg man.
- Blood consists of the **plasma**, a pale yellow liquid containing the microscopically visible formed elements of the blood: the **erythrocytes**, (or red blood corpuscles); the **leucocytes**, (or white blood corpuscles); and the **platelets**, (or thrombocytes).
- **Plasma** is the relatively clear liquid protein, slightly alkaline (pH–7.4) and salt solution which carries the red cells, white cells, and platelets.
- **Red cells** (or **erythrocytes**) are relatively large **microscopic cells without nuclei**. In this latter trait, they are similar to the primitive prokaryotic cells of bacteria.
- **Haemoglobin** is the gas transporting protein molecule that makes up 95% of a red cell.
- In mammals (except camel and Llama), red blood cells are non-nucleated biconcave and circular. The total count of RBC (number of erythrocytes per microlitre of 1 mm^3 of blood) is 5 millions and 4.5 million in adult man and woman respectively.
- The **mature RBC lacks all organelles** and almost entire volume of the cell is filled with haemoglobin.
- **White blood cells** (also called **leucocytes or immune cells**) help to defend the body against infectious disease and foreign materials as part of the immune system.
- There are **two major types of white blood cells**: **granulocytes** and **agranulocyte**.
- **Granulocytes** are characterised by the fact that all types have differently staining granules in their cytoplasm on light microscopy. There are **three types of granulocytes**: **neutrophils**, **basophils**, and **eosinophils** (named according to their staining properties).
- **Agranulocytes** are not found in the cytoplasm. They are **formed in spleen and lymph nodes**. They are of **two types- lymphocyte** and **monocytes**.
- **Platelets** are non-nucleated round or oval biconvex disc like bodies. They bud off from the cytoplasm of very large megakaryocyte cells of bone marrow.
- Blood platelets **help in coagulation of blood** by producing platelet factors (such as **thromboplastin**).

  [*Note : For more on blood refer chapter Body fluids and circulation*.]

MUSCULAR TISSUE

- **Muscle** is a **contractile tissue that both generates and transmits force**.
- Muscular tissue is **responsible for the movement of the body** and for the **movement of its various parts with respect to one another**.

- It is made up of **long**, **excitable cells or muscle fibres containing sarcomeres** (composed of actin and myosin), and **devoid of matrix**.
- **Myoblast** (spindle shaped muscle precursor cells) give rise to muscle fibre and each fibre consists of fine fibrils present in the cytoplasm (known as **sarcoplasm**).
- Muscular tissue carries out **mechanical work** by contracting, which involves a **shortening and thickening of its fibres.**
- Two proteins, **actin and myosin are part of the machinery** and **ATP** is the **immediate energy source for the contraction**.
- Muscular tissue is **derived from the mesodermal layer** of embryonic germ cells.
- These are **arranged in a parallel pattern** within the cytoplasm of muscle cell.
- The membrane of a single muscle fibre is known as **sarcolemma.**
- Each muscle fibre contains proteinaceous fibrils, known as **myofibrils** which can be **seen by both light and electron microscopy**.
- Connective tissue over a single muscle fibre is known as **endomysium**.
- **Perimysium** is a fibrous sheat that surrounds and protects bundles of muscle fibres (called **fasicles**).
- Several such bundles are again covered by connective tissue to form a muscle block. This outermost cover is called **epimysium.**
- Epimysium is **continuous with tendons**.
- The muscle fibres are composed mainly of **proteins**. About **20%** of the chemical constituents of this tissue is **protein**, **75%** is **water** and remaining **5%** is composed of **inorganic material, carbohydrates** etc.
- **Muscle proteins** are **characterized by their elasticity,** which confers contractile power on this tissue.
- The contractile elements are the minute thread like **myofilaments** within the fibre.
- Myofilaments can again be categorised into **thick and thin filament.**
- **Thin myofilaments** consist of **three types of proteins - actin, tropomyosin** and **troponin.**
- **Myosin** is the most **abundant muscle protein of thick myofilament** which is globulin in nature.
- **Vladimir Englehardt** and **Militsa Lyubimova** discovered in 1939, that **myosin is an ATPase.**
- Myosin is a very large molecule of molecular weight 500,000.
- **Actin molecules** are filamentous proteins, consisting of two strings of globular units (G protein) wound round one another to form a rope like structure (F actin).
- **Tropomyosin** is a two-stranded a - helical rod which is located in the groove between the two helical strands of actin and blocks the interaction of myosin head with the actin filament.
- **Troponin** is a complex of 3 polypeptide chains designated as **TPC** (calcium binding subunit), **TPI** (inhibitory subunit) and **TPT** (tropomyosin binding subunit).
- **Myosin and actin** are the **force generating/ transmitting proteins**.
- Tropomyosin and troponin **regulate the interaction of actin and myosin**.
- **Calcium ions triggers** the **interaction of actin and myosin**.
- A **troponin complex** is attached to the tropomyosin at intervals of about 385 Å.
- **Ca^{2+}, Mg^{2+} and ATP** are **required internally for muscle contraction**. ATP and Ca^{++} are **required to form actomyosin complex** and magnesium ion along with enzyme myosin ATPase and Ca^{++} is **responsible for the breaking of ATP into ADP, phosphorous and energy**.
- When Na^+ in excess of K^+ enters into the muscle, muscle contraction starts.
- On the basis of **structure, location and function, muscular tissue** is divided into **striated skeletal muscle, smooth muscle** and **cardiac muscle**.
- **Skeletal and cardiac muscles** are known as **striated muscles** because their cells have transverse stripes and the muscles of the internal organs in the wall of the bladder, intestine, blood vessels, uterus and so on are **unstriated** (also called **smooth muscle**).
- **Striated muscle fibres** are present in the body by attaching to bones by tendons. They are therefore called as **skeletal muscles**.
- Skeletal muscle work according to our will, hence are **voluntary in nature.**
- The voluntary muscle fibres are **long** and **cylindrical** and **multinucleated cells** upto 40 mm in length.

- Their **nuclei are located towards the periphery of the fibre** and vacates the central part of the muscle fibres for myofibrils.
- Each myofibril of this muscle fibre **has alternate light or isotropic (I band) and a dark or anisotropic (A band).**
- A thin **Z membrane or Krause membrane** is present in between the light band and a **H-disc or Hensen's disc** is present in between the dark (or A) band.
- The portion in between two Z membrane is a **sarcomere**.
- Sarcomere is the **fundamental structural unit of muscle fibre or myofibril.**
- **In the sarcomere –**
  - I band has only thin actin filaments (secondary filament).
  - A band has both actin and tropomyosin and troponin protein filaments.
  - H band has only myosin filaments (primary filament).
  - Actin filaments are attached on both sides of Z line.
- These muscle fibres are **richly supplied with blood vessel (highly vascular), nerves and connective tissues.**
- They have a **network of sarcoplasmic reticulum and a large number of mitochondria.**
- The neurons which innervate striated muscles come from the somatic or voluntary branch of the nervous system.
- Striated muscle fibre is **found in arms, hands, leg, feet, body wall, tongue and upper part of pharynx.**
- There are **two types of fibres** for skeletal muscles **- type I (red, slow twitch)** and **type II (fast twitch and white).**
- **Type I muscle cells** shorten at a relatively slow speed and generate energy from both fats and carbohydrates *via* aerobic metabolism as they have high concentration of mitochondria, increased intracellular myoglobin to store and transport O_2, low concentration of glycolytic enzymes used for anaerobic metabolism.
- **Type II muscle cells** are less efficient and are almost entirely dependent on glycogen as fuel as they have low concentration of mitochondria, high concentration of ATP and glycolytic (ATPase) enzymes and a rate of shortening 3 to 5 times that of a type I muscle cell.

Muscle regeneration

Skeletal muscle is a terminally differentiated tissue. It is no longer capable of undergoing mitosis. When muscle fibres are damaged (cut or crushed) they can be repaired by small cells **(satellite cells)**, little more than nuclei and thin rim of cytoplasm. They differ from myoblasts. Damage initiates a reaction in which these cells are activated and fuse with existing fibres to repair the damaged sarcolemma. There appears to be a finite number of times that these cells can effect this kind of repair. After that the muscle can no longer repair but becomes invaded by scar tissue. This is particularly relevant in muscular dystrophy.

- The **strength of skeletal muscle is directly proportional to its cross sectional area.**
- Skeletal muscle cells are **stimulated by acetylcholine** which is released at neuromuscular junctions by motor neurons.
- **Smooth muscle** is the **earliest form of muscle to evolve.**
- Smooth muscle, a type of non striated muscle, is also known as **visceral muscle** as it covers any visceral organs.
- Smooth muscle tissue is organized into **sheets of long, spindle shaped cells**, each cell containing a single nucleus.
- The cells are **50 mm in length** and **6 mm in diameter**.
- Sarcolemma is not always present, however, the cell has only a thin membrane covering.
- A smooth muscle fibre is **shorter than the striated muscle fibre.**
- In smooth muscles **mitochondria are less in number** and sarcoplasmic reticulum is less expensive.
- **Functionally smooth muscle fibres are of two types-** single unit smooth muscle **(found in gastrointestinal tract and urinary bladder)** and multiunit smooth muscle **(found in hair roots and walls of large vessel).**
- Smooth muscle fibres are **involuntary in nature.**
- The **most striking feature of smooth muscle** is **the lack of visible cross striations** but the

Table : Distribution and functions of muscular tissues in human body.

	Functions	Distribution (location)	Muscle Type
1.	Hair movements, squeezing oil from oil glands	Dermis of skin, between hair follicle and basement membrane of epidermis	Smooth
2.	Digestion	Lips, jaw muscles, tongue, pharynx. Walls of oesophagus, stomach, intestines and villi Internal anal sphincter External anal sphincter	Striated Smooth Smooth Striated
3.	Breathing (ventilation)	Diaphragm, intercostal muscles	Striated
4.	Blood circulation	Heart Walls of arteries and veins	Cardiac Smooth
5.	Excretion	Walls of renal pelvis, ureters and bladder Internal sphincter between bladder and urethra External sphincter near exit from body	Smooth Smooth Striated
6.	Maintenance and change of posture	Skeletal muscles	Striated
7.	Heat production	Skeletal muscles (exercise, shivering)	Striated
8.	Vision Eye movement	Iris, ciliary body Extrinsic eye muscles	Smooth Striated
9.	Ejaculation Parturition Scrotal sac movement	Wall of genital tract Uterine wall, cervix Abdominal muscles, diaphragm Wall of scrotal sac	Smooth Smooth Striated Smooth
10.	Movement of secretions	Walls of ducts	Smooth

contraction depends on the same proteins as in striated muscles *i.e.,* actin and myosin and on a supply of energy from ATP.

- Smooth muscle cells mediated by the autonomic nervous system but can also react on stimuli from neighbouring cells and on hormones (vasodilators or vasoconstrictor) within the medium that it carries.
- **Cardiac muscles** are found **in heart only.** Its **function** is to pump blood through the circulatory system by contracting.
- Cardiac muscles are **involuntary, cross striated** (due to Z lines which occurs at regular intervals along each myofibril) and **nonfatigued fibres.**
- It is striated as actin and myosin are arranged in sarcomere.
- Cardiac muscles form the **myocardium**.
- Each cardiac muscle fibre is formed of several cells joined together.
- **Intercalated discs** are present in between two cells.
- These are the specialized regions of the cell membrane and functions as **boosters for muscle contraction waves.**
- Cardiac muscles **never get fatigued** because it rests and work for equal duration. The resting period (0.4 sec) is as long as contractive time (0.1 sec + 0.3 sec).
- Fibres of these muscles contain **large number of mitochondria** and **glycogen granules** as they require large amount of energy.
- They are **richly supplied with blood**.
- Unlike skeletal muscle which contracts in response to nerve stimulation and like smooth muscle, cardiac muscle is **myogenic,** meaning that it stimulates its own contraction without a requisite electrical impulse.
- Cardiac muscle tissue **has no regenerative capacity**. During myocardial infarction, cardiac muscle tissue dies and are replaced by fibroblast rich scar tissue.

A **unique aspect of cardiac muscle** is the number of nuclei found inside the cell. Skeletal muscle cells are multinucleated from the fusion of muscle cells and smooth muscle cells are strictly mononucleated, while cardiac muscle cells are mononucleated, binucleated and multinucleated. In the foetus and post parturition infant most cardiac muscle cells are mononucleated. Shortly after birth (within a few months) most cardiac muscles undergo a change of nucleation from mononucleated to primarily binucleated, and some go on to become multinucleated. Generally among species the cardiac muscle is 90% binucleated cells and 5% both mono and multinucleated cells, but exact numbers depend upon the species.

NERVOUS TISSUE

- **Nervous tissue** is specialised to react to stimuli and to conduct impulses to various organs in the body which bring about a response to the stimulus.
- Nervous tissue is **found in the brain, spinal cord, and nerves.**
- It is **responsible for coordinating and controlling many body activities.**
- It stimulates muscle contraction, creates an awareness of the environment, and play a major role in emotions, memory, and reasoning. To do all these things, cells in nervous tissue need to be able to communicate with each other by way of **electrical nerve impulses.**
- Normally the **electrical impulse (messages) travel through a neuron in only one direction.**
- The **cells in the nervous tissue** that generate and conduct impulse are called **neurons** or **nerve cells.**
- **Neurons** forms the **structural and functional unit of nervous tissue/system**.
- Nervous cells **originate from embryonic ectoderm**.
- Neurons **occur** within the **grey matter of the brain**, in **spinal cord** and in the **ganglia of the cranial** and **spinal nerves** and in the **autonomic nervous system.**
- Neurons are the **largest cell in the body.**
- The word **neuron was coined** by the German scientist **Heinrich Wilhelm Gottfried Von Waldeyer Hartz** in 1981. (He also coined the term chromosomes).
- Human nervous system has about **100 billion neurons**. Fully formed neurons **never divide** and remain in interphase throughout life (unless they are cancerous).
- A **nerve** is **made up of many nerve cell fibres (neurons) bound together by connective tissue**.
- The parallel bundles of nerve fibres are called **fasiculi**.
- A sheath of dense connective tissue, the **epineurium surrounds the nerve**. This sheath penetrates the nerve to form the **perineurium** which **surrounds bundles of nerve fibres**. Blood vessels of various sizes can be seen in the epineurium.
- The **endoneurium**, which consists of a thin layer of loose fibrous connective tissue, surrounds the individual nerve fibres.
- Endoneurium **contains collagen fibres, fibroblasts, Schwann cells, macrophages and fats** which cushions the nerve fibres (the **loss of fat can lead to pressure on fibres and paralysis**).
- There are **three main types of neurons,** which are **classified according their functions** : **sensory, motor** and **interneurons**.
- **Sensory (or afferent) neurons** conduct impulses from the sensory organs to the central nervous system (brain and spinal cord).
- **Motor (or efferent) neurons** conduct impulses from the central nervous system to the effector organs (such as muscles and glands). Autonomic motor or efferent neurons transmits impulses to the involuntary muscles and glands.
- **Interneurons** (also **known as connector neurons or association neurons**) are those that connect sensory neurons to motor neurons as well as different parts of the central nervous system.
- On the **basis of their structure**, neurons can also be classified into **three main types** – **unipolar**, **multipolar** and **bipolar neurons**.
- **Unipolar neurons** are sensory neurons, **have only a single process or fibre** which divides close to the cell body into two main branches (axon and dendrite).
- Unipolar neurons are **found in embryos** and **dorsal root ganglia of adult vertebrates**.
- **Multipolar neurons** are motor neurons, which have numerous cell processes (an axon and many dendrites). **Interneurons are also multipolar**. Most

neurons in the brain and spinal cord are of this type (*i.e.* multipolar neurons).

- **Bipolar neurons** are spindle shaped, with a dendrite at one end and an axon at the other. An example can be found in the light-sensitive retina of the eye, olfactory epithelium and inner ear.
- Neurons have **long processes (neurites)**, which extend from the part of the **cell body** around the nucleus, the **perikaryon or soma.**
- Neurites can be divided into **two functionally and morphologically different groups-dendrites and axons.**
- Bundles of axons and dendrites are called **nerves**. They are **sensory** if they consists of dendrites only, **motor** if they consists of axons only and **mixed** if they consists of both.
- The processess of neurons can be **demonstrated by silver impregnation (golgi method)** when the cell appear as browny black silhouettes.
- **Dendrites** are part of the **receptive surface of the neurons.** It **typically carries signal towards the cell body**.
- Neurons **have one to several primary dendrites**, which emerge from the perikaryon. Primary dendrites may divide into secondary, tertiary etc. dendrites.
- Some dendrites are studded with small, **mushroom-shaped appendages**, which are called **spines.**
- Each neuron has as a rule one axon, and never more than one axon which emerges from the perikaryon or close to the trunks of one of the primary dendrites.
- The **point of origin of the axon from the perikaryon** is the **axon hillock** (the **most sensitive part**).
- The axon may, like the dendrites, branch as it travels through the nervous tissue to its destination(s). The **axon** is the **"transmitting" process of the neuron.**
- The axon **conducts nerve impulses away from** the **cell body** to another neuron or tissue, therefore called **efferent process**.
- **Axon** is a longer process and branches distally into many fine filaments called **telodendria.**
- The knobbed ends of telodendria are called **end bulbs, axon terminal or boutons**.
- The **cytoplasm of an axon** is called **axoplasm** and surrounded by a plasma membrane called **axolemma.**
- Nissl bodies are **absent in the axon and axon hillock**.
- An axon usually originates from the cell body as a small conical elevation called the **axon hillock.**
- Axon hillock is very distinct from the rest of the cell body when examined microscopically, it is completely devoid of the ribosomes, Nissl's granule, golgi complex, fat globules and endoplasmic reticulum etc. that characterize the rest of the cell body and the neighbouring portions of the dentrites. Instead, there are numerous microtubules and microfilaments, which form the basis of a transportation system for the axon, aiding in the movement of substances from the cell body to the end feet.
- The axon **depend on cell body for proteins**.
- The axons ends in a group of branches, the **terminal arborization**. The latter (terminal arborization) when meet dendrites (telodendria) of another neuron to form a **synapse** it form synaptic-knobs (for motor end plates in muscle fibres and gland cells). The synaptic knobs contain mitochondria and secretory vesicles.
- **Synapses** are morphologically specialized contacts between a bouton formed by one neuron, the presynaptic neuron and the cell surface of another neuron, the postsynaptic neuron.
- A typical neuron has about 1,000 to 10,000 synapses (*that is* it communicates with 1,000 - 10,000 other neurons, muscle cells, glands, etc.).
- **Synaptic vesicles contains the neurotransmitters**. Synaptic vesicles typically accumulate close to the site of contact between the bouton and the postsynaptic neuron.
- The **release of the neurotransmitter** from the synaptic vesicles into the synaptic cleft, *i.e.*, the space between the bouton and the postsynaptic neuron, **mediates the transfer of information from the pre– to the post-synaptic neuron.**
- **Two types of axons** are **myelinated** and **unmyelinated**.
- The **myelinated or medullated** or white fibre is surrounded by a phospholipid covering called **myelin sheath**.
- The myelin sheath is **produced by flattened cells** called **Schwann cells.** It consists of 70-80% lipids (fats) and 20-30% proteins.
- **Myelin sheath** is a layer covering of vertebrate nerve fibre.

- The unmyelinated gaps or constrictions in the axons are called **nodes of Ranvier**.
- Myelin **serves as an insulating material** [as it coats and insulates the axon (except the nodes of Ranvier)]. It **causes saltatory conduction of impulses**.
- The **conduction of impulses is faster in myelinated fibres**.
- The cell body of a neuron is called **cyton, perikaryon** or **soma**.
- Cyton of most **neurons** in our body occur in brain.
- The cell body varies in form and size. It may be up to 13.5 mm in diameter, irregular, rounded star shaped or pyramidal.
- Like a typical cell it contains mitochondria, golgi apparatus, abundant cytoplasm (called **neuroplasm**) and a relatively large nucleus with a distinct nucleolus (which is rich in protein) and rough endoplasmic reticulum.
- The neuroplasm contains fat globules, pigment granules **neurofibrils**, **neurotubules** and **Nissl's granules** or **Nissl's bodies** or **trigoid granules**.
- Nissl's granules are believed to be **equivalent to ribosomes**.
- The neurofibrils (consisting of microfibrils and microtubules) forms an intricate network both in cyton and axon and are used in transmission of impulses.
- **Neurotubules** are the microtubules (no centrioles) which maintain the shape of the neuron.
- The Nissl's granules (found to be **rich in RNA**) are the rough endoplasmic reticulum attached to ribosomes and polysomes that synthesize proteins for the cell.
- The Nissl granules are **restricted to cyton, dendrites** and **axon hillock**.
- The ageing neuron may **contain a pigment called lipofuscin (derived from lysosomes)**.
- Cyton is **concerned with metabolic maintenance and growth**.
- Nervous tissue **also includes cells that do not transmit impulses**, but instead **support the activities of the neurons**. These are the **glial cells (neuroglial cells)**, together termed the **neuroglia**.
- Supporting, or glial cells **bind neurons together** and **insulate the neurons**. Some are phagocytic and protect against bacterial invasion, while others provide nutrients by binding blood vessels to the neurons.
- Neuroglia cells outnumber the neurons and are of two types - **macroglia** (large glial cells) and **microglia** (small glial cell) and play various vital roles.
- Macroglia are of **two types - astrocytes** and **oligodendrocytes**.
- **Astrocytes** (**most abundant of all supporting cells in the CNS**) are star shaped glial cells that perform a variety of functions in the CNS.
- Astrocytes **provide physical support to neurons**. They also provide neurons with some of the chemicals needed for proper functioning and help control the chemical composition of fluid surrounding neurons. Finally, astrocytes play a role in providing nourishment to neurons.
- Astrocytes also perform a process known as phagocytosis. Phagocytosis occurs when an astrocyte contacts a piece of neural debris with its processe (arm of the astrocyte) and then pushes itself against the debris eventually engulfing and digesting it.
- Astrocytes are of two types - **fibrous** and **protoplasmic**.
- The **principle function of oligodendrocytes** is to provide support to axons and to produce the myelin sheath, which insulates axons. Myelin is 80% lipid and 20% protein and allows for the efficient conduction of action potentials down the axon.
- **Microglia** are the **smallest of the glial cells**. Some act as phagocytes cleaning up CNS debris. Most serve as **representatives of the immune system in the brain**.
- Microglia are actually a special form of macrophage (a type of white blood cells involved in fighting infection and protecting the body), oval in shape with thorny processes. As such these cells are actually derived from a blood cell called a monocyte.
- Oligodendrocytes resemble astrocytes but processes are fewer and smaller.
- Microglia are **mesodermal in origin**.
- At 70 years of age, about 20% neurons are destroyed.
- Nervous tissue has some properties like **excitability or irritability** (ability to perceive a stimulus and

Components of Nervous tissue

Neurons
The information processing nerve cells

- **Human beings contain :** 100 billion neurons
- **Consists of**
  - **Cell body** (Soma or Cyton)
    The cell body integrates information from the dendrites and other synaptic inputs in determining the messages to be transmitted to other cells through its axon.
  - **Neurites** (nerve fibres) — Comprises
    - **Dendrite:** Short thick processes which branch out of the soma, conduct impulses to the soma.
    - **Axon:** Long nerve processes, carry nerve impulses from soma to other neurons through synapses.
  - Neurites are of two types
    - **Medullary or myelinated : C**ontain myelin sheath which increases the speed of action potential along an axon.
    - **Non-medullary or nonmyelinated :** Lacks myelin sheath and nodes of Ranvier.
- **Life span:** Neurons cannot grow after damage (except neurons from the hippocampus)
- Has about 1,000 to 10,000 **synapses** (the point of communication between one neuron to another)
- Classification on the basis of
  - **Structure**
    - **Non polar**—No functional difference between dendrite and axon, e.g. *Hydra*.
    - **Unipolar**—Single process comes out of the cell body and divides into two branches.
    - **Multipolar**—One axon and many dendrites
    - **Bipolar**—Two processes; one axon and one dendrite
  - **Functions**
    - **Sensory (receptor)**—Brings information to the CNS
    - **Motor effector**—Takes information from CNS to other parts of body
    - **Interneurons**—Help coordinate and integrate information between sensory and motor components
- **Properties and characteristics**
  - Normally the electrical impulses (messages) travel through a neuron **in only one direction.**
  - The axon may be surrounded by a 'coat' of lipids (fats) and proteins known as the **myelin sheath** which acts as an insulator.
  - Neurons are specialist cells that have **lost the ability to reproduce themselves**. Once the soma of a neuron has died the entire neuron dies, and can never be replaced.
  - Repair of damaged neurons only occurs in myelinated neurons.

Supporting cells (or glial cells)

- Non-conducting cells that are in intimate physical contact with neurons.
- Provide physical support, insulation, metabolic exchange with vascular system.
- These are ten times more numerous than neurons and are found throughout the CNS

enter a state of activity), **conductivity** (ability to transmit excitation), **all or none law**, **refractory period**, **synaptic delay**, **synaptic fatigue**, etc.

- **All or none law** states that a nerve conducts a stimulus when its intensity reaches threshold value. A stimulated nerve fibre conducts the impulse as per its own characteristic, independent of the intensity of stimulus.
- **Refractory period** is the interval in which a nerve fails to respond to a second stimulus. It is about 1 millisecond.
- **Synaptic delay** is the time taken for an impulse to cross a synapse is 0.3 - 0.5 millisecond.
- **Synaptic fatigue** is a temporary suspension of impulse transmission in the region of synapse due to exhaustion.
- Thicker auditory nerve is found in bat comprising of 30,000 neurons.

Table : Common names of some nerves.

Musician's nerve	Ulnar
Labourer's nerve	Median nerve
Jacobson's nerve	Branch of IXth cranial nerve
Dentist's nerve	Trigeminal nerve
Thinnest & smallest cranial nerve	Trochlear
Longest cranial nerve	Vagus

End of the Chapter

Chapter 32

Integumentary System

- The **integument, or skin (cutis)** is an anatomically and physiologically specialized **boundary lamina** essential to life.
- It is a **major (and largest) organ** of the body, forming about **8% of its total mass** and having an **area between 1.2-2.2 m^2**.
- In **total thickness** it ranges from about **1.5-4.0 mm**.
- The study of the structure and functions of the skin and its derivative is called **dermatology.**
- Skin of human is **elastic** and covered with hair.
- Skin is a most effective **barrier** against microbial invasion and dehydration and against mechanical, chemical, osmotic, thermal and photic damage.
- Skin limits and **regulates heat loss**. Skin is a **major sensory surface** with elaborate systems of varied receptor types, is capable of limited excretion and absorption and carries out many specialized biochemical functions, including the formation of vitamin D_3.
- Skin also has good **frictional properties**, assisting locomotion and manipulation by its texture.
- The outer surface of skin is covered by various markings, some of them large and conspicuous and others delicate. These are often referred to collectively as **skin lines**.
- Skin lines include, externally visible grooves of the epidermis, *i.e.,* **flexure lines**, positioned near or opposite synovial joints, **tension lines** which form a delicate pattern of geometric shapes over the surface of thin, hairy skin, and **papillary ridges**, forming fields of parallel lines on the thick, hairless skin of hands and feet.
- **Skin line formed during pregnancy** is called **striae gravidarum**.
- **Two major classes of skin** which cover large areas of the body, but show important differences of detailed structure and functional properties are– thin, **hairy (hirsute) skin**, which constitutes the great majority of the body's covering, and **thick, hairless (glabrous) skin** forming the surfaces of the digits.
- Thick hairless skin **forms frictional surfaces** for manipulation and locomotion and requires extra strength and numerous sweat glands for cooling during sustained activity.
- Thin hairy skin is responsible for the **general cutaneous functions** over the remainder of the body.
- Microscopically, skin is formed as an intimate association between **two distinct tissues** : keratinized stratified squamous epithelium superficially, the **epidermis**, and a deeper layer of moderately dense connective tissue, the **dermis**.
- Beneath the two layers, a **subcutaneous layer** of loose connective tissue or **hypodermis** is found which binds the skin to underlying structures.
- The **main function of the subcutaneous** layer is to provide a cushion for delicate organs lying beneath the skin. It also functions to insulate the body to maintain body temperature.
- **Texidermy** is a process in which epidermis and dermis both are preserved by chemicals.
- The **epidermis** is composed of **keratinized stratified squamous epithelium**.
- The cells present in the epidermis are **keratinocytes,** pigment forming **melanocytes**, phagocytic **Langerhan's cells**, and neurally associated **Merkel's cells.**
- Small localized accumulations of pigment cells in the epidermis are **naevi** or **moles.**
- The **epidermis** is divided into a number of strata representing different stages of **keratinocyte.**
- From deep to superficial, these strata are **stratum basale, stratum spinosum**, **stratum granulosum**, **stratum lucidum** and **stratum corneum.**

- **Stratum basale** and **stratum spinosum** together are called **stratum malpighii**.
- The cells of stratum basale are active and produce new cells by mitotic division, hence the name **germinative layer.**
- The **rate of cell division in the stratum germinativum** is **highest** during sleep and **lowest** during muscular exercise and stress.
- The **cells of stratum granulosum** become flattened and accumulate many large (0.5 mm) **basophil granules**.
- Such cells contain **keratohyalin granules.**
- **Odland bodies** are present in stratum granulosum and they act as the precursor of skin specific lipid bilayer.
- The **stratum lucidum** is **only found in thick, glabrous skin** and represents a rather poorly understood stage in keratinization.
- Stratum corneum of epidermis become keratinized by acquiring **-keratohyaline protein** (in columnar cells); **eleiden protein** (in cuboidal cell); **keratin protein** (in squamous cell).
- In **stratum corneum** basic protein or **profilaggrin is present** which eventually matures into the protein filaggrin.

Filaggrins are an important class of intermediate filament-associated proteins that interact with keratin intermediate filaments of terminally differentiating mammalian epidermis. They show wide species variations and their aberrant expression has been implicated in a number of keratinizing disorders such as ichthyosis fetalis.

- The stratum corneum consists of **closely packed layers of flattened, dead keratinocytes (squames)**.
- In thin skin, e.g., of the scalp, this stratum is only a **few cells deep**, but in thick skin it may be more than **50 cells deep**.
- The cells are compact and contain high concentrations of keratin filaments each about **8-10 nm thick**, often lying parallel and 8 nm apart.
- **Melanosomes** are oblong, membrane-bound, rounded bodies containing the dark brown pigment **eumelanin**.
- **Eumelanin** is a highly insoluble, proteinoid polymer of DOPA quinone, formed by a series of reactions involving tyrosinase and other oxidative enzymes.
- **'Voigt lines'** mark differences in pigmentation between the darker extensor and polar flexor surfaces of the arms.
- Pigments of mature skin are usually present only in the basal layer of epidermis and hair, the chief being the brown black **melanin**.
- A reddish-yellow pigment **phaeomelanin,** is present in phaeomelanosomes, that occur mainly in reddish hair.
- **Merkel cells** are present only in thick hairless skin, they are thought to play a role in **sensory transduction.**
- The **basement membrane** of skin consists of a basal lamina and it is about 80 nm thick.
- The **dermis** consists of irregular, **moderately dense, soft connective tissue**.
- Dermis **has its own blood supply** due to which more complex structures are able to exit here, like sweat glands, to collect water and various wastes from the blood stream and to excrete them through pores in the epidermis.
- The dermis can be **divided into two distinct zones**– a narrow superficial **papillary layer** and a deeper **reticular layer**.
- The **papillary layer** is immediately deep to the epidermis and is specialized to provide mechanical anchorage, metabolic support and trophic maintenance to the overlaying tissue, as well as housing rich networks of sensory nerve endings and blood vessels.
- **Meissner's corpuscle and nerve endings** are present in papillary layer.
- The **reticular layer** is found in close association with papillary layer.
- The **collagen fibres** in the reticular region provide the skin with strength and **extensibility** (= ability to stretch) and **elastic fibres** provide its **elasticity** (= ability to return to the original shape after stretching).
- The **gradual stretching of collagen** fibres causes **wrinkles in a later life**.
- The dermis is also the **site of hair roots** where the growth of hair takes place.
- In most mammals, there is a layer of sub-dermal adipose tissue of fat, forms a continuous layer called **panniculus adiposus.**
- **Heat and cold receptors** are present in skin.
- Derivatives of skin may be **soft derivative (e.g.,**

sweat and sebaceous glands) or **hard derivatives** (e.g., **hairs, scale, beak, horn, claw etc).**

- The skin glands include **sudoriferous glands** (secrete sweat) ; **sebaceous glands** (produce oily material, the sebum) ; **mammary glands** (that secrete milk); **Meibomian glands** (which add an oil film into the eyes); **glands of Zeis** (that pour oily substances into the follicles of eyelashes) and **ceruminous glands** which secrete wax into the ear canal.
- Sweat glands are **eccrine** (similar to apocrine, cytoplasm is broken before discharge) or **merocrine** in nature.
- Sweat glands are **primarily concerned with regulation of body temperature**.
- Sweat gland maintain homeostasis of water and salts.
- Sweat glands are **more numerous on palms, soles, forehead and axillae (arm pit)**.
- Sweat glands are **absent** in ant-eaters, sea cows whales.
- Sweat contains 95% water, 5% of other constituents like chlorides, phosphates, ammonia, urea and uric acid. Sweat is like diluted urine.
- **Sebum** produced by sebaceous glands make the hair soft and supple. It is also **antibacterial in nature**.
- Mammary glands are modified sweat gland in **eutheria** or modified sebaceous glands in **prototheria**.
- **Meibomian glands** are also called **tarsal glands** and are modified sebaceous glands on the edges of eyelids, keep a thin film of oil over the cornea.
- **Zeis glands** are sebaceous glands associated with follicles of eye lashes. Their secretion keeps the eye lashes smooth and oily.
- **Infection of Zeis gland** causes a **stye or hordeolum**.
- **Ceruminous glands** are **modified sweat glands**.
- In amphibia and birds meibomian glands are known as **herdarian glands** whose secretion lubricates the surface of eye ball.
- **Perineal gland**, found in dermis of skin around the genital organs, are modified sebaceous gland.
- Lacrimal gland has **lysozymal protein**.
- **Blubber** is a very thick layer of adipose connective tissue found in whale, elephant, seal etc.
- **Tanning** is darkening of skin after exposure to UV light of the sun. It results from darkening of the pre-existing melanin followed by rapid synthesis of fresh melanin.
- The **nails** are translucent plates of approximately rectangular shape lying on the extensor surface of the **distal segment of each digit**.
- The **thickness** of mature nails varies from about **0.5 to 0.75 mm**.
- The **nail** includes **three major regions**– the proximal **root (radix), the exposed body of the nail, and the free distal border**.
- **Lunula** (a white, crescent shaped, half moon shaped structure) is the **most actively growing region** of the nail root.
- At the attachement site of the nail bed the dermis is very **vascular, accounting for the pink colour** seen through the translucent nail.
- Microscopically, **nails are homologous with the stratum corneum**, consisting of compact, dead, anucleate keratin-filled squames, derived from the maturation of cells generated in the germinal matrix and underside of the proximal nail fold.
- The **nail bed** itself is lined by stratified squamous epithelium in which the surface layer is only parakeratinized, retaining its nuclei.
- The rate of nail growth varies with **digit, age, environmental temperature, time of day** and other factors.
- Generally its speed is related to the length of the digit, being fastest (about 0.1 mm per day) in the **third digit of the hand** (medius) and **slowest in the fifth** (minimus).
- Finger nails **grow up to four times faster than toe nails.**
- **Hairs (pili) are filamentous, keratinized structures** (develop from tubular pits called **hair follicle**) present over almost all of the body surface and are derivatives of the epidermis which assist in thermoregulation, provide some protection against injury, have sensory functions and subserve various subtle roles in social communication.
- Hairs are **absent** from a few areas of the body, including the **thick skin of palms, soles and flexor surfaces of digits** and certain other regions like **umbilicus, nipples, glans penis and clitoris,** the **labia minora and the inner aspects of the labia majora** and **prepuce**.
- In length they range **less than a millimetre** to more **than a metre**, in width from 0.005 to 0.6 mm.

SKIN

Has several layers

- Outer layer — **Epidermis** — has — no direct blood supply — fed and supported by — **Inner layer Dermis**
- **Inner layer Dermis** — contain equipments — lots of nerve fibres, sensory receptors, blood and lymphatic vessels as well as the hair follicles, and the sebaceous and sweat glands.
- Fatty layer (not a part of skin) — **Subcutaneous / hypodermis** — Consists of adipose tissue plus some areolar tissue.

Epidermis consists of:

Cell types

Keratinocytes : Produce a protein - the keratin that helps waterproof the skin and that protects the skin and the underlying tissues from heat, microbes, abrasion and chemicals.

Merkel cells : Sensory receptors (touch), associate with a disclike sensory nerve ending to form the merkel disc.

Melanocytes: Synthesize is melanin pigments which protect the skin against ultraviolet damage.

Langerhans cells : Macrophages used in the defense against micro organisms.

Layers

(From the deepest to the most superficial)

Malpighian / Basal / Germinativum

The deepest living epidermal layer, consists of one row of cuboidal to columnar shaped cells. The cells are mostly stem cells that divide rapidly to produce new keratinocytes which push up toward the surface and become part of the more superficial layers.

Above basal
Stratum spinosum (little spine)

8-10 layers thick.
The keratinocytes contain thick bundles of intermediate filaments (tonofilaments) made of a tension-resisting protein.
Scattered amongst keratinocytes are the Langerhans' cells that are most abundant in this layer.

Above spinosum
Stratum granulosum

(contains basophilic and refractile keratohyaline granules)

The keratinization process begins and the cells begin to die. This layer is called granulosum, because the cells contain granules of the precursor of keratin.

Outside granulosum
Stratum lucidum

Only found in thickened areas of the epidermis such as the sole of the feet.
The cells appear clear because of an accumulation of keratin precursor.
The cells begin to degenerate.
After dissolving keratohyaline granules transformed into eleidin which makes cells semitransparent, shiny and water proof.

Outermost layer of dead, flat, keratinized cells
Stratum corneum

- filled with — Keratin protein
- thicker in — Palms & feets wear & tear areas

Inner layer Dermis consists of two layers

Papillary Layer

Outer layer closest to the epidermis, composed of areolar loose connective tissue proper.

Reticular Layer

Deeper layer and the thickest (4/5 th of the dermis), made of dense irregular connective tissue proper containing thick bundles of interlacing collagen fibres and some coarse elastic fibres that run in several directions.

- Each hair consists of a **shaft** (scapus) and a **root** (radix) lying within a tubular invagination of the epidermis, the **hair follicle** (folliculus pili).
- At the proximal end of the root the hair is expanded to form the **hair bulb** (bulbus), which is continuous basally with the epithelium of the hair follicle. The bulb is deeply indented on its deep surface by a conical vascular dermal **papilla**.
- Cells in the bulb are **mitotically active**.
- A tiny involuntary smooth muscle called **arrector pili** or **elevator of the hair** operates the hair.
- The growth rate of hairs varies with their site and **thickness**, ranging from about I.5 mm (fine hair) to 2.2 mm (coarse hair) a week when actively growing.
- **Fast growing hairs** are said to be in the **anagen phase,** this is followed by the involuting or **catagen phase**, when **growth ceases**, then the resting phase is **telogen phase**.
- No hair follicle develops after birth.
- **Grey hair** is the result of a reduction in pigment formation and reflection of light from an increased number of air space.
- **Metachrosis** is the phenomenon of change in colour in lower vertebrates.
- Nail **develops from the epidermis.**
- Small scales of dead keratinized epidermal cells among the scalp hair form **dandruff**.
- **Albinism** is an inherited (usually autosomal recessive) **deficiency or absence of pigment** in the skin, hair and eyes or eyes only due to an **abnormality in the production of melanin**.
- **Thinnest skin** occurs over the **eyelids** (0.5 mm or less).

End of the Chapter

Chapter 33

Morphology & Anatomy of Animals

EARTHWORM
(*Pheretima posthuma*)

- The **common Indian earthworm**, *Pheretima posthuma* **belongs to class oligochaete of the phylum annelida**.
- The generic name *Pheretima* was first used by **Kinbery** in 1867.
- The anatomy of *Pheretima* has been worked out by late Professor **K.N. Bahl (1926)**.
- *Pheretima posthuma* is a terrestrial earthworm lives in **damp soil** & burrows (fussorial) and is nocturnal.
- **Brown colour of the body** is due to a pigment called **porphyrin**, present in the circular muscles of body wall. Porphyrin **protects the animal from ultraviolet rays**.
- **Moisture is essential** for the **survival of earthworm**.
- *Pheretima* **has no specialized respiratory organs**.
- The **moist skin acts as a respiratory organ**. The respiration in earthworm is called **cutaneous respiration**.
- Skin of earthworm is kept moist by **mucous**, **coelomic fluid** & **moisture of soil**. Mucous serves not only in respiratory exchange but it also lubricates the worm body & easy passage through the burrow. The mucous covered skin help in binding soil particles together & prevents the walls of burrow from collapsing.
- In *Pheretima*, **epidermal receptors** are present all over the body. They are of two types – **tangoreceptors** (sense of touch) and **chemoreceptors** (sense of chemical stimuli).
- In *Pheretima*, **buccal receptors** are found in the buccal cavity. They are of two types – **gustatory receptors** (organs of taste) and **olfactory receptors** (organs to detect smell).
- If the **skin is dry,** respiration cannot take place and the **earthworm dies by suffocation**.
- During rainy season it comes out of their burrows for respiration & to escape from endosmosis.
- Earthworm **lacks** a **distinct head** and **sense organs like eyes, cirri & tentacles**.

Earthworm **do not have special sense organ**. Yet they show behaviour to all kinds of stimuli. This is mainly due to presence of receptors cells for taste, touch & apparently vibration all over the body surface. There is a concentration of sensory cells at the anterior end of prostomium. Because of these receptors they feel the vibrations of animals moving nearby.

- **1st segment** (or **peristomium**) has a **ventral mouth** with a dorsal lobe or **prostomium** & the **last segment has anus**.
- Earthworm has **great power of regeneration**.
- **Clitellum** (or cingulum) is a glandular organ used for the **formation of cocoon**.
- Clitellum completely and permanently **surrounds the segments 14th to 16th** in the form of a girdle like thick band of glandular tissue.
- Due to presence of clitellum, the body is distinguished into *periclitellar*, **clitellar** and **post clitellar regions**.
- **Setae** or **chaetae (made by chitin)** are S-shaped structures occur in median whorls (perichaetine

Table : Number of segment with the structures located on it in earthworm

No. of segments	Structures located
1^{st} segment (Peristomium)	Mouth
6^{th}, 7^{th}, 8^{th}, 9^{th}	Spermathecae
14^{th} to 16^{th}	Clitellum
14^{th}	One female genital opening
18^{th}	A pair of male genital opening
4^{th}	Pharynx
5^{th} – 7^{th}	Oesophagus
8^{th}	Gizzard
15^{th} – last	Intestine
17^{th} and 19^{th}	Genital papillae
15^{th} – last	Septal nephridia
3^{rd} – last	Integumentary nephridia
4^{th}, 5^{th}, 6^{th}	Pharyngeal nephridia or branched nephridia
10^{th}, 11^{th}	Testes, testis sacs
13^{th}	Ovary
17^{th}, 19^{th}	Accessory glands
16^{th} – 21^{st}	Prostate gland
11^{th}, 12^{th}	Seminal vesicles
26^{th} – 95^{th}	Typhlosole
7^{th}, 9^{th}	Lateral hearts
12^{th}, 13^{th}	Lateral oesophageal hearts
10^{th}, 11^{th}	Anterior loops
5/6, 6/7, 7/8, 8/9	Spermathecal opening
4^{th}, 5^{th}, 6^{th}	Blood glands

arrangement = arrangement of numerous setae in a ring) **in all except first (peristomium), last & clitellar segments**.

- Setae **helps in locomotion by anchoring structure**s.
- In *Pheretima*, **four pairs of spermathecal openings** are present on the **inter segmental grooves of 5/6, 6/7, 7/8 and 8/9 segments**, one pair in each groove.
- In *Pheretima*, single **female genital opening** is present on the mid ventral side of the **14^{th} segment** and one pair of **male genital openings** are seen on the ventral side of the **18^{th} segment**.
- In *Pheretima*, close to the male genital pores, two pairs of **genital papillae** are present ventrally, one pair in the **17^{th} segment** and the other pair in the **19^{th} segment**. They **act as suckers** for attachment during copulation.
- **Accessory glands** of **17^{th} and 19^{th} segments** open to the exterior on genital papillae in *Pheretima*.
- The **body wall** of *Pheretima* is **derived from ectoderm and somatic mesoderm**.
- Body wall of *Pheretima* shows **circular** and **longitudinal muscles**.
- The **muscles of body wall** of *Pheretima* **help in locomotion in association with setae.**
- The outer coelomic epithelium of body wall is made by **squamous epithelium**.
- **Body cavity** is a true coelom **(schizocoel)**, containing milky white alkaline coelomic fluid.
- Septa divide coelom into chambers.
- Coelomic fluid contains corpuscles of following types– **phagocytes** (largest, more numerous, amoeboid corpuscles), **mucocytes, circular nucleated cells** and **chloragogen cells**.
- Coelomic fluid **serves as a hydraulic skeleton during locomotion**.
- Septal wall is **absent in the first four segments** and also **between 9^{th} and 10^{th} segments**.
- The **speed of progression** of *Pheretima* is **25 cm per minute.**
- The **muscles of alimentary canal** of *Pheretima* **helps in peristalsis**.
- Earthworm has a straight alimentary canal, representing a **tube in tube plan**.
- Pharyngeal glands with **some chromophil cells** are present on the roof of the pharynx. They **produce mucin and proteolytic enzymes (protease)**.
- **Gizzard** (present in the 8^{th} segment) is a thick walled, highly muscular and lined internally by cuticle for grinding.
- In *Pheretima*, glandular cells of stomach contains calciferous gland which secrete calcium oxalate and **neutralizes the humic acid of the food**.
- In *Pheretima*, the dorsal wall of intestine shows **typhlosole**. Typhlosole is the **largest villus for increasing absorptive area**.
- In *Pheretima* the **intestine is divisible into 3 parts** based on the presence of typhlosole –
  - **Pre-typhlosolar region** from **15^{th} to 26^{th} segments.**
  - **Typhlosolar region** extends from **27^{th} segment to 23^{rd} or 25^{th} segment in front of anus.**
  - **Post-typhlosolar region** occupies the **last 23^{rd} or 25^{th} segment.**

- In *Pheretima*, the intestine shows a pair of **intestinal caecae** in **the 26th segment**. They **extend upto 22nd or 23rd segment**. They secrete **amylase enzyme**.
- Earthworms are **omnivorous**.
- The food of *Pheretima* consists of dead and decaying organic matter mixed in the soil.
- In *Pheretima*, undigested food with soil is sent out through anus in the form of **worm castings or faecal pellets**.
- The **digestion is extracellular** in earthworm.
- **Blood vascular system** of earthworm is a **closed type** consisting of blood vessels and capillaries.
- Blood is **red in colour due to presence of haemoglobin which is dissolved in blood plasma**.
- In *Pheretima*, there are **three main blood vessels- dorsal blood vessel**, **ventral blood vessel** and **subneural blood vessel**.
- **Dorsal blood vessel** is the **largest blood vessel** extending from one end of the body to the other end. It has thick, muscular walls with valves. It **drives the blood in forward direction**.
- In the intestinal region *i.e.*, **behind 14th segment**, **dorsal vessel acts as a collecting vessel**.
- The dorsal blood vessel **acts as a distributing vessel** in the **first 13th segments**.
- The **ventral blood vessel** extends from one end of the body to the other end. It is **non-muscular** and **non-valvular vessel**.
- Ventral blood vessel is **the chief distributing vessel**, in which blood flows from anterior to posterior end.
- **Sub-neural blood vessel** is present beneath the ventral nerve cord. It extends from 14th segment to the posterior end. It is a **collecting vessel**.
- **Supraoesophageal blood vessel** is a short thin walled collecting vessel lying mid dorsally above the stomach and confined to **segments 9 to 13**.
- On the lateral sides of the alimentary canal from **1st to 13th segments** a pair of **lateral oesophageal blood vessel is seen.**
- A pair of large, thick, muscular and rhythmically contractile vertical vessels, called **hearts**, are **present in each of the segments 7, 9, 12 and 13**.
- **Lateral hearts** that are **present in 7th and 9th segments**, connect dorsal blood vessel with ventral blood vessel.
- Above the alimentary canal in **4th, 5th and 6th segments**, 3 pairs of globular structures called **blood glands** are present. Blood gland **produce haemoglobin** and **blood cells**.
- **Lymph glands**, present on both sides of dorsal blood vessel from segment 26th and those behind it, are supposed to produce certain phagocytic cells.
- In *Pheretima*, there are **three types of nephridia** (ectodermal in origin) according to their location – pharyngeal nephridia, integumentary nephridia and septal nephridia.
- The **pharyngeal nephridia** are **present in 4th, 5th and 6th segments** (one pair in each). Nephrostome and nephridiopore are **absent** in pharyngeal nephridia.
- Pharyngeal nephridia open in the anterior part of alimentary canal *i.e.* buccal cavity and pharynx thus are also called **enteronephric**.
- Pharyngeal nephridia of *Pheretima* are called **peptonephridia** (4th and 5th groups open into pharynx, 6th group opens into buccal cavity).
- **Integumentary nephridia** are microscopic V-shaped. They are small and have **no nephrostome** and are **exonephric type**.
- In the clitellar region each segment has 2000 to 2500 micronephridia. They are called **forest of nephridia**.
- **Septal nephridia** are the **largest nephridia** and the **only nephridia with nephrostome** (a ciliated funnel communicating with the coelom).
- The septal nephridia are open to **enteronephric nephridia**. They perform both **excretion** and **osmoregulation**.
- Earthworms are mainly **ureotelic (excrete urea)**.
- **Chlorogogen cells** (or **yellow cells**) are star shaped, small sized cells. They perform excretion by removing excretory products from coelomic fluid. It is bright yellow or orange colour cells derived from splanchnic peritoneum which explains its position and distribution on the surface.
- **Chlorogogen cells** are **analogous to liver of vertebrates** because of the connection with storage and synthesis of glycogen & fat, deamination & urea formation.
- Earthworm has a **well developed nervous system**, it has a brain but no head.
- The **nervous system includes a nerve ring** around pharynx in 3rd and 4th segments.
- **Brain hormone** produced by supra-pharyngeal ganglia brings **regeneration of the posterior segments**.
- Neurons in earthworm are– **motor**, **sensory** and

adjustor (association neurons).

- **Photoreceptors** of *Pheretima* contain a L-shaped lens called **phaosome** or **optic organelle** (made up of a hyaline substance). It **cannot form an image**.
- Photoreceptors enable worms to judge the intensity & duration of light. **Photoreceptors restricted to dorsal surface, are more numerous on prostomium and peristomium**.
- *Pheretima* are monoecious or **hermaphrodite organism**.
- In earthworm **cross fertilization takes place** instead of self fertilization. This is due to **protandrous condition** (where testes mature earlier than ovaries).
- In *Pheretima*, the **spermathecae** (or **receptacula seminales**) **show one diverticulum and a big ampulla**. **Diverticulum** stores sperms and **ampulla** gives nourishment to the stored sperms.
- **Copulation** takes place for **one hour** between two mature earthworms in the **night time**.
- **Fertilization** is **external** and **occurs in cocoon**.
- **Cleavage** is **holoblastic and unequal** and **development is direct** without any free larval stage.
- Earthworms are **friends of farmers** because they enrich the soil by nephridial excretion, that increases the fertility of soil.
- Earthworms found in South India are *Megascolex, Lampito, Octochaetus, Drawida, Eutyphaeus* etc.
- *Drawida grandis* is the **largest earthworm in India**.
- **Largest earthworm in world** is *Megascoloides australis*.
- **Megascolex** is abundantly found in Andhra Pradesh.
- *Pheretima* and *Eutyphaeus* are found in North India. *Pheretima posthuma* is also found in Kerala state.
- *Lumbricus terrestris* is an European earthworm, **not found in India**.
- *Allolobophora* is found in hilly regions of North India.

COCKROACH
(*Periplaneta americana*)

- Cockroaches belong to the class **insecta of phylum arthropoda**.
- Class insecta is the **largest in the animal kingdom**, as there are more species of insects (about 80,000) than all other species of animals combined.
- **Four species of cockroaches** found in India are– *Blattella germanica* (the German or croton cockroach); *Blatta orientalis* (the Oriental or Indian cockroach); *Periplanata americana* (the American cockroach or ship cockroach); and *Periplaneta australasiae* (the Australian cockroach).
- Cockroaches are **nocturnal** (active in night), **cursorial** (fast runners) and **omnivorous** and **scavangerous** in diet.
- *Blatta orientalis* is black in colour and it is commonly known as **black beetle**.
- *Periplaneta americana* is the **largest and most common species**.
- The wings are **well developed in both sexes** of *Periplaneta americana* and extend beyond the body.
- The wings are **reduced in male** and **vestigial in female** *Blatta orientalis*.
- Body is covered with non-living, brown coloured, hard jointed and chitinous exoskeleton of sclerites which are formed by thin, flexible **arthrodial** or **articular membranes** to allow movements.
- The dorsal sclerite of the exoskeleton of cockroach is called **tergum** or **tergite**, ventral sclerite is **sternum** or **sternite** and two lateral sclerites are called **pleura** or **pleurites**.
- Body of cockroach is distinctly divided into **head**, **thorax** and **abdomen**.
- The part of head between and behind the eyes is **epicranium (vertex)**.
- The front of head capsule is made up of three unpaired flattened sclerites called **frons, clypeus** and **labrum**.
- Head bears a **pair of long antennae**, a **pair of ocelli or fenestrae** (simple eyes) and a **pair of compound eyes**.
- The **thorax** of cockroach consists of three segments – **prothorax, mesothorax** and **metathorax**.
- Thorax **bears three pairs of jointed appendages** (**walking legs**) and **two pairs of wings** on mesothorax and metathorax.
- **Abdomen** is the **largest and broadest part** consisting of **ten segments (11 segments in embryo) without appendages**.
- The 11th somite of embryo is represented in adult by **podical plates**.
- Abdomen is **long & narrow in male** but is **short and broad in female.**
- **8 pairs of tracheal openings or spiracles** are **present** on lateral pleura of **first 8 abdominal segments**.

- **Main appendages** of cockroach are **antennae and mouthparts** (on head); **legs and wings** (on thorax) and **external genitala** (on abdomen).
- The **antenna** is made of many segments called **podomeres**. The **first segment is scape** (largest), **second pedicel** and **rest many jointed flagellum**.
- Antenna is a **thigmoreceptor sensitive to touch** and **smell**.
- Mouthparts of cockroaches are **mandibulate type** or **cutting and chewing type**.
- Mouthparts consists of **labrum** (upper lip), **labium** (lower lip), **maxillae** (segmented and resemble to a leg), **mandibles** and **hypopharynx** (tongue).
- The **main structures** and **well developed part of mastication (chewing)** are **mandibles** which are short with teeth.
- The **mandibles work as jaws** and are **used for crushing and cutting the food materials**.
- Each **leg of cockroach** (used for walking, running and climbing) is **made up of 5 segments (or) podomeres**. They are **coxa, trochanter, femur, tibia** and **tarsus**.
- Tarsus is subdivided into five tarsomeres. The last tarsomere is called **pretarsus** forming the claws and bearing an adhesive **arolium** or **pulvillus**.
- Similar but smaller adhesive pads called **plantula** are located at each joint of the tarsus.
- The **most swollen segment in the leg** of cockroach is **coxa**.
- **Tibia** is the **largest podomere** in the leg of cockroach. The bristles on tibia are called **tibial spurs**.
- **Mesothoracic wings or forewings** are thick leathery and opaque wings. They are **not used in flight** but **protective in function**.
- **Metathoracic or hindwings** are broad, thin and membraneous wings which are **used in flight.**
- **Anal cerci** and **anal styles** are the **external genitalia** which are **involved in sexual dimorphism**, **mating** and **deposition of eggs**.
- **Anal cerci**, a pair of many jointed structures are **present on the tergite of 10th segment in both sexes**.
- **Anal styles**, a pair of small, spine-like unjointed structures are **present on sternite of the segment in males only**.
- **Body wall of cockroach** is made up of **two layers** - outer **cuticle** and **inner hypodermis**.
- **Cuticle** is invaginated forming endoskeletal elements like **tentorium** in head and **apodemes** in thorax. They **provide sites for attachment of muscles**.
- Cuticle is **principally made of chitin**, a horny proteinous substance, chemically an amino-polysaccharide, insoluble in water and resistant to most solvents.
- The cuticle has **three distinct layers**: outer primary cuticle or **epicuticle**, middle thick **exocuticle** and inner thick **endocuticle**. All three are secreted by hypodermis.
- Exo- and endocuticle together constitute the so called **'procuticle'**.
- Exo- and endocuticle **contain chitin**, a structural polysaccharide, basic unit being **N-acetyl glucosamine**.
- **Melanin** pigment is **found only in exocuticle**.
- **Hypodermis** is a single layered epithelium. Some of its cells are modified into large oval **trichogen cells** concerned with secretion of movable bristles on the body of cockroach.
- Besides secreting cuticle, hypodermis resorbs endocuticle before each moult or ecdysis.
- The **alimentary canal** is long and divisible into three main parts namely **foregut, midgut** and **hindgut**.
- **Foregut** (**stomodaeum**) is differentiated into five parts: **buccal chamber, pharynx, oesophagus, crop** and **gizzard**.
- **Crop or ingluvius** occupies the entire thoracic and some abdominal part and **stores the food.**
- **Gizzard** is adapted for grinding the food into a pulp. The **main part of gizzard** is called **armarium** [anterior part with **teeth** (which masticate the food) and **pulvillii** (whose bristles form a strainer which allow only fine food particles to pass through)].
- **Stomodeal valve** is posterior narrow and tubular part of gizzard which projects into the midgut to prevent backflow of food.
- From the junction of midgut and gizzards arises seven to eight finger like structures called **hepatic caecae**.
- **Midgut** (**mesenteron or ventriculus**) is short, tubular lined with glandular endoderm.
- Midgut **forms the true stomach** serving mainly for digestion and absorption.
- Internally mesenteron is not lined by cuticle but it is **covered by a very thin and transparent**

peritrophic membrane formed of chitin and proteins.

- **Peritrophic membrane** is **secreted by stomodeal valve of gizzard** and serves to **protect the wall of midgut from abrasion due to friction of food particles**.
- **Hindgut** (**proctodaeum**) comprises ileum, colon and rectum.
- Most of the nutrients of food are digested in the crop.
- **Digestive glands** includes one pair of salivary gland, each is formed of two parts - sac like **resorvoir** or (**receptacle**) and a bipartite **glandular part**.
- The **digestive enzymes** of **saliva** are mainly **zymase** and **amylase**.
- Digestion is **intercellular** in cockroach.
- **Absorption of digested food** takes place in **mesenteron**.
- **Circulatory system** of cockroach is **open** or **lacunar type**. The **blood flows through haemocoelic system**.
- Haemocoel is divided into a dorsal **pericardial sinus** (containing heart), a middle **perivisceral sinus** (containing the gut) and a ventral **perineural sinus** (containing the nerve cord) by two perforated diaphragms.
- **Heart** is longitudinally **beaded with 13 chambers perforated by ostia having valves**.
- The **blood circulation is maintained** by 13 pairs of wing-shaped involuntary **alary muscles**.
- **Heart** of cockroach is **neurogenic** (myogenic in frog, rabbit and man).
- In addition to the main heart there are present very small **accessory heart** or **pulsatile vesicles** one at the base of each antenna located in the head, to pump the blood from the head sinuses to the antenna.
- The **blood** of cockroach is **colourless due to the lack of respiratory pigment**. It consists of colourless plasma and corpuscles called haemocytes.
- **Pacemakers are absent** in the cockroach heart.
- In cockroach, oxygen is carried to individual cell without participation of blood.
- All body tissues **receives oxygen directly**.
- The **rate of heart beat** in *Periplaneta* is **49/min**.
- Blood circulartion in cockroach is **completed in 5-6 minutes.**

The pathways follow as

Heart → Aorta → Head sinuses
↓
Perineural sinus → Perivisceral sinus → Pericardial sinus → Heart

- **Respiratory system** of cockroach consists of **tracheal system** (containing tracheae, tracheoles and spiracles).
- The tracheal system open outside by ten pairs of **spiracles** or **stigmata** (two pairs thoracic and eight pairs of abdominal). The spiracles are with valves.
- The **trachea** is lined with spiral thickening of cuticle called **intima** or **taenidia** which prevents the tracheal tubes from collapsing (trachea of rabbit is also noncollapsible).
- **Ventilation of tracheal system** is by alternate contraction and relaxation of abdominal muscles (tergo-sternal muscles).
- Respiratory movements **depend on the activity of insects and temperature**, greater the muscular activity the more vigorous is the pumping in and out of air.
- Respiratory movement are **coordinated and regulated by nerve centres in thoracic ganglia** which are stimulated by low O_2 and higher CO_2 concentrations in tissue fluids.
  Tracheal systems of respiration is also found in centipedes, millipedes, ticks and *Peripatus*.
- **Excretory organs** of cockroach are **malpighian tubules** [long, very fine unbranched yellow coloured blind tubules attached at the junction of midgut and hindgut (ileum)], **fatbody cells**; **uricose glands** and **cuticle**.
- Malpighian tubules **absorb excretory substances from haemolymph and fat bodies and pass into the proctodaeum**.
- Fat body of cockroach contains mainly four types of cells, *viz*., **trophocytes, mycetocytes, oenocytes** and **urate cells**.
- The **trophocytes** are most numerous **containing reserve food in the form of fats, glycogen and proteins**.
- **Mycetocytes** contain symbiotic bacteria which help in synthesis of some amino acids, vitamins and of glycogen from glucose.
- **Oenoctyes** are supposed to help intermediary metabolism at times of ecdysis. **It secretes wax**

which covers the cuticle of cockroach.

- **Urate cells** absorb nitrogenous waste products from haemolymph and synthesize uric acid from these for storage **(storage excretion)**.
- The **fat body of cockroach** is functionally **analogous to liver of vertebrates**.
- **Uricose gland** are long, blind tubules present at the periphery of mushroom gland in the male cockroach.
- These tubules **store uric acid** and discharge it over the spermatophore during copulation.
- Uricose gland **serves as storage excretory organs between matings** and as **active excretory organs during copulation**.
- **Excretory products** of cockroach are **uric acid** (**hence uricotelic)** and **urates of sodium and potassium**, so they are **uricotelic**.
- The **nitrogeneous waste** which are deposited **beneath the cuticle are eliminated by the body during moulting** (**ecdysis**).
- **Nephrocytes** are large colourless ovoid binucleate cells attached to diaphragm in the body cavity. These are arranged on the lateral sides of heart hence also called **pericardial cells,** which probably regulates the pulsation of the heart and also help in excretion.
- Cockroach has a **well developed nervous system** with central, peripheral and sympathetic system.
- Central nervous system consists of **cerebral or supraoesophageal ganglion** (brain), **suboesophageal ganglion, paired circumoesophageal connectives** and **double ventral nerve cord** (with three thoracic and six abdominal compound segmental ganglia.)
- The **total number of ganglia in ventral nerve cord** of cockroach is **nine**.
- **Sense organs** in cockroach are – **photoreceptors** (compound and simple eye), **thigmoreceptors** (antennae), **chemoreceptors** (on maxillary and labial palps, labuim and hypopharynx) and **auditory receptors** on anal cerci.
- Each **compound eye** of cockroach is composed of about **2000 visual units** called **ommatidia**.
- Each **ommatidium** is composed of a **cuticular lens**, two **corneagen cells**, a **crystalline cone** surrounded by four cone cells, a **rhabdome** surrounded by seven reticular cells and a **basement membrane**.
- There are **two types of vision in insects** – **mosaic vision** (or **apposition image**) during day time and **superposition** (or **dull image**) in dim light.
- But in cockroach, **pigment sheath of ommatidia is noncontractile** so capable of **only mosaic vision** even during night.
- In cockroach, **sexes are separate**, so **dioecious**.
- **Male organs** consists of **testes**, **vasa deferentia**, **ejaculatory duct**, **mushroom or utricular gland, phallic or conglobate gland** and **male gonaphophysis**.
- **Testes** of cockroach are **located in the abdominal segments 4, 5 and 6**.
- **Mushroom gland** consists of two types of tubules- the long slender tubules, the **utriculi majores** or **peripheral tubules**; and short tubules, the **utriculi breviores**, making up of the **major part** of the gland.
- All sperms of a seminal vesicle are glued together into a large bundle called **spermatophore**.
- Spermatophore has three-layered wall: inner layer secreted by **utriculi majores**; middle layer secreted by **ejaculatory duct** and outer layer secreted by **phallic gland**.
- There are three asymmetrical chitinous structures called male **gonapophyses** or **phallomeres**. These are right phallomere, left phallomere (**largest**) and ventral phallomere (**smallest**).
- **Female organs** consist of **ovaries, oviducts, vagina, genital chamber, spermathecae, collaterial glands** and **female gonapophysis** (**ovipositor processes**).
- **Copulatory organ** of cockroach is **pseudopenis**.
- **Copulation** in cockroach **occur at night**.
- Each ovary (located in the abdominal segments 2 to 6) of cockroach consists of **eight ovarioles**.
- The egg of cockroach is **centrolecithal type, yolk being in the centre**.
- Nymph of cockroach **emerge out from ootheca**.
- Nymph of cockroach **undergoes 13 moults to reach the adult form.**
- **Ootheca** or egg case (**formed of a protein secreted by collaterial gland**) of **cockroach contains sixteen fertilized eggs**.
- **Metamorphosis** in cockroach is **incomplete or paurometabolous type**.
- **Instar** is a stage in the development of insect (larval instar, nymphal instar).
- Period between two moults in insects is termed as **stadium**.

- *Periplaneta americana* has **11 nymphal instars in female** and **12 nymphal instars in male**. *Blatta orientalis* moults 6 times.
- Gonapophyses **acts as external genitalia** & **help in copulation.**
- **Metamorphosis is regulated** by two hormones, **ecdysone** (secreted by prothoracic glands) and **juvenile hormone** or **neotinin** (secreted by corpora allata).

FROG (*Rana tigrina*)

- Frog, belongs to amphibia class of vertebrate, is a cold blooded or poikilothermic anamniote.
- Frog is **selected for type study** due to being non poisonous, easy to procure, less expensive, kept alive in captivity for a long time very easily and its internal anatomy can be seen by simply opening its body cavity.
- Frog is an **amphibious animal** *i.e.,* it lives in fresh water and on terrestrial environment.
- Because of possessing amphibious mode of life frog has streamlined body, the characteristic of the aquatic animals assisting in swimming in water.
- The body of the frog is divided into **head** and **trunk**, the true neck and tail of tadpole being absent.
- Because frogs have eyes and nostrils on the top of their head, they can see and breathe while the rest of the body is under water.
- Frogs have smooth skin and long legs to help them leap.
- **Skin** of frog **consists of two types of glands**: **mucous** and **poison glands.**
- Both glands are the **derivative of epidermis** but lying in the dermis.
- The **mucous glands** secretes a colourless watery fluid (mucous) that keeps the skin moist, glistening and sticky, whereas the **poison gland** secrete a mild poison for protecting the animal from the enemies.
- Skin of frog forms a **chief respiratory organ** as its moist surface brings about an exchange of respiratory gases in between the body of the animal and the environment.
- Being devoid of sweat glands, **skin of frog acts as an excretory organ** as the shedding of stratum corneum helps in removing the excretory wastes.
- Skin of frog larva produces certain enzymes (called **hatching enzymes**) which dissolves the egg membrane and help in hatching.
- **Exoskeleton is absent** is frog.
- Frog's endoskeleton is made by bones and cartilage. But in **tadpole larva** the **entire skeleton is cartilaginous**.
- The **skull** of frog is **dicondylic** and consists of the following regions - cranium, olfactory capsule, auditory capsules, orbits, upper jaw, lower jaw and hyoid apparatus.
- The skull of frog is **platybasic** *i.e.,* an inter-orbital septum is absent and cranium extends beyonds orbits.
- **Cranium is made by 6 bones** and divisible into 3 regions - **occipital region, fronto-parietal region** and **ethmoid region.**
- **Occipital region** is formed by two irregular exoccipital bones (replacing bones) which are present on either side of the foramen magnum.
- The **roof of the cranium is constituted by two fronto-parietals** fusing in the middle line forming compound bones (In tadpole stage **these two bones are distinct**).
- The **floor of the cranium** is covered by a median dagger shaped or inverted T-shaped bone called **parasphenoid.**
- **Sphenethmoid**, a ring shaped girdle bone **surrounds the anterior part of the cranium** and is **divisible into an anterior ethmoidal portion** and **a posterior sphenoidal portion**.
- **Auditory capsule** consists of **pro-otic bone** (saddle shaped cartilage bone) in the anterior face, **columnella auris** (derived from hyomandibular) and **stapedial plate** (cartilage) in the middle ear.
- Auditory capsules **communicates by fenestra ovalis.**
- **Fenestra ovalis** is the opening of pro-otic bone in which the columnella auris fits in.
- **Olfactory capsule** consists of ethmoidal portion of sphenethmoid, paired nasal, vomers and septomaxillaries.
- **Nasals** are large triangular bones covering the roof of olfactory capsules.
- **Vomers** form the floor of the olfactory capsules, bearing about seven vomerine teeth in the posterior margin of each bone.
- **Septomaxillaries** are a pair of small irregular bones bounding external nares. Each consists of a basal plate, small limb and a large limb.
- **Upper jaw** consists of **premaxilla** (anterior most bone of upper jaw with four to five teeth), **maxilla**

(side bone of upper jaw with four to five teeth) and **quadratojugals** (coma shaped, small slender bone of posterior outer margin of upper jaw).

- **Quadrate cartilage** is found at angle of jaw. **It is attached to lower jaw through autostylic suspensorium**.
- **Three pairs of suspensoria bones** connecting upper jaw with cranium are : **palatines, pterygoids** and **squamosals.**
- **Lower jaw** consists of **mento-meckelian** (found at the tip of lower jaw), **dentary** (outer surface of anterior half of jaw), **angulo-splenial** (3 pair of bones, at the inner surface and lower edge of the jaw) and **Meckel's cartilage** (found at the articular surface).
- **Teeth** are **entirely absent in the lower jaw** of frog.
- **Hyoid apparatus** lies in the floor of buccopharyngeal cavity and **provides attachment and support to the tongue**.
- Hyoid apparatus consists of **body** (a cartilaginous plate), **alar processes** (also called anterior process 'wing like'), **posterior processes** (present in posterior lateral margin), **anterior cornua** (two long processes articulating with auditory capsule) and **posterior cornua** (two short processes, replacing bones).
- Frog has total **ten vertebrae** including **urostyle**.
- **First vertebra** is called **atlas** with reduced centrum and without pre-zygapophyses and transverse processes.
- **2nd to 7th vertebra have same structure**, called **typical vertebrae**, characterized by **procoelous** condition, **centrum concave in front and convex behind**.
- **8th vertebra** is **amphicoelous** as the centrum is biconcave.
- **9th vertebra** is **acoelous** as the centrum is convex on both the sides.
- 9th vertebra is also called **sacral**, its transverse processes are backwardly directed and articulated with ilium of pelvic girdle (**sacroiliac joint**).
- **Urostyle** is the **10th vertebra**, as long as remaining vertebral column.
- Urostyle has dorsal keel or crest or ridge.
- Spinal cord in frog extends up to the anterior part of urostyle.
- **Ribs are absent in frog**, so sternum (also called breast bone) articulates directly with the pectoral girdle.
- Sternum of frog has **four parts** : **episternum** (anterior flattened circular cartilage), **omosternum** (inverted 'Y' shaped cartilage bone articulated with clavicles), **mesosternum** (rod-like cartilage bone articulated with epicoracoids), **xiphisternum** (terminal circular cartilage).
- **Vertebral column terminates** by **urostyle** in frog, **coccyx** in man and **pygostyle** in bird.
- Each half of **pectoral girdle** consists of **suprascapula** (a calcified cartilage), **scapula, coracoid, precoracoid, epicoracoid** and **paraglenoid cartilage.**
- **Clavicle** is a slender rod, separated from the coracoid by a wide gap called coracoid foramen.
- In between the coracoid and clavicle a big space is present. It is called **coracoid fenestra** or **coracoid fontanella.**
- In frog the **pelvic girdle** is V-shaped and composed of two similar halves called **os-innominatum.**
- Each *os-innominatum* is **composed of 3 bones- ilium** (greatly elongated and forms the major part), **pubis** (smallest, triangular calcified cartilage) and **ischium.**
- The **bones of forelimbs** includes **humerus**, **radio ulna** and **the bones of hand**.
- There are **four digits in forelimbs** and **five digits in hindlimb**.
- The bones of hindlimbs includes **femur, tibiofibula, astragalus, calcaneum** and **bones of foot.**
- **Tibio fibula** is the **longest bone** in frog.
- Tibio fibula **forms knee joint** with femur.
- Digital formula of forelimb and hindlimb are **0, 2, 2, 3, 3** and **2, 2, 3, 4, 3** respectively.
- The **digestive system** of frog shows two parts– food catching organ, the **alimentary canal** and the **digestive glands**.
- **Alimentary canal** consists of mouth, buccopharyngeal cavity, oesophagus, stomach, duodenum, ileum, rectum, and anus which opens out by cloaca.
- **Digestive glands** include **liver**, **pancreas** and the **glands of gut wall**.
- **Salivary glands are not present in frog**.
- The **buccopharyngeal cavity** is bounded by upper and lower jaws. At the floor of the cavity, there is a sticky tongue. It is useful to catch the prey.
- The **teeth** are **pleurodont, homodont** and **polyphydont** type. There are also a pair of

vomerine teeth. Teeth are useful only to avoid the escape of the prey.

- **Oesophagous** is **very short due to absence of neck**.
- The **food taken by frog** includes proteins, fats, carbohydrates, vitamins and mineral salts.
- Frog is **carnivorous** in its feeding habit and feeds on small insects, spiders and earthworm which are caught by throwing out the extensible sticky mucous coated tongue.
- Digestion starts in the stomach by the action of gastric juice. Food is completely digested in the intestine by the action of pancreatic juice and succus entericus.
- The end products of digestion are aminoacids from proteins, glucose from carbohydrates, fatty acids and glycerol from fats.
- Digested food is absorbed by villi of intestine and undigested food is sent out through cloaca.
- Frog respire by means of **cutaneous respiration** (skin), **buccopharyngeal respiration** (buccopharyngeal cavity), and **pulmonary respiration** (lungs).
- In frog, **diaphragm is absent** and is **not related with respiration**.
- Contraction of **sternohyal muscle** during breathing **lowers floor of oral cavity**.
- Contraction of **petrohyal muscle** during breathing **raises the floor of buccal cavity**.
- **Epithelial lining of the alveoli** of frog's lung **facing lung cavity is columnar and ciliated**.
- During pulmonary respiration of frog, **mouth remain closed**.
- In frog, glottis is controlled by muscles of **arytenoid cartilages**.
- The **lungs** of frogs are **not only the organs of respiration** but also an **hydrostatic organ** as they enable frog to float in water when they are inflated.
- In frog **cutaneous respiration takes place always**, therefore frog dies if the skin dries up as the cutaneous respiration is impaired.
- During severe cold winter frog will go for **winter sleep** or **hibernation.**
- During winter sleep lung breathing is stopped, while skin breathing continues which suffice the need of oxygen.
- During severe summer frog will go for **summer sleep or aestivation.**
- In this state it performs minimal metabolic activities, minimal cutaneous respiration and excrete uric acid.
- The **spring and rainy seasons** are the **periods of great activity for the frogs**.
- The **circulatory system** of frog shows **blood vascular system** and **lymphatic system**.
- The **life span of RBC** in frog is **100 days.**
- The heart of frog is **three chambered with two auricles and one ventricle**. It is enclosed in double walled pericardium. Two additional chambers are also present, these are - **sinus venosus** and **truncus arteriorus**.
- The **circulation can be described as incomplete double circulation**. The blood is pumped to various parts of the body by arteries which constitute the arterial system. Various veins of the venous system collect the blood and bring it to the heart.
- The **portal system** is **well developed** with both hepatic and renal portal systems.
- The **hepatic portal system** has much significance by taking the end products of digestion first to the liver.
- The **renal portal system** is significant by taking the impure blood to the kidney where it is filtered even before it reaches the heart.
- The **lymphatic system** is closely associated with blood vascular system.
- The lymphatic system consists of **lymph capillaries**, **lymph vessels**, **lymph hearts** and **lymph sinuses**.
- A colourless fluid called **lymph** flows through the lymphatic system.
- Lymph **acts as middle man** between vascular system and tissue fluids.
- **Spleen** is the **largest lymphatic gland**.
- At the base of the internal carotid artery of frog carotid labyrinth is present. It **work as chemo- and baroreceptor.**
- The sequence of heart contraction in frog are sinuous venousus, auricles and ventricles.
- The frog has a **highly developed nervous system**. It consists of **brain, a spinal cord** and **nerves**.
- Frog has **ten pairs of cranial nerves** arises from brain (olfactory, optic, oculomotor, trochlear, trigeminal, abducens, facial, auditory, glossopharyngeal, vagus) and **10 pairs of spinal nerve**.
- Frog shows **monocular visions** as the two eyes are situated far away from each other over the head and their images also do not coincide.

- Frog eye has **no power of accommodation**.
- **Harderian gland** present at the inner angle of the eye, produces oily secretion, which lubricate the eye ball and nictitating membrane.
- The **external ear is absent** in frog. Both ear drums or tympanic membrane are exposed. These is **only bone in the frog's middle ear**.
- In frog the **excretory system and reproductive system are intimately associated**. So these two systems are together referred as **urinogenital system**.
- The **excretory system** consists of a pair of kidneys, a pair of ureters, the urinary bladder and cloaca.
- Each kidney consists of a large number of excretory units called uriniferous tubules or nephrons.
- The nephron is divisible into two parts namely the **malpighian capsule** and **nephric tubule**.
- The malpighian capsule is the **filtration unit of excretory system** and the nephric tubule is **useful for secretion and selective reabsorption**.
- The **main excretory product** in frog is **urea**.
- The urea along with some unnecessary salts and water is collected into the urinary bladder in the form of urine. It will be stored there for some time and is sent out through cloaca. So frog is described as **ureotelic animal**.
- **Excretory product of tadpole larva** is **ammonia**.
- Kidneys are **pronephros** in tadpoles and **mesonephric in adult frog**.
- Frog shows **sexual dimorphism**. Male frog shows **vocal sacs** and **nuptial pads**.
- **Vocal sacs** are present at the junction of two jaws on the ventral side of the head.
- Vocal sacs are **resonators of the sounds and produce croaking sound**.
- **Amplexusory pads** or **nuptial pads** are **present on the index finger of the forelimb**.
- These pads **help male animal to clasp the female firmly during copulation**.
- The forelimbs of frogs are short and hindlimbs of frogs are long. Long hind limbs help in **leaping**.
- Neck is absent in frog as an aquatic adaptation.
- The posterior end of trunk of frog show cloacal aperture.
- In frog testis is attached to the kidney by **mesorchium** (peritoneal layer).
- In adult male toad **bidder's organ** is present. If testes are removed bidder's organ will become ovary.
- The **mass of sperms** liberated by male frog is called **milt**.
- The **mass of eggs liberated by female frog** is called **spawn**.
- In frog **fertilization is external**.
- Zygote undergoes cleavage and develops into morula and blastula. **The cleavage is holoblastic and unequal**.
- The blastula changes into gastrula by **epiboly**, **modified invagination** and **involution**.
- The gastrula has three germ layers which further differentiate and give rise to various organs.
- The **life history of frog includes** three stages - **egg, larva and adult**.
- The **tadpole undergoes metamorphosis** to become the adult. The **metamorphosis is complete**. Finally the aquatic gill breathing, herbivorous, fish like tadpole transforms into an amphibious, lung breathing, carnivorous adult frog.
- **Thyroxine controls the metamorphosis** in frog.
- The **tail of tadpole** is the **locomotory organ**.
- During metamorphosis the tail is absorbed by **auto-phagocytosis.**

RABBIT (*Oryctolagus cuniculus*)

- *Oryctolagus cuniculus* or the rabbit is a **fossorial, nocturnal**, **herbivorous**, and **polygamous animal**.
- Rabbit is **crepuscular**(that is coming out of burrows for feeding in twilight chiefly at dawn or dusk), **timid**, **can be domesticated**.
- Its body is **pointed anteriorly** and **broad posteriorly** which is covered with fur and hairs.
- The rabbit are **gregarious** in habit *i.e.* they live in groups and even several families consisting of hundred of rabbits may live in one burrow.
- The body is divided into **head, neck, trunk** (which is **divided into thorax and abdomen**) and **tail**.
- **Head** is large, pear shaped, distinct and anterior pointed blunt snout has a terminal, transverse slit like **mouth**, which is divided into left and right equal halves due to a vertical cleft, which continues upto the nostrils. Such divided lips are known as **hare lip**.
- Due to hare lip **front incisors are exposed**.
- From the sides of upper lip thick tactile hairs or **vibrissae** or **whiskers** project outward.
- **Vibrissae** are stiff, long and sensory in function because they have nerve ending at their base.

- **Nictitating membrane** is present in the inner corner of the eye, which is movable and used for cleaning cornea.
- Just above the mouth, large, oblique slit like, olfactory **nostrils** are present which is **respiratory in nature.**
- Ear opening is surrounded by movable pinna. Tympanic membrane is sunken at the base of external auditory meatus.
- Vocal sacs are **absent**.
- **Neck** is short, flexible and well demarcated from head and trunk.
- **Trunk** is differentiated into **anterior thorax** and posterior **abdomen** which is covered with hairs.
- Paired forelimb and hind limbs are present. Forelimb bears **5 clawed digit adapted for digging the burrow**. Hind limb **bears 4 clawed digit**, which is **adapted for walking and leaping**.
- On the ventral side between thorax and abdomen 4-5 pairs of teeths or nipples are present which are functional in female only.
- Separate anus and urinogenital opening present at the hind end.
- Short, bushy, curved upward tail is present. Tail is **used for giving warning, signals, when danger approaches** and **as balancer during leaping**.
- A female reaches maturity at the age of **6 months** only and average **life span to about 8 years**.
- At the time of birth the young are blind, deaf, naked (hairless) and helpless. They are fed on milk by mother who shows parental care.
- They show **coprophagy** or **rejection**, by eating their soft night doppings without mastication, so the same food passes twice through gut to provide maximum nourishment.
- **Skin** of rabbit is made of **epidermis** and **dermis.**
- **Epidermis** is highly stratified. Stratum corneum is composed of hard, scale-like, dead, fully, keratinized flattened cells.
- The complex epidermis is primarily made of two zones–the deep **malpighian layer** and the superficial **cornified layer**.
- **Malpighian layer** is further divided into **stratum germinativum**, **stratum spinosum** (also called **prickle cell layer**), **stratum granulosum** and **stratum lucidum**.
- The outermost cells on the skin surface are **thin dead and fully keratinized.**
- **Stratum granulosum** contains basophilic and refractile **keratohyaline** granules.
- In **stratum lucidum**, keratohyaline granules are dissolved and transformed into **eleidin** which makes cells semitransparent, shiny and waterproof.
- In **stratum corneum**, eleidin is replaced by **keratin,** a scleroprotein which is insoluble in water.
- When keratin is synthesized in a cell, the cell is said to be keratinized or cornified and it dies.
- The cells of stratum corneum are **non-living, flattened**, **keratinized without nuclei.**
- Presence of dead dry cornified cells of stratum corneum helps to **prevent evaporation of water from its surface**.
- **Dermis** is thickest, consists of connective tissue fibres, unstriped muscles, blood capillaries, nerves, fat cells, tactile receptors and pigment cells.
- Deeper part of the dermis is composed by subdermal **adipose tissue** or **panniculus adiposes**.
- It is concerned with **storage of fat.**
- Pigment granules are present in the hairs. **Pigment cells found** in the **basal layer of epidermis.**
- Skin is **highly glandular** due to presence of sweat glands, sebaceous glands, mammary glands and scent glands, but **mucous gland is absent**.
- Skin or integument **serves a variety of important functions** like it gives shape, protection, defence, homoiothermy (maintenance of a fairly constant body temperature), synthesis of vitamin D, excretion, secretion, sexual selection etc.
- The **skull** of rabbit consists of two main regions– **posterior cranial region** and **anterior facial region**.
- Three segments of cranium are : **occipital segment, parietal segment** and **frontal segment**.
- There are **four bones in occipital segment** surrounding foramen magnum: **supraoccipital** (1), **exoccipitals** (2) and **basioccipital** (1).
- The skull of rabbit is **dicondylic with two occipital condyles**.
- There are **five bones in parietal segment**. They are **parietals** (2) in the roof, **alisphenoids** (2) in sides and **basisphenoid** (1) in the floor.
- A depression called **"sella turcica"** is on the basisphenoid **to lodge pituitary gland.**
- There are **five bones in frontal segment**. They are **frontals** (2) in the roof, **orbitosphenoids** (2) in sides

and **presphenoid** (1) in the floor.

- An **ethmoid bone** (cribriform plate) perforated with many small holes closes the cranial cavity in front.
- Auditory capsule consists of **periotic bone** and **tympanic bulla**.
- **Periotic** is a compound bone formed by the fusion of **pro-otic**, **epiotic** and **opisthotic**.
- Periotic is **located between squamosal and occipital ring**.
- **Tympanic bulla** is a flask-shaped bone applied to outside of periotic between the basisphenoid and squamosal.
- Tympanic bulla encloses tympanic cavity or middle ear containing tympanic membrane and a chain of the 3 ear ossicles, which from outside are **malleus, incus** and **stapes**.
- **Stapes** is the **smallest bone in the body**.
- Ear ossicles are **concerned with hearing.**
- Periotic consists of **two parts** : an internal hard bony **petrous part** enclosing internal ear, and a posterior light and **porous mastoid part**.
- **Orbits** are situated on the sides of frontal segment of the cranial region.
- The skull of rabbit is **tropibasic**, *i.e.*, an inter-orbital septum is present.
- The front wall of each eye orbit contains a small bone called **lachrymal** having a notch for tear duct.
- **Facial region** consists of **bones of olfactory capsule** and **jaws**.
- **Olfactory capsule** consists of **nasals** in the roof, **vomer** in the floor (median formed by the fusion of two), **premaxillae** and **maxillae** at the sides.
- **Mesethmoid** or **internal septum** separates two nasal chambers.
- Each olfactory or nasal chamber encloses an irregular mass of **turbinal** or **scroll bone**.
- Scroll bones help in **increasing the sensory surface of olfactory chamber**.
- The **upper jaw** consists of the following bones: premaxilla, maxilla, palatine, pterygoid, squamosal and jugal.
- Each ramus of lower jaw is made up of a single **dentary**.
- Dentary has a conspicuous **condyle**, **coronoid process** and **angular process**.
- Teeth in each dentary are **incisor (1), premolars (2)** and **molars (3)**.
- The **jaw suspensorium** in rabbit is **craniostylic** *i.e.*, lower jaw articulates with upper jaw by squamosal.
- Main part of the body of **hyoid apparatus** located beneath and supporting root of tongue, is called **basihyal**.
- Vertebrae of mammals are **acoelous** or **amphiplatyan**.
- Total number of vertebrae in rabbit varies from **45 to 47**.
- The vertebral column in divisible into **five regions**, namely– **cervical, thoracic, lumbar, sacral** and **caudal**.
- Vertebral formula of rabbit is $\mathbf{C_7T_{12\text{-}13}L_{6\text{-}7}S_4Cd_{16}}$.
- The first cervical vertebra is **atlas**. **Centrum** is **absent**. It is articulated to skull through occipital condyle, **zygapophyses** are **absent**. **Odontoid fossa** are **present**.
- Second cervical is the **axis**. It has **odontoid process**.
- All cervical vertebrae except 7th possess **vertebrarterial canals** for the passage of cervical blood vessels and nerves.
- In **between the centra**, there are **intervertebral discs of fibrocartilage**.
- The central portion of the vertebral disc is called **nucleus pulposus** which represents the remnant of notochord in the adult.
- Sternum of rabbit consists of **seven sternebrae**, and a **xiphoid cartilage**.
- Sternum is composed of **seven rod-like pieces**.
- The **first piece** is called **pre–sternum** or **manubrium**.
- Remaining five sternebrae constitute **mesosternum** (**gladiolus**).
- This is followed by rod-like last sternebra **metasternum**. Metasternum terminates in an expanded plate of cartilage, the **xiphisternal cartilage** or **xiphoid cartilage**.
- There are **12 or 13 pairs of thoracic ribs** present in a rabbit.
- **Three types of ribs** in rabbit are : **true ribs** (1st to 6th pair); **false ribs** [7, 8 and 9th pair (3 pairs)]; and **floating ribs** [10, 11 and 12th pairs (3 pairs), not attached to sternum].
- Vertebral rib is **bicephalous** (with two heads). It is articulated to thoracic vertebra by tuberculum to transverse process and by capitulum to centrum.
- **Pectoral girdle** of rabbit consists of two bones, a membranous bone called **clavicle** and a large replacing bone called **shoulder blade** or **scapula-coracoid**.

- Dorsal or vertebral edge of scapula is made of a thin strip of cartilage, the **suprascapula**.
- A **glenoid cavity** for articulation of head of humerus is present at the tip of scapula and coracoid process. Clavicle is articulated with **acromian process.**
- **Pelvic girdle** of rabbit is **W-shaped**. Each half consists of four bones namely **ilium, ischium, pubis** and **cotyloid**.
- A **small cotyloid bone** is present on the inner side of acetabulum between ilium and ischium.

Cotyloid bone (acetabular bone) is **not found in the pelvic girdle of frog.**

- In rabbit, a ninth carpal may be present called **pisciform, sesamoid bone.**
- In rabbit, there are **five digits** in forelimb and **four digits** in hindlimb.
- Digital formula of **forelimb** is **2, 3, 3, 3, 3.**
- Digital formula of **hindlimb** is **0, 3, 3, 3, 3.**
- Rabbit has **no hallux**.
- **Femur** is the **longest** and **stoutest bone** of the body in a mammal. Proximally it bears a **head, greater trochanter, lesser trochanter** and **third trochanter**.
- The proximal end of tibia bears a small sharp ridge called **cnemial crest**.
- Proximal part of humerus bears a slight **deltoid ridge** and distally it bears a pulley like **trochlea**.
- Above trochlea are present **supratrochlear foramen** and **olecranon fossa.**
- The **digestive system** of rabbit consists of **alimentary canal** and **digestive glands.**
- The various parts of alimentary canal are **mouth, vestibule, buccal cavity, pharynx, oesophagous, stomach, small intestine, caecum, large intestine** and **anus**.
- **Dental formula** of a rabbit is **2033/1023**.
- Total number of teeth in rabbit is **28**.
- Number of teeth in upper jaw of rabbit is **16** and **12** in the lower jaw.
- Rabbit has no **canine teeth**, it is **herbivorous**.
- In rabbit, teeth are **heterodont, diphyodont** and **thecodont**.
- The **mouth** of the rabbit is a transverse slit-like terminal aperture situated at the snout.
- The mouth opens into a large spacious **buccal cavity** between the jaws.
- The **tongue** in its dorsal surface bears numerous papillae containing taste buds.
- The buccal cavity merges behind into a short, narrow chamber, the **pharynx**.
- A soft palate divides the pharynx into **3 parts** as **nasopharynx** lies dorsal to the soft palate, the **oropharynx** below the soft palate, and both communicate behind with the **laryngopharynx**.
- The floor of laryngopharynx carries a median verticle slit, the **glottis** leading into the **larynx**.
- Larynx is guarded by a bilobed thin cartilaginous flap or tissue, the **epiglottis**.
- The laryngopharynx leads posteriorly into the oesophagus through a wide aperture, the **gullet**.
- **Oesophagous** is a long narrow, elastic and muscular tube. Its inner wall has several longitudinal folds.
- The **stomach** is differentiated into **three regions**: a broad **cardiac region** into which oesophagus opens, a narrow **pyloric region** which leads into the duodenum and the third part is situated in between cardiac and pyloric regions called **fundic region**.
- Small intestine following stomach made of three parts– **duodenum, jejunum** and **ileum**.
- Large intestine consists of two regions– **colon** and **rectum**.
- At the junction of ileum and colon a wide about 50 cm long, thin walled tube, the **caecum** is present.
- **Rectum** opens outside through anus, situated at the base of tail and guarded by **anal spincter**.
- Rectum of rabbit is the narrow terminal part with the faecal pellets present inside which gives it a **beaded appearance**.
- Distally caecum terminates in a small, about 15 cm long narrow thick walled blind tube, the **vermiform appendix**.
- The caecum is very **large** and **spacious in herbivores** such as rabbit, horse and ass.
- Caecum of rabbit is thin wall tube with peculiar external spiral constriction, which marks the presence of an internal spiral valve.
- **Digestion of cellulose** in rabbit takes place in caecum (stomach in ruminants).
- The various **salivary gland** of rabbit are **parotid gland** (situated at the base of pinna), **submandibular gland** (situated on the inner side of the angles of lower jaw); **sublingual glands** (situated below the tongue) and **infra–orbital glands** (situated below the orbit).
- **Liver of rabbit** is partly **divided into 5 lobes** : three

lobes on left side are a small **spigelian, left lateral** and **left central**, while two lobes on the right side are **caudate** and **right central** or **cystic**.

- The cellulose in the diet of rabbit remains undigested, for which it passes in the caecum. Thus the digestion of cellulose occurs in the caecum which is well developed in rabbit and herbivorous mammals.
- Cellulose decomposing bacteria and protozoans are **found in the caecum**, where it is decomposed to soluble sugars.
- Rabbit feeds on night excreta (**coprophagy**) which is moist and soft for the digestion of remaining cellulose.
- **Respiratory system** of rabbit consists of nasal cavity, pharynx, larynx, trachea, bronchi, bronchioles and alveoli.
- A cartilaginous partition called **mesethmoid** separates the right and left nasal passage or respiratory passage.
- The respiratory passage is lined by richly vascularized, ciliated, mucous secreting epithelium.
- Respiratory passage performs the function of warming the air before entering into trachea and lungs; filtering air etc.
- **Lungs** are the **sole respiratory surface** in rabbit and are **without central cavities**.
- Lung is divided into **two lobes**-right and left lung.
- **Right lung** is divided into **four lobes** while **left lung** into **two lobes**.
- The **larynx or voice-box** is the **sound producing organ** of rabbit which is a modified anterior part of the trachea.
- The larynx leads into the trachea which is a long tube **supported by a series of incomplete rings of elastic cartilage**.
- The larynx is supported be **four cartilages**.
- The largest shield-shaped and most anterior is the **thyroid cartilage** which supports the larynx ventrally and is incomplete dorsally. Just a bit posterior to it is a ring-like **cricoid cartilage** which is broad on the dorsal side but narrow ventrally.
- A pair of **arytenoid cartilages** are situated at the anterior end of the dorsal side of the cricoid.
- There is also a pair of small nodules the **cartilages of Santorini**.
- Rabbit **does not produce audible sound.**
- **Trachea** is **lined with a pseudostratified ciliated epithelium** and **helps in pushing mucous out.**
- Even there is no air in trachea, it **does not collapse due to presence of C-shaped narrow cartilaginous rings.**
- Larynx of rabbit **acts as a valve for controlling the movement of air and organ for producing low pitched sound.**
- The **mechanism of breathing** consists of intake of fresh air into the lungs **(inspiration)** and elimination of respired air from the lungs **(expiration)**.
- **Inspiration** is an **active process** during which firstly the **external intercostal muscles** contract dragging the ribs forwards and downwards and the sternum is moved downwards.
- **Gaseous exchange takes place in the alveoli** where inspired air comes in contact with the blood capillaries.
- Oxygen from the air diffuses in the blood and CO_2 from the blood diffuses out in the air through the thin alveolar wall.
- **Expiration** is more or less a passive action during which internal intercostal muscles contract, thereby the ribs and sternum attain their normal position.
- Ribs, intercostal muscles and diaphragm are **helpful in pulmonary respiration.**
- The respiratory pigment **haemoglobin,** present in RBC of rabbit, plays a pivotal part in the transport of O_2 from blood to tissue and of CO_2 from tissue to blood.
- **Scroll like bones** are present in the cavity of nasal passage which are called **turbinals**.
- There are three such structures called **naso-turbinals, ethmo-turbinals** and **maxillo-turbinals**.
- In rabbit, there is **no sexual difference pertaining to ventilation movements** in male and female as observed in human.
- **Blood vascular system** of rabbit is of **closed type**.
- The **blood vascular system** of rabbit consists of a circulatory media called the **blood**, channels through which the circulatory media flows called **blood-vessels** and a central pumping organ, the **heart** which pumps the circulatory media in the blood vessels.
- The **lymph hearts are not found in rabbit**, therefore the lymph flows in the lymph vessels with the help of body muscles.
- Mature RBC of rabbit are **biconcave, enucleate, contain haemoglobin** and **contain antigens on their plasmalemma.**

- RBC have a **short life**.
- Fragile, weak, senescent and abnormal RBC are phagocytised by **spleen cells** which is aptly called the **'grave yard' of RBC.**
- **WBC** are **nucleated**, fewer in number as compared to RBC, **devoid of pigment and are motile** (by pseudopodia).
- **Heart** of rabbit is **4-chambered** and is enclosed by a double walled **pericardium**.
- The **pericardial cavity** present between the outer parietal and inner visceral pericardium is filled with **pericardial fluid** and **protects the heart from external shocks, lubricates it to facilitate smooth systolic and diastolic movement.**
- The **heart muscles** (=cardiac muscles) are **striated** but **involuntary**. They consists of outer **epicardium**, middle **myocardium** and inner **endocardium**.
- Rabbit **does not have sinus venosus** which is incorporated in the wall of right auricle. The **truncus arteriosus is also absent**.
- The two aorta–the pulmonary and systemic **arise directly and separately from the ventricle.**
- The **eustachian valve** is present between the openings of 2 pre-cavals and **thebesian valve** (form a crescentic fold) bounds the opening of left pre-caval.
- The **ventricles** are **thick-walled and muscular** as compared to atria.
- The left ventricle is **larger and more muscular than the right ventricle.** This difference is due to the fact that left ventricle pumps blood to all parts of the body while the right provides the propulsive force to drive the blood only to lungs.
- The longitudinal ridges present on the surface of ventricle is called **columnae carnae** which extends into the ventricular cavity.
- **Papillary muscles** are conical muscular projections on the walls of ventricles.
- The opening between the right auricle and right ventricle is guarded by **tricuspid** (tri = 3, cusp = flaps) **valve**, while the one between left auricle and left ventricle is guarded by **bicuspid or mitral valve**.
- The rate of heart beat in rabbit is **210/min**. Each heart beat consists of a contraction (systole) and relaxation (diastole).
- The systole **creates the necessary pressure to push the blood**, while diastole **facilitates refilling**.
- In rabbit the oxygenated and deoxygenated blood flows *via* different channels (circuits). The blood during its complete circulation passes through heart twice and hence this is called **double circulation**.
- The **blood vessels** in rabbit is a system of closed channels through which blood flows.
- The wall of blood vessel is typically made of three layers: **tunica externa; tunica media;** and **tunica interna.**
- Arteries carry blood **away from heart**. They are **stronger** and **thicker than veins.**
- The **largest artery** in the body is **aorta.**
- Both pulmonary artery and renal artery have a **thick muscular coat as compared to the respective veins.**
- **Capillaries** are the **smallest blood vessels** in the body.
- Capillary has **no muscular wall**. Its wall is made of a single layer of flat **endothelial cells** and is consequently very **permeable to water and small solutes**, but **not to proteins and other macromolecules**.
- One **major difference between an artery and vein** is that vein has a **thin muscular wall**.
- Veins **contain valves to prevent backflow of blood.**
- Weak valves can lead to **varicose veins or haemorrhoids.**
- All veins **carry deoxygenated blood except pulmonary veins**. Pulmonary veins carry pure blood from lungs back to heart.
- Renal portal sysem is **absent in mammals**, only **hepatic portal system is present.**
- **Nervous system** of rabbit consists of **central nervous system** (brain and spinal cord); **peripheral nervous system** (cranial and spinal nerves) and **autonomic nervous system** (sympathetic and parasympathetic nervous system).
- **Brain** lies in the cranial cavity of the skull surrounded by **3 meninges: duramater** (outer), **arachnoid** (middle) and **piamater** (inner).
- The brain of rabbit can be divided into three regions: (a) the **fore-brain** (or **prosencephalon**), (b) the **mid-brain** (or **mesencephalon)**, and (c) the **hind-brain** (or **rhombencephalon)**.
- Fore brain consists of **olfactory lobes**, **cerebral hemispheres** and **diencephalon**.
- **Olfactory lobes** are **responsible for controlling the organs of smell.**

- The **cerebral hemispheres** (or **telencephalon**) are **well developed** and form about **2/3 of the whole brain**.
- **Corpus callosum** is a thick whitish band of semicircular nerve fibres interconnecting two cerebral hemispheres (found only in mammals).
- **Genu** is a small front part and **splenium** is the posterior part of corpus callosum.
- **Corpus striatum** is found in the floor of cerebrum.
- **Diencephalon** is a small and narrow posterior part of the forebrain.
- Diencephalon is dorsally overlapped by cerebral hemispheres except for **epiphysis or pineal body**.
- **Corpus albicans** is the **swollen part of pituitary stalk.**
- **Midbrain** of rabbit **consists of four optic lobes** (= **corpora quadrigemina**).
- Optic lobes are solid and **optocoels are absent**.
- **Crura cerebri** or **cerebral peduncles** are two thick fibrous white matter tracts on the ventral and lateral regions of midbrain.
- **Hindbrain** includes **cerebellum and medulla oblongata**.
- **Cerebellum** has five lobes namely a median **vermis**, **two laterals** and two **flocculi**.
- The anterior ventral part of cerebellum forms **pons varolii**.
- **Arbor vitae** is a branched tree-like structure composed of white matter, seen in the section of cerebellum.
- Cavity in olfactory lobe is known as **rhinocoel.**
- **Ventricles I and II** are called as **paracoels** or **lateral ventricles**.
- **Ventricle IV** is the **metacoel**.
- **Foramen of Monro** connects lateral ventricles with diocoel.
- Cavity of midbrain called **iter** or **aqueduct of Sylvius communicates diocoel with fourth ventricle of hindbrain.**
- **Optocoels** are **present in frog** but **absent in rabbit.**
- **Formamen of Magendie** is the aperture present in the roof of fourth ventricle or metacoel.
- **Foramina of Luschka** are present on the lateral wall of metacoel.
- Foramen of Magendie and foramina of Luschka "three holes" **permit cerebrospinal fluid to flow out** into the subarachnoid space from metacoel.
- The medulla oblongata **exits from the skull *via* foramen magnum** and becomes spinal cord which extends to the trunk region of the rabbit.
- Spinal cord in rabbit **extends upto 4th lumbar vertebra.**
- **Filum terminale** is the terminal non-nervous part (made of only piamater) of spinal cord in the lumbar region.
- **Cauda equina** (horse-tail) is the tail-like collection of roots of spinal nerves at the posterior end of spinal cord.
- In spinal cord, **white matter** is found outside the **gray matter** (reverse in brain).
- Internally the spinal cord consists of a **neurocoel** which is continuous with the metacoel of brain.
- Neurocoel is lined by **ependymal epithelium** and **filled with cerebrospinal fluid.**
- Rabbit has **12 pairs of cranial nerves** just like all other amniote vertebrates (anamniotes have 10 pairs).
- These nerves are of 3 **types** (a) **sensory,** e.g. olfactory, optic, auditory (b) **motor,** e.g. oculmotor and (c) **mixed** *i.e.* have both sensory and motor fibres.
- **Spinal nerves** of rabbit **arise from spinal cord** (in pairs) and **exit *via* intervertebral foramen** between the vertebra.
- Each spinal nerve arises from a dorsal root (sensory) and a ventral root (motor).
- The **spinal nerves** in rabbit are **37 pairs** which can be divided into five zones, *viz.,* **8 pairs cervical**, **12 pairs thoracic**, **7 pairs lumbar**, **4 pairs sacral** and **6 pairs caudal nerves**.
- The autonomic nervous system in mainly **responsible for controlling the involuntary activities of the body.**
- The sympathetic and parasympathetic nervous systems **work independently but opposite to one another.**
- Thus each visceral organ is supplied by a **sympathetic fibre** which **stimulates** the organ to start the function and a **parasympathetic fibre** which inhibits and stops the function.
- Sympathetic preganglionic motor fibres in **rabbit** occur only in its **thoracic** and anterior 3 pairs of **lumbar spinal nerves.**
- Total number of sympathetic ganglia in rabbit is **18 pairs.**
- Sympathetic nervous system **increases defence system of body against adverse conditions.** It is **active in stress condition, pain, fear and anger.**

- Parasympathetic provides **relaxation, comfort, pleasure at the time of rest.** It helps in the **restoration and conservation of energy.**
- The **hypothalamus** controls and integrates the autonomic nervous system.
- Sympathetic is **accelerator** by release of **adrenaline**.
- Parasympathetic is **inhibitor** by release of **acetylcholine**.
- Rabbit, like all other mammals has a wide variety of sensory organs which perceive diverse stimuli. The type of receptors are–
  - **Tactile** (touch) or **thigmoreceptor** [sensitive to touch (cutaneous)];
  - **Pressure receptor, baroreceptors** (Meissner's corpuscles);
  - **Olfactory sensilla** [in nasal epithelium (Jacobson's organ)];
  - **Gustatory sense organs** (taste buds present on tongue);
  - **Sensilla of common chemical sense** (detect deleterious chemicals and when stimulated give avoidance reaction);
  - **Proprioceptor** (present in stomach);
  - **Pain receptors** (present in skin).
- In rabbit all cutaneous receptors are naked. Vibroreceptors of rabbit are naked nerve ending present upon the follicles of vibrissae.
- The nictitating membrane in rabbit is a **vestigeal structure** and is called **plica semilunaris.**
- Rabbit exhibit **ureotelic excretion** *i.e.* its principal nitrogenous waste is **urea**.
- The **urinary** or **excretory** and the genital or **reproductive systems** are closely associated with each other, therefore, these systems are considered together and collectively known as **urinogenital system.**
- The excretory system consists of paired **kidney**; paired **ureter** (which open independently into the urinary bladder); **urethra**; and **urinogenital aperture** (which **acts as common passage for urine and sperm** in male and is present on the ventral aspect of glans penis. In female the **urethra opens into the vulva**).
- **Kidney** of rabbit is bean shaped, **metanephric**, measure 25 mm in length, dark pink in color.
- The right kidney is **usually larger than the left**.
- Both kidney are **convex on the outside** and **concave on the inner side.**
- A notch-like structure called **hilus** in present through which renal artery, nerves; lymphatic channels enter the substance of the kidney, and the renal vein and ureter exit.
- **Afferent arteriole** carries blood to glomerulus while **efferent arteriole** collects blood from it.
- The diameter of afferent arteriole is **much more than that of efferent arteriole.**
- In nephron Henle's loop is present **to concentrate the urine**.
- Rabbit manifests **sexual dimorphism.**
- **Male reproductive system** consists of **testis** [(= cytogenous gland), scrotal, and site of spermatogenesis and androgenesis]; **epididymis** (tripartite); **vas deferens**; **urethra**; **penis** and associated male genital glands includes **prostate gland** (major contributor of seminal fluid); **seminal vesicles** (= uterus masculinus); **Cowper's gland** (=bulbo-urethral gland); **perineal gland; rectal glands.**
- In rabbit, the testes are migratory *i.e.* present in scrotum **during breeding season** but are pulled up in abdominal cavity in the **non-breeding state.**
- Testicular sperm of rabbit transit *via* rete testis and vasa efferentia into epididymis.
- **Female reproductive system** of rabbit consists of **ovaries**, **fallopian or uterine tubes, vagina, urethra**, **vestibule**, **vulva**, accessory reproductive glands (include bartholin's, rectal and perineal glands.
- **Uterus** is **bicornuate** in rabbit.
- Rabbits are **polyestrous mammals**.
- The **ovulation** is of the **reflex (induced) type** and mating is pre-requisite for it.
- Fertilization of ovum is **internal** and occur **in the upper part of oviduct.**
- Rabbit has well **developed endocrine system** with **pituitary** as **master gland**.

End of the Chapter

Chapter 34

Water Relations of Plants

- **Water** is essential for all physiological activities of plants.
- Water plays a key role in photosynthesis and acts as a source of oxygen.
- Water also plays a direct role in many useful reactions operating in cells.
- Water is a **major constituent of protoplasm** (about 90%).
- Protoplasm has a capacity of retaining its life even when there is **bare minimum of water**.
- If the bare minimum of water **decreases** protoplasm cannot restore its life even after the addition of water.
- **Properties of H_2O :** Water has high specific heat, latent heat of evaporisation, adhesive force, cohesive force and high surface tension.
- Two hydrogen atoms are attached to the atom of O_2 at an angle of **105^0**.
- Water is an **universal solvent**.
- Water is **useful for maintaining the turgidity of cells** which is **essential for cell enlargement**, **growth and the form of herbs**.
- Water is a **reactant** in many biochemical reactions.
- **Dispersal of fruits**, **seeds**, **spores** and **mobility of gametes** depends upon by water.
- Water is used to **regulate the heat in plants through transpiration**, **guttation**, **evaporation**.

DIFFUSION, IMBIBITION, OSMOSIS

- Physical processes associated with water relations of plants are : **diffusion**, **imbibition**, and **osmosis**.
- The movement of ions, atoms or molecules from a region of higher concentration to a region of lower concentration is called **diffusion**.
- Diffusion **cannot occur between two solids**.
- Solutions are formed by diffusion of **solute in a solvent**.
- When alcohol and water are mixed **water diffuses into alcohol** and **alcohol diffuses into water**.
- When O_2 and CO_2 are mixed **O_2 diffuses into CO_2** and **CO_2 diffuses into O_2**.
- **A plant cells has three physiological compartment -** cell wall, protoplast and central vacuole.
- Two membranes separate these three compartements, tonoplast around central vacuole and plasmalemma around protoplast but below the cell wall. Both are selectively permeable.
- Central vacuole contains an osmotically active fluid called cell sap.
- **Diffusion processes involved in plants** are -
  - Passive absorption of ions
  - Entry of ions into apoplast
  - Liberation of water vapour through stomata
  - Exchange of gases through stomata
  - Entry of water from the cell wall into the cell.
- **Apoplast** is the system of cell walls extending through a plant body and along which water containing mineral salts, etc. can move passively. It is an important pathway for movement of these substances outside the xylem.
- **Symplast** is the living system of interconnected protoplasts extending through a plant body.
- The process of increase of the volume of a solid due to absorption of water by hydrophilic colloids is called **imbibition**.
- Increase of a solid is due to **absorption of water** by hydrophilic colloids (imbibants) such as proteins, cellulose, starch etc.
- Imbibition **involves three important**

characteristics : **volume change**, **heat production** and **pressure development**.

- As the water molecules are arranged on the surface in the process of imbibition, they **lose some of their kinetic energy** which then appear as the heat in the system.
- The substance which shows imbibition is called **imbibant** and the pressure created by imbibant is called **imbibitional pressure**.
- Wooden pieces of doors and windows become tight during **rainy season** due to the process of **imbibition**.
- Rubber **does not show** imbibition.
- Imbibition processes in plants are exhibited by the following – **(i) raisins, (ii) dry seeds, (iii) cell walls, (iv) velamen roots, (v) dry lichens** etc.
- **Significance of imbibition** –
  - It is the **dominant and first step of water absorption.**
  - Imbibition is the **first step in germination of seeds**, *i.e.*, first imbibition occurs by seed coat and then by embryo and other parts.
- The term osmosis was coined by **Abby Nollet** (1978).
- **Osmosis** is the diffusion of water from its pure state into a solution when the two are separated by semipermeable membrane or it is the diffusion of water or solvent **from a dilute solution to a strong solution** through a semipermeable membrane.
- A solution which can cause an osmotic entry of water into it is said to be **osmotically active solution**.
- Membrane which **allows diffusion of both solvent and solute molecules and ions through** it, is called **permeable membrane**, *eg.*- cellulose wall of cells.
- Membranes which **do not allow diffusion of both solvent and solute particles** through them are called **impermeable membranes**, *eg.*- suberised cell walls in plants.
- Membranes which **allow some solutes to pass through them along with the solvent molecules** using different mechanisms, are called **differentially permeable membrane**, *eg.*- Plasma membrane, tonoplast and membrane surrounding cell organelles.
- Semipermeable membranes **allow diffusion of solvent molecules** but **do not allow the passage of solute molecules**.
- **Egg membrane** is a semipermeable membrane.
- Semipermeable membranes prepared in the laboratory are **collodian**, **cellophane**, **parchment paper**, etc.
- Semipermeable membrane is permeable to ions of salt but not to the **sugar molecules**.
- Common experiment to demonstrate osmosis is **thistle funnel experiment**.
- Experiment useful for demonstrating osmosis by using a living tissue is **potato osmoscope**.
- **Osmosis in plants helps in** –
  - Absorption of water
  - Maintaining turgidity and expansion of cell
  - Movement of water
  - Opening and closing of stomata.
- **Reverse osmosis** is expulsion of pure water from a solution through a semipermeable membrane under the influence of external pressure higher than O.P. of solution.
- Reverse osmosis is **used in removing salts from saline water as well as extrapurification of water.**
- **Signification of osmosis** are –
  - Osmosis is responsible for absorption of water by roots.
  - Osmosis is responsible for turgidity of plant organs.
  - Osmosis is responsible for cell to cell movement of water.
  - It is responsible for opening & closing of stomata.
  - It is responsible for resistance of plant to drought, frost, etc.
- **Factors controlling osmosis** are –
  - Presence of a perfectly semipermeable membrane is a must for the operation of osmosis.
  - Concentration of dissolved solute on the two sides of semipermeable membrane.
- Pressure required to prevent the entry of water into a solution is called **osmotic pressure**.
- The term osmotic pressure was proposed by **Pfeffer**.
- Osmotic pressure is a **positive value**.
- Pure solvent has **no osmotic pressure**.
- When solute is added to pure solvent it **develops osmotic pressure**.

- Osmotic pressure (O.P.) can be **calculated by OP – CRT**, *where* C is molar concentration of solution, R is gas constant and T is absolute concentration.
- The value of osmotic pressure is related to **number of particles** and **not molecules**.
- In **non-electrolytes** the number of particles and number of molecules is **same**.
- In **electrolytes** (eg. NaCl) number of particles (or ions) is **more** than the number of molecules.
- Osmotic pressure value of solution of ionising substance will be **greater** than osmotic pressure of solution of non-ionising substance though their concentrations are same.
- Pressure exerted by diffusing ions or molecules is called **diffusion pressure**.
- **Diffusion pressure** is the pressure exerted by a substance due to tendency of its particles to diffuse. It is also called **suction pressure** (S.P.), the pressure with which water enters into a cell.
- **Diffusion pressure deficit** (D.P.D) is the reduction in the diffusion pressure of water over its pure state.
- Diffusion pressure of a **pure solvent is maximum** and it decreases with the addition of solute.
- Water moves from a system with **low D.P.D.** to a system with **high D.P.D.**
- When water diffuses into a cell through the process of osmosis the cell becomes swollen, thus swollen cell is called **turgid cell**.
- A system have two or more types of diffusing particles, eg., oxygen and carbon dioxide.
- Each diffusing substance exerts its own diffusion pressure called **partial diffusion**.
- Particles of different substances diffuse according to their own partial pressure.
- Tendency of different substances to diffuse according to their own partial pressures or concentrations is known as **independent diffusion**.
- Outward pressure exerted by plasma membrane on the cell wall is called **turgor pressure**.
- Inward pressure exerted by cell wall on the plasma membrane is called **wall pressure**.
- The values of turgor pressure and wall pressure are equal.
- In a flaccid cell **suction pressure is equal to osmotic pressure**.
- Suction pressure in a turgid cell and turgor pressure in a flaccid cell is **zero**.
- In a turgid cell **osmotic pressure is equal to turgor pressure**.
- When water moves along the energy gradient free energy is liberated. The amount of energy liberated from a substance when its potential energy is converted into kinetic energy is called **free energy**.
- Free energy present in 1 mole of a substance (Avogadro no. of substance 6.023×10^{23}) is called **chemical potential**.
- Chemical potential of water is called **water potential**.
- The term **water potential** is **used in the place of D.P.D. and SP.** The difference between free energy of water in a system and free energy of pure water at atmospheric pressure is also called **water potential**.
- The term water potential was proposed by **Slatyer and Taylor**.
- **Symbol** of water potential is ψ.
- Water potential of pure water is **zero**.
- When a solute is added to pure water, **water potential of solution decreases** and is expressed in **–ve values**.
- Water potential is measured in **bars**. **1 bar** = **0.998 atm** (0.987 atm) or **10^6 dynes/cm^2.**
- The difference between water potentials of two solutions is expressed as **$D\psi W$**.
- If y *W* value of cell *A* is - 2 bars and y *W* value of cell *B* is - 10 bars water diffuses into *B* cell. Therefore water moves from a system **with a high water potential to a system with low water potential**.
- Potential required for the entry of water into a solution is called **osmotic potential**.
- Osmotic potential has a **–ve value** and its symbol is **yp (ys)**.
- The **symbol for pressure potential** is ψ ***P***.
- Pressure potential is **used in the place of turgor pressure**.
- The **relation between water potential, osmotic potential and pressure potential** can be represented as : $\psi W = \psi\pi + \psi P$.
- Entry of water into a cell through a plasma membrane is called **endosmosis**.

- Exit of water from a cell through a plasma membrane is called **exosmosis**.
- Solution that has the same osmotic concentration as that of another solution is called **isotonic**.
- Solution having an osmotic concentration lower than that of another solution is called **hypotonic solution**.
- Solution which has an osmotic concentration higher than that of another solution is called **hypertonic solution**.
- If a cell is placed in hypotonic solution **endosmosis takes place.**
- If a cell is placed in hypertonic solution **exosmosis takes place.**
- If a cell is placed in isotonic solution **no changes occur** which means that number of molecules entering into cell is equal to number coming out.
- Shrinkage of plasma membrane or protoplast from the cell wall due to exosmosis is called **plasmolysis**.
- The cell showing plasmolysis is called **plasmolysed cell**.
- In a plasmolysed cell **turgor pressure is zero** and space between cell wall and plasma membrane is **occupied by hypertonic solution**.
- Cell wall is **permeable** to solution.
- Stage at which plasma membrane or protoplast showing starting of shrinkage is called **incipient plasmolysis**.
- When a plasmolysed cell is placed in a hypotonic solution endosmosis takes place and this phenomenon is called **deplasmolysis**.
- Lower epidermal cells of *Tradescantia* leaves are generally used for the demonstration of plasmolysis because their cells contain **anthocyanin pigments**.
- Saprohytic bacteria or fungi cannot survive on **salted dishes due to plasmolysis**.
- Weeds are killed by adding salt. The principle involved is **plasmolysis**.

ABSORPTION OF WATER AND ASCENT OF SAP

- Land plant absorb water mainly from the **soil**.
- For this the roots must be metabotically active, respiring and continuously growing.
- Roots are usually restricted to that area of soil which lies well above the water table.
- Soil has several **types of water - capillary, gravitational, hygroscopic, combined and water vapours.**
- The chief source of water to the soil is **rain**.
- Other sources of water to the soil are **water table, melting of snow or ice** and **irrigation of fields**.
- **Water table** is the depth at which the earth crust is saturated with water.
- The total amount of water present in the soil is called **holard**.
- Available water to the plant is called **chesard** and water which is not available to plant is called **echard**.
- The **capillary water** is readily available to the plants and it is the main source of practically all the water absorbed by plants.
- **Field capacity** is the maximum amount of water a soil can hold after gravitational flow has stopped.
- Water beyond field capacity causes **water-logging**.
- Water logging **reduces soil oxygen and decreases water absorption.**
- Under water logging conditions the soil air is expelled out and plants fail to survive due to **deficiency of air in the soil**.
- If the amount of water in the soil is less than field capacity, the **plants show symptoms of wilting**.
- Water is absorbed by plants in **small quantity** in the saturated atmosphere.
- Most of the water absorption occurs **through roots** from the soil.
- Plants **absorb all gases and nutrients which are dissolved in water.**
- Region of root useful for absorption of water is **root hair region** or **piliferous zone**.
- Structures useful for absorption of water in piliferous zone are **root hairs**.
- Root hairs serve to **increase the area of contact between the root surface and soil.**
- **Kramer** recognized two distinct mechanisms which independently operate in the absorption of water plants.
- **Two mechanisms of water absorption** are –
  - **Active absorption –** Water is absorbed **by the roots** *i.e.* roots takes part actively in absorption and the pressure responsible for absorption develops in roots itself.

– **Passive absorption** – Water is absorbed **through** the roots *i.e.* the roots are passively involved in the absorption. The pressure responsible for pull of water develops in the shoot.

- Absorption of water due to activity of root itself is called **active absorption**.
- Cell sap of root hair usually possesses **higher OP (2 - 8 atm)** compared to OP of soil water (< 1 atm).
- Water always moves according to the **potential gradient**.
- Soil water with **high potential gradient** moves into **root, stem, leaf** and **finally reaches atmosphere** having **low potential gradient,** in the form of water vapour.
- Active absorption takes place according to the principle of **osmosis** and it **requires energy**. (**According to Renner**, active absorption of water occurs in the absence of **transpiration**.)
- **Osmotic theory of active absorption** was proposed by **Atkins** and **Priestly**.
- **Osmotic theory of active water absorption** states that entry of solute as well as water at the surface of cell membrane takes place due to **imbibition by cell wall of root hairs**.

Principle involved in osmotic theory of active water absorption

High O.P. and low T.P. in root hairs
↓ causes
Increase in D.P.D. (in root hairs)
↓ results in
Endosmosis
↓
Absorption of water by root hair
↓ results in
Increase T.P. and thus D.P.D. is decreased in root hair with respect to adjacent cell
↓
Same process, *i.e.*, Increase in T.P. and decrease in D.P.D. occurs in the cells of intermediate channels like cortex, endodermis etc.
↓ thus
Water finally reaches to xylem

- Absorption of water against concentration gradient utilising respiratory energy is **non-osmotic theory of active water absorption**.
- The factors such as low temperature, poor O_2 supply etc. **reduces the rate of respiration and water absorption**.
- **Auxin** increases the rate of respiration as well as water absorption.
- Absorption of water due to pressure developed in shoot is called **passive absorption**.
- Passive absorption of water is due to **transpiration pull**.
- Passive absorption of water was proposed by **Kramer** and **Lachenmeir**.
- The **theory of passive absorption works on the following principle**.

Loss of water in mesophyll cells due to transpiration
↓ causes
Decrease in T.P.and hence increase in D.P.D
↓ causes
Water absorption by mesophyll from adjacent xylem cells
↓
This creates transpiration pull
↓
This pull is transmitted downwards upto roots
↓ which is
Removed after absorption of water from soil

- Movement of water from root hairs to the xylem vessels through cortical cells is called **lateral** or **radial conduction of water**.
- This movement of water occurs according to the **osmotic potential gradient**.
- Plant absorbs water between **field capacity** and **permanent wilting percentage**.
- If loss of water from aerial parts of a plant (transpiration) exceeds the rate of absorption, plant wilts.
- The partial loss of turgidity which does not cause visible wilting is known as **incipient wilting**.
- If plants fails to regain their original stage due to general loss of turgor, **stage represents permanent wilting.**
- In herbaceous plant during summer season, plant wilt during hot days and regain their turgidity and freshness during night, the type of wilting is called as **temporary wilting.**
- Wilting is observed usually in those plants in which tissues are made up of thin walled. Parenchymatous cells are **responsible for maintaining the turgidity in plants.**

- **Permanent wilting percentage (PWP)** is the percentage of water on the dry weight basis of the soil that is present in the soil when the plants growing in it fresh, touch the condition of permanent wilting.
- This value varies between 1–15% and depends upon the texture of soil, e.g., clay has higher PWP than sand.
- No water is absorbed **below permanent wilting percentage** or wilting coefficient.
- No water is absorbed in **frozen soil** as frozen soil is **impermeable** for water.
- Rate of water absorption decreases below 20°C because of **increased viscosity of water**, **decreased permeability of membrane**, **poor root growth** and **low metabolic rate**.
- Water is generally absorbed when concentration of root hair cell sap is **more than outer soil water**.
- Upward movement of water (sap) through xylem against the force of gravity is called **ascent of sap**.
- Ringing experiments were proposed by **Malpighi** and **Stephen Hales** to demonstrate that ascent of sap takes place through xylem vessels.
- **Types of theories to explain ascent of sap** are – **vital theories**, **root-pressure theory** and **physical theories**.
- Theories which consider the **living cells responsible for ascent of sap are vital theories**, eg. **relay pump theory, pulsation theory** etc.
- Scientists who proposed vital theories are - **Godlewski**, **Mac Dougel** and **Jagadish Chandra Bose**.
- According to **relay pump theory** (clambering theory) proposed by **Godlewski (1883),** ascent of sap takes place due to rhythmic changes of O.P of xylem parenchyma cells.
- **Pulsation theory** was proposed by **J.C. Bose**, (1923).
- The plant used by J.C. Bose is *Desmodium gyrans*.
- According to pulsation theory ascent of sap takes place due to the **pulsating activity of living cells of innermost layers of cortex**.
- Ascent of sap occurred even after **killing the living tissues** with picric acid and cyanides. This was reported by **Strasburger (1891)** and thus discarded vital theories.
- The term **root pressure** was coined by **Stephen Hales**.
- A positive hydrostatic pressure developed in roots due to accumulation of absorbed water is called **root pressure**. This theory was proposed by **Priestley** (1916).
- Root pressure can be measured by **manometer**.
- Maximum root pressure in plants will be around **2-3 bars** (0.2 - 0.3 MP). 1 MP = 10 bars.
- **Root pressure theory explains mechanism of ascent of sap in herbs.**
- Root pressure theory is not acceptable because **root pressure is absent in gymnosperms and actively transpiring plants**, though ascent of sap occurs in them.
- Ascent of sap also takes place after the **removal of root system** (reported by Strasburger).
- Root pressure exhibits **negative tension**.
- Water drops formed at the margins of leaves of grasses after humid warm nights are the **best evidence of root pressure**.
- The exudation of water in the form of liquid from the aerial parts of a plant is called **guttation**.
- In *Saxifraga* guttation is more during flowering season.
- **Cavitation** is the formation of water vapour pocket, which puts a "break" in chain and stops flow.
- Theories which consider the physical forces are responsible for ascent of sap are called **physical theories**.
- **Capillary theory** (1874) was put forward by **Bohm** (1863).
- Unger (1869) and Sachs (1874) proposed **imbibition theory**.
- **Dixon and Jolly** (1894) proposed **cohesion-tension theory**.
- **Cohesion-tension theory is widely accepted** physical theory for ascent of sap.
- **Main principles involved in ascent of sap** are –
  – Adhesive forces of water
  – Cohesive forces of water
  – Transpiration pull.
- **Backbone of cohesion-tension theory** is high surface tension of water.
- Surface energy of water is available to surface films of water. As a result water molecules are adhered to the **innerwalls of xylem vessels**.
- Water molecules are attached to one another due to their cohesive forces (cohesion). As a result **water column is formed in xylem vessels**.

- Water column extends upto the **vein endings** of leaves.
- Main force useful for ascent of sap is **transpiration pull**.
- Wall surfaces of mesophyll cells lose water thereby water potential decreases in **mesophyll cells**.
- **Water potential gradient** is established between mesophyll cells and xylem vessels of root.
- **Transpiration pull** is a force developed in mesophyll cells due to transpiration.
- Tension developed in mesophyll cells is transmitted to the root system through **xylem vessels**. Due to this tension developed in the mesophyll cell water volume is pulled to the upper part of the plant.
- If concentration of soil water is high due to dissolved salts (saline soil), there are chances of exosmosis. Such soils are called **physiologically dry soils**.
- Absorption of water proceeds more rapidly in well aerated soil as compared to those which are not.
- In poorly aerated soil root growth is poor and thus **water absorption is low**.

In poorly aerated soil, O_2 concentration reduces and CO_2 increases. If O_2 concentration in soil is low, rate of respiration of root cells is reduced and thus influence (reduces) metabolic activity. Reduced metabolic activity causes poor root growth and hence low absorption of water.

Poorly aerated soil
↓
Lack of O_2 increase in CO_2
↓
Increase in viscosity $\xrightarrow{\text{Why ?}}$ Viscosity is directly proportional to density. As CO_2 is denser than O_2, hence increase in CO_2 increases viscosity of water.

The density of system and hence viscosity of water increases
↓
Decrease in permeability $\xrightarrow{\text{Why ?}}$ Higher the viscosity denser will be the liquid and hence lower will be the permeability of membrane for it.
↓
Poor root growth
↓
Low water absorption

- In poorly aerated soil, water is absorbed slowly also **because of increased viscosity of water and poor permeability of membrane.**
- **When transpiration is low**, the root has to take part actively in absorption. Thus slowly transpiring plants show active absorption.
- **When transpiration is high,** the tension developed in mesophyll cells pull water upwards. There, roots do not play any significant role rather work as mere intermediate channel in water absorption. Thus rapidly transpiring plants show passive absorption.
- The aerial roots of epiphytic roots have **specialized tissue (velamen)** for absorbing rain water and condensed water vapours.
- **Soil plant atmosphere continnum** (SPAC) is the pathway for water moving from soil through the plant to the atmosphere.
- The transport of water along this pathway occurs in separate components, defined differently between three scientific disciplines of the environment.

TRANSPIRATION

- The loss of absorbed water in the form of vapours from the living tissue of aerial parts of the plant is termed as **transpiration**.
- A very small fraction of water absorbed by plant **(generally less than 5%) is utilized in plant development and metabolic processes** and the remaining is lost in the process of transpiration,
- It is also estimated that loss of water from a forest is about 36,400 litres per acre per day.
- A **corn plant** may **transpire upto 54 gallons of water** in one growing season (which equals to about 100 times of its own weight).
- From a **deciduous forest**, during one complete year, the water loss can be equal to 30% of rainfall of the area.
- In a **crop**, 90 to 500 kg of water is lost for the production of 1 kg of dry matter.
- **Transpiration ratio** or **water requirement** or **efficiency of transpiration** is the amount of water transpired by a plant for the synthesis of a unit dry matter.
- Transpiration ratio gives an idea of the **requirement of water/irrigation by crops**, shrubs and trees.

- Transpiration is useful for **passive absorption of water.**
- Transpiration is **responsible for mass flow or bulk flow of mineral along with water.**
- The pressure developed by transpiration is responsible for **ascent of sap**.
- It is useful for temperature regulation in plants because heat is removed by transpiration.
- Water deficit formed due to transpiration **leads to wilting and injury in plants.**
- Some chemicals when sprayed on leaves reduce the rate of transpiration. Such substances are called **antitranspirants**.
- Antitranspirants are of **two types - metabolic inhibitors and surface films**.
- **Metabolic inhibitors** reduce transpiration by reducing the stomatal opening for a period of two or more weeks without influencing other metabolic processs. The most promising of these inhibitor is phenyl mercuric acetate (PMA, 10^{-4} M). Another is abscissic acid (ABA).
- **Film forming chemical** check transpiration by forming a thin film on the transpiring surface. They are sufficiently permeable to carbon dioxide and oxygen to allow photosynthesis and respiration but prevent movement of water vapours through them.
- The important chemicals of this group are silicon emulsions, colourless plastic resins and low viscosity waxes.
- When crop plants are suffering from water deficit, antitranspirants are given as **foliar spray**.
- Common experiment used to demonstrate transpiration is **bell jar experiment**.
- Chemical used in transpiration experiments is **cobalt chloride**.
- The diagramatic representation of the size of stoma at different times of the day is **stomatal clock (prepared by Von Mohl)**.
- **Potometer** is an instrument for measuring the rate of transpiration by shoots by measuring the rate of their water absorption.
- **Porometer** is an instrument for measuring the degree of stomatal opening.
- **Psychrometer** is an instrument for measuring both the relative humidity and transpiration.
- **Tensiometer** is an instrument used for measuring soil-water tension.

Types of transpiration

- Transpiration is of **four types** : **cuticular**, **stomatal lenticular** and **bark transpiration**.
- **Cuticular transpiration** is the loss of water in vapour form from the general surface (leaves and young stems) through the layer of cuticle.
- Cuticular transpiration continues throughout the **day and night**. About **10%** of water is lost by this type of transpiration.
- **Stomatal transpiration** is the loss of water in the vapour form from stomata present on the surface of leaves and to a lesser extent from the surface of flowers and young stems (cauline transpiration).
- Stomatal transpiration occurs only when **stomata are open**. About **90%** of the total transpiration occurs through stomata.
- Transpiration which occurs through stomata of leaves is called **foliar transpiration**.
- **Lenticular transpiration** occurs through the lenticles which are small regions on bark and bears small loosely arranged cells called complementary cells. Negligible amount of water is lost through lenticular transpiration.
- Lenticular transpiration is the **main method of water loss from deciduous trees after leaf fall.**
- Lenticular transpiration **continues throughout day and night**.
- A very small quantity (0.17%) of water is lost from the corky bark of the stem. It is known as **bark transpiration**.
- **Mayor (1956)** has reported that some of the herbaceous plants, under favourable conditions, transpire the entire volume of water which a plant has and it is replaced within a single day.

Stomata

- Stem and leaf epidermis are provided with numerous pores called **stomata**. The number of stomata per sq. cm of leaf epidermis is variable.
- **Stomata** are **meant for gaseous exchange** during photosynthesis and respiration but **also the main source of transpiration**.
- Stomata consists of two guard cells, which are

generally bean shaped or kidney shaped, but in grasses they are dumbell shaped.

- The guard cell usually measured 45 × 15 micron in size and they cover just 1 - 2% of total leaf area.
- Stomatal width increases when they are close.

Type of plant	Type of stomata	Location of stomata
Apple and mulberry type	Hypostomatous	On the lower surface of leaf, eg, apple, peach
Potato type	Amphistomatous	On both surface of leaf but numerous on the lower surface, e.g. potato, bean.
Oat type	Isostomatous	Equally distributed on both the surfaces of leaf, eg. wheat, rice, potato, bean.
Water-lily type	Epistomatous	Only on the upper surface of leaf. These are found in plants with floating leaves.
Potamogeton type	Astomatous	Either absent or non-functional. This is characteristic feature of submerged hydrophytes.

- They enclose a tiny opening called **stomatal pore or stoma.**

	Type of stomata	Nature of stomata
1.	**Barley or cereal type** (dumb-bell shaped), eg. maize, wheat.	Open for a few hours during the day.
2.	In **Alfafa or leucerne type,** eg. pea, bean, grape	Remain open throughout the day, close at night.
3.	In **Potato type**, eg. potato, *Cucurbita*, bananas	Open throughout day and night but close for a few hours in case of water deficiency.
4.	In *Equisetum* **type**, eg emergent hydrophytes	Remain open and seldom close.

- The term stomatal apparatus is then applied to the opening as well as guard cells and guard cells may be surrounded by varying number of specialised epidermal cells called subsidiary or accessory cells.
- Stomatal opening **depends upon availability of K^+ ions from adjacent epidermal cells.**
- A number of other minerals are also essential for stomatal movemets, *e.g.*, P, N, Mg, Ca, etc.
- When guard cells are **fully turgid**, **stoma opens**. When guard cells are in **flaccid state**, **stomata closes**.
- Based on stomatal distribution, plants are divided into categories - **apple and mulberry type, potato type, oat type, water lily type, potamogeton type.**
- Depending upon the periods of opening and closing stomata are of four types as given below.
- **Main theories about the mechanism of stomatal movement are** –
  – **Guard cell photosynthesis theory** - Given by **Schwendener (1881)** and also hinted by **Von Mohl (1856)**.
  – **Starch hydrolysis theory** - First given by **Llyod**. Formulated by **J.D. Sayre (1923)** and modified by **Steward (1964)**.
  – **Malate or K^+ ion pump hypothesis** - Proposed by **Levitt (1974)** and elaborated by **Raschke (1975)** and **Bowling (1976)**.
- In night guard cells become flaccid in absence of sugar which is only formed by photosynthesis and **stomata become closed**.
- **Guard cell photosynthesis theory may be represented as** –

Chloroplast in guard cells
↓ Photosynthesis in day time
Formation of sugar in guard cells
↓
Osmotic concentration in guard cell increases
↓
Induces water absorption from adjacent cells
↓
Guard cells turgid
↓
Stomata open

- **Objections to guard cell photosynthesis theory** are –
  - Photosynthetic activity of the guard cell chloroplasts is not confirmed.
  - Sugar does not occur in detectable quantity in the guard cells.
  - In some plants stomata open during night.
- **According to Llyod** (1908), **the conversion of starch into sugar** in the day time and *vice versa* at night causes opening & closing of stomata. **Sayre** (**1926**), **Scarth** (**1932**) **suggested** that this conversion is **controlled only by pH of the guard cells** whereas **Steward** (**1964**), regards that this is partly enzymatic and partly controlled by pH.
- **Starch-hydrolysis theory may be represented as-**

In day time

CO_2 of intercellular spaces
↓ photosynthesis
Starch
↓ H^+ concentration lowers and enzyme phosphorylase activates
Glucose-1-phosphate
↓ phosphoglucomutase
Glucose-6-phosphate
↓ phosphate
Glucose + phosphate
↓
OP & OPD of guard cell increase
↓
Water absorption by guard cells from adjacent cells
↓
Guard cell become turgid and swell
↓
Stomata open

In dark

Glucose
↓ pH decrease due to accumulation of CO_2 in substomatal cavity
Glucose - 1 - phosphate
↓
Starch
↓
OP & OPD of cell sap decreased
↓
Guard cell become flaccid
↓
Stomata close

- **Objection of starch-hydrolysis theory** are –
  - Glucose does not occur in detectable quantity in the guard cells of open stomata.
  - Starch $\rightleftharpoons$ sugar interconversion is too slow to account for rapid stomatal opening and closing.
- **According to Levitt** (1974), opening and closing of stomata is controlled by active K^+ transport and pH of guard cells.
- **Theory of K^+ transport and hormonal regulation may be represented as** –

During daytime

Rise in pH
↓
Hydrolysis of starch
↓
PEP
↓ PEPcase, CO_2
OAA
↓
Malic acid in guard cells
↓
H^+ + malate ions
↓ K^+ ion exchange from subsidiary cells
K^+ + malate ion
↓
Osmotic pressure of guard cells increase
↓
Endosmosis
↓
Stomata open

During night time

↓
CO_2 conc. increases in substomatal cavity
↓
ABA participation
↓
K^+ ion exchange stopped
↓
K^+ ion back into subsidiary cells
↓
pH decreased
↓
Synthesis of starch
↓
Osmotic pressure decreases
↓
Exosmosis
↓
Stomata close

- **Scotoactive stomata** are stomata which **open in dark and close during daytime.** These **occur in succulents.**
- Both **red and blue lights** stimulates stomatal opening though blue light is slightly more effective.
- In dry weather, stomata tend to close while in humid environment they remain open for longer period.
- **Rise in temperature** induces stomatal opening and *vice-versa.*
- At 38° - 40°, stomata open even in dark.

Factors affecting transpiration

- Transpiration is **directly proportional** to the **light intensity, temperature, wind velocity, leaf surface area, root-shoot ratio, number of stomata**.
- Transpiration is **inversely proportional** to **CO_2 concentration** and **atmospheric humidity**.
- Low **carbon dioxide** concentration induces stomatal opening and *vice-versa.*
- Increase in carbon dioxide causes **stomatal closure** hence reduce transpiration.

External factors

- *Light* – Light increases transpiration through opening of stomata and increased protoplasmic permeability.
- *Temperature* – The temperature of the leaf is slightly higher than the environment. Increase in temperature brings about an increase in vapour pressure gradient thus increases transpiration.
  For eg., at 30°C a leaf may transpire three times as fast as it does at 20°C.
- *Humidity* – Increase in humidity decreases transpiration & *vice-versa*.
- *Atmospheric pressure* – The rate of transpiration is inversely proportional to atmospheric pressure.
- *Availability of soil water* – Transpiration is directly influenced by availability of water. Reduced availability of soil water causes wilting or loss of turgidity resulting in drooping & rolling.
- *Wind velocity* – Wind has an significant effect on transpiration. Air movement increases the rate of transpiration by bringing dry air and removing moist air around the transpiring material. High velocity wind, however, closes stomata.

Internal factors

- *Structure of leaves* – Thick cuticle, waxy coating on leaves, sunken stomata, covering of dead hairs on leaves decreases transpiration, therefore these **adaptation are found in xerophytes**. Reduced leaf area reduces the rate of transpiration as in succulents. (cacti or euphorbias). Plants possessing broad leaves show high rate of transpiration (due to increase surface area) and *vice-versa.*
- *Root-shoot ratio* – The roots absorbs water and the leaves transpire. If the rate of absorption becomes slower than transpiration, the latter is also decreased correspondingly. According to Parker, 1949 the transpiration increases with the increase of root-shoot ratio.
- *Stomatal frequency* – The rate of transpiration is directly proportional to the stomatal frequency (no. of stomata per unit of leaf area). Rate of transpiration will be high in leaves having more stomata per unit area.

Significance of transpiration

- It controls the rate of absorption of water from soil.
- It helps in absorption of mineral salts.
- It is responsible for ascent of sap.
- It regulates the plant temperature by contributing to cooling of leaves and also the surroundings.
- It protects the leaves from heat injury, particularly under conditions of high temperature and intense sunlight.
- Transpiration causes loss of huge amount of water absorbed by plants. Also water deficit formed due to transpiration leads to wilting and injury in plants. It often produces water deficit in plant which check photosynthesis, reduces growth and if too severe may cause death from dessication.
- Inspite of various disadvantages the plant cannot avoid transpiration due to their peculiar structure of leaves which is basically meant for gaseous exchange during respiration and photosynthesis. Therefore **transpiration is also regarded as "necessary evil" by Curtis (1926) or "unavoidable evil" by Steward (1959)**.

GUTTATION

- Loss of water as droplets from the tips and margins of leaves is called **guttation**.
- The term guttation was coined by **Bergerstein**.
- Guttation takes place through **hydathodes** and the motivative force is **root pressure**.
- **Hydathodes** are stomata like pores generally present at the tip or margins of leaves of those plants that grow in moist shady places. (e.g., *Tropaeolum*).
- Pores are present over a mass of loosely arranged cells with large intercellular spaces called epithem.
- For this the roots must be metabolically active, respiring and continuously growing.
  The term **bleeding** simply means a **slow exudation** of **water sap from a cut or injured part of plant**.
- The exudation of latex in the para rubber tree is the best example of this type.

End of the Chapter

Chapter 35

Mineral Nutrition in Plants

TYPES OF NUTRITION

- A large number of substances are required from outside for completion of life cycle normally and efficiently.
- The chemical substances that provide nourishment to living organisms are called **nutrients**.
- **Nutrition** is the process that involves the absorption of various mineral ions by the plants for their growth and development.
- **Except for hydrogen**, carbon and oxygen which constitutes about 90 percent of dry weight, all other inorganic plant requirements are obtained from soil.
- It is well known that the yield of a crop depends upon the mineral constitution of the soil. As the sources of these inorganic requirements are minerals, the elements are called **mineral nutrients** and thus nutrition is known as **mineral nutrition**.
- Many of them are represented as a part of structural organic compounds, e.g., nitrogen, phosphorous, sulphur and calcium. Nitrogen and sulphur are taken up in the inorganic form and converted into organic molecules as amino acids.
- A nutrient can be simple or complex organic molecule called **organic nutrient** or a mineral ion, called **inorganic nutrient.**
- CO_2 is an inorganic nutrient for plants.
- Protein component of our diet is organic nutrient for human being.
- **Plant nutrition** is mainly of **two types** : **autotrophic nutrition** and **heterotrophic nutrition**.
- **Autotrophic nutrition** is the type of nutrition where organism manufacture their own food from simple inorganic raw material.
- Autotrophs can be **photoautotrophs** (obtain energy from solar radiation) or **chemoautotrophs** (obtain energy from chemicals).
- **Heterotrophs** are those organism which fail to synthesize their own organic nutrients from inorganic substances and depend on other sources for food. e.g. some bacteria, fungi, bryophytes, pteridophytes and angiosperms.
- This type of nutrition is called **special in case of angiosperm** because generally angiosperms are chlorophyllous and manufacture their own food.
- **Heterotrophic plants** are broadly c**lassified into three** categories **depending upon the source from which they obtain food** - saprophytes, parasites and insectivores.
- **Saprophytes** live upon dead organic matter and are responsible for conversion of complex organic substance into simple inorganic substances. E.g
  - Algae - *Polytoma*
  - Bryophyte - *Buxbaumia*, *Sphagnum*
  - Pteridophyte - *Botrychium*, *Lycopodium*
  - Angiosperm - *Neottia* (birds nest orchid).
- Saprophyte can also be **facultative or obligate**.
- **Obligate saprophytes** are strict saprophytes or holosaprophytes.
- **Facultative saprophytes** are plants with other types of nutrition which can live as saprophytes.
- **Parasite** is an organism which lives in constant association with some other organism (called **host**) and obtain its food without killing the host.
- Parasites can be **total** (or **holoparasite)** or **partial** (or **semiparasite)** parasites.
- The parasites **which are non-green and obtain their total food** (including organic nutrients, water and minerals) **from the hosts** are called **holoparasites**. E.g. *Cuscuta*, *Cassytha*, *Orobanche*, *Balanophora*, *Rafflesia*, *Cistanche*, etc.
- The **parasites which are green and can synthesize their own food but depend on host for water**

and mineral supply are called **partial** or **semiparasites**. E.g. *Loranthus*, *Viscus*, *Arceutobium*, *Striga*, *Santalum album*, *Thesium* etc.

- **Important angiospermic parasites** are –
  – **Total stem parasite** - *Cuscuta* (Amarbel)
  – **Partial stem parasite** - *Viscum* (Mistletoe) and *Loranthus*
  – **Total root parasite** - *Orobanche* (Broom rape)
  – **Partial root parasite** - *Santalum* on roots of Dalbergia, *Striga* on roots of sugar cane and *Thesium* on the roots of grasses.
- Parasitic plants **obtain nutrition** from host plants **by penetrating with their haustoria**.
- Haustoria are **small modified adventitious roots** which deeply penetrate into the body of host. The vascular tissue of parasite makes contact with that of the host through these haustoria.
- *Orobanche* have no **chlorophylls**.
- *Rafflesia* is a total root parasite. It is the **largest flower** in the world. It was discovered by **Sir Stamford Raffles**.
- *Santalum album* is an **evergreen partial root parasite** and grows at many places in South India.
- Parasite can be **obligate** or **facultative**.
- **Obligate parasite** remain parasitic throughout their life. They cannot live independent of the host.
- **Epiphytes** lives on the plants only for the sake of shelter.
- *Viscum*, having permanent attachment to the host, **considered as partial parasite because of the presence of green leaves**.
- **Insectivorous plants** are predator plants which are otherwise autotrophic but they grow in marshy or muddy soils, which are generally deficient in nitrogen and in order to fulfil their nitrogen requirement, these plants catch small insects and are also called **carnivorous plants**.
- They **have poorly developed roots** and thus, they have to **depend on captured insects for their nitrogen requirement**.
- The organs and **specially leaves** of carnivorous plants are modified variously to catch the insects.
- These plants have glands which secretes **proteolytic enzymes** for breaking complex proteins into simple nitrogenous substance, which inturn are absorbed by plants.
- Insectivorous plants are example of **predation** *i.e.* first killing and then eating.

Table : Some common insectivorous plants

Scientific name	Common name
Nepenthes	Pitcher plant
Drosera	Sundew plant
Utricularia	Bladderwort
Pinguicula	Butterwort
Sarracenia	Devil's boot
Aldrovanda	Water flea trap
Cephalotus	Fly catcher plant
Dionaea	Venus fly hap

- *N. khasiana*. is the only Indian species grown in north east.
- Mature leaf of *Drosera* possesses large number of club shaped hairs called **tentacles**.
- The digestive glands in *Pinguicula* are of two types - the **stalked glands** (or mucilage glands) that secrete mucilage and **sessile glands** (or digestive glands) which secrete digestive fluid.
- *Dionaea* has a sole species - *D.muscipula*, distributed in damp, mossy spots in the South-Eastern states of the U.S.A.
- *Aldrovanda* (water fly trap), widely distributed, is **small, root-less, aquatic free-floating herb**. Each lobe bears a large number of sensitive hairs and digestive glands on its upper surface to trap and digest the insects.
- When a bladder of *Utricularia* is full of unassimilated matter, it degenerates.
- In *Nepenthes* the insect proteins are digested by the enzyme **pepsin hydrochloride**.
- About **600 species** of insectivorous plants exists.
- The genus with largest number of species (among carnivorous plants) is *Utricularia*.
- The **biggest carnivorous plant** is in the genus *Nepenthes*.

MINERAL NUTRITION

- Absorption of minerals and their utilisation by plants is called **mineral nutrition**.
- Mineral elements present in plants are estimated by **ash analysis**.
- Aristotle thought that plants absorb nutrients in the **organic form** from the soil.
- Water is more important for plant's growth and was proved experimentally by **J.B. Von Helmont** (17th century).
- Not only water but materials dissolved in it are essential for plant growth. This was proved by **John Woodward**.

- Elements which are required by plants for normal growth and development and without which plants cannot complete their life cycle are called **essential elements**.
- Elements which are present in the plant body and are not so required by plants are called **non-essential elements**, *eg* : Na, Si, Al, Se, Sr, V.
- **Number of essential elements** required by plants **is 16**. (C, H, O, N, P, K, S, Mg, Ca, Fe, B, Mn, Cu, Zn, Mo, Cl).
- Criteria of essentiality were proposed by **Arnon** and **Stout** and are popularly known as **Arnon's criteria of essentiality**.
- Deficiency of essential element cannot be compensated by any other element.
- Element must form a component which is bio-chemically or directly involved in a metabolic process.
- Essential elements required by plants in **large quantity** are called **macronutrients** and in **minute quantity** are called **micronutrients** or **trace elements**.
- **Nine macro elements** are C, H, O, N, P, K, S, Ca, Mg.
- **Seven micronutrients** are Fe, Mn, Mo, B, Zn, Cu, Cl.
- Nitrogen, potassium and phosphorus are called **critical elements** because these are the minerals which become deficient in agricultural soil.
- Fertilizers containing all the three critical elements (N, P, K) are called **complete fertilizers**.
- Essential elements derived from soil are termed as **mineral element**, eg P, K, S, Mg, Ca, Fe, Zn, Mn, B, Cu, Mo, Cl, N.
- Essential elements obtained from air or water are called **non-mineral element**, eg. C, O, H, N.

Elements required by plants

- **Essential**
  Required by plant from external means
  - **Macro nutrient**
    required in large quantity
  - **Micro nutrient**
    required in less quantity
- **Non Essential**
  Not required by plants from external means, present in plant body

- **Deficiency symptoms, also called hunger signs**, are externally visible pathological conditions (morphological and physiological deformities or abnormalities) which are produced due to **absence or deficiency of some essential nutritive substance**.
- **Deficiency symptoms (diseases) of essential elements** are **determined by water culture** and **sand culture experiments**.
- Cultivation of plants in a balanced nutrient solution without any soil is called **hydroponics**. It is also known as **soil less culture/water culture/ solution culture**. Water culture experiments were first conducted by **Sachs**.
- The book on the diagnosis of mineral deficiencies in plants was written by - **Wallace**.
- Hydroponic culture solution was first prepared by **Knop**.
- **Hydroponics or soilless culture helps in knowing** –
  - The essentiality of mineral elements.
  - The deficiency symptoms developed due to non-availability of particular nutrient.
  - Toxicity to plant when element is present in excess.
  - Possible interaction among different elements present in plants.
  - The role of essential elements in the metabolism of plant.
- Cultivation of plants in sterilized sand supplemented with nutrient solution is called **sand culture**.
- Sand culture experiment is **advantageous** since it provides physical support and aeration to the root system.
- **Disadvantages of soil culture** are : pH values of the media cannot be adjusted; quantities of mineral elements absorbed by plants cannot be estimated.
- **Balanced nutrient solution** is prepared by dissolving different proportions of minerals in distilled water.
- The famous nutrient solutions are **Knop solution, Hoagland solution**, **Arnon's solution** and **Sach's solution**.
- **Mottling** is patches of green and nongreen areas.
- **White bud** is chlorosis affecting young leaves as well as buds so that the latter are whitish instead of greenish colour.
- **Nickel** is called **17th essential element** by Dalton *et al*, 1988. It is the **component of enzyme urease**.
- **Law of minimum** was given by **Liebig (1840)** which states that productivity of a soil depends upon the proportionate amount of deficient mineral.

- The elements which produce protoplasmic constitutents like proteins, nucleic acids etc. are called **protoplasmic elements**.

Macronutrients

- C, H, O are the **structural elements or frame work or building block elements**.
- Element which is absorbed by plants exclusively from air is **carbon** (in the form of CO_2).
- Element **which forms a main component of the dry weight of the plant body** is (45%) **carbon**.
- An **element which is useful in reduction reactions** and **in the formation of metabolic water** is **hydrogen**.
- The element which is **absorbed from air and water** both is **oxygen**.
- Element **which forms main component of fresh weight** is **oxygen**.
- Deficiency symptoms are **not formed for C, H, O** because plants cannot survive without C, H, O.

Nitrogen

- Nitrogen is the constituent of organic compounds such as chlorophyll, aminoacids, purines, pyrimidines, enzymes, and many coenzymes, e.g. NAD, FAD, NADP & ATP.
- Main form in which nitrogen is absorbed by plants is **nitrates.** Plants also absorb nitrogen in the form of **NH_4^+ (ammonium) ions**.
- **After carbon, hydrogen and oxygen,** nitrogen **is the major constituent of the protoplasm.**
- **Nitrogen deficiency** in the soil occurs because
  - Nitrogen compounds are absent in the parent rocks.
  - Excess utilization of N_2 by plants.
- N_2 deficiency in the soil can be **rectified by** supplying manures, urea, DAP (diammonium phosphate), green manure and biofertilizers.
- Deficiency of N_2 results in **chlorosis of older leaves** (yellowing of leaves).
- For mobile elements deficiency symptoms first appear in **older leaves** and **later in younger leaves**.
- **Chlorosis** is the **most common deficiency symptom of minerals**.
- Plant parts become purple due to deficiency of N_2 which results in the **formation of anthocyanin pigments**.
- Nitrogen is the main **constituent of the amino acids and proteins**. Hence its deficiency results in many metabolic disorders like smaller cells with slow division rate, less yield, decreased protein synthesis etc.

Phosphorus

- Phosphorus is absorbed by the plants as **phosphate** $(H_2PO_4^{2-}, PO_4^{3-})$ **ions**.
- It is essential for the synthesis of ATP and $NADP^+$.
- Phosphorus is a **component of nucleic acids, phospholipids, coenzymes NAD, NADP, energy rich compounds ATP, ADP, GTP** and **cell membranes.**
- Phosphorus is **found abundantly in the growing and storage organs**.
- Chlorosis of old leaves, purple colour, stunted growth, premature leaf fall and delayed flowering are the **deficiency symptoms of phosphorus.**

Potassium

- Potassium is absorbed as **K^+ ions (cations)**.
- K^+ ion is **not a component of plant body**.
- It is **abundant in clayed soils but absent in loose soils (sandy soils) due to leaching.**
- **Most common free ion** in the cell is K^+.
- Element essential for **maintaining the turgidity of guard cells** is K^+. Hence it is involved in **stomatal movements**.
- Element essential for **maintaining ionic equilibrium.**
- K^+ is an **activator for many enzymes** like **pyruvic kinase, DNA polymerase**.
- It **helps in the permeability of cell membranes** and **translocation of organic solutes in the phloem**.
- **Deficiency symptoms of potassium** are -
  - Mottled chlorosis appearing first in older leaves,
  - Marginal yellowing or scorch and curling, premature death,
  - Loss of apical dominance
  - Cereals may show lodging, falling of cereal crops by the time of harvesting.

Sulphur

- Sulphur is absorbed by the plants as **sulphate ions. (SO_4^-)**. It is also absorbed from **air as SO_2**.
- The **pungent smell of onion and garlic** is due to sulphur (contained in allyl oils).
- Sulphur containing amino acids are **cysteine, cystine, methionine**.
- Sulphur is an **important element because** –

- It plays a role in the **synthesis of chlorophyll**
- It is a constitutent of **ferredoxin** and **some lipids of chloroplasts**
- It is essential for **nodulation in legumes**
- It determines the **structure of protein**
- It plays a role as a part of **active centre of some enzymes** and **affects various metabolic processes**.

- **Deficiency symptoms of sulphur** are –
  - Chlorosis more commonly appearing first in young leaves and leaf curl
  - Less juice content in *Citrus*
  - Reduced nodulation in legumes and defoliation in tea.

Calcium

- Calcium is absorbed by plants as **Ca^{+} ions**.
- It is the component of **middle lamella** (associated with pectic substances).
- It is present in the vacuoles in the form of **$CaCO_3$** and **calcium oxalate crystals**.
- **Calcium is also essential** because
  - It takes part in the **formation of root nodules.**
  - It is an **activator of enzyme amylase**
  - It **controls cell permeability**
  - It is important in the **formation of cell membranes**
  - It is essential for **continued growth of the apical meristem**. Calcium in small amounts is necessary for normal mitosis as it is important in chromatin or mitotic spindle organization
  - It is responsible to **reduce toxicity by forming calcium salts or organic acids.**
- **Deficiency of calcium** causes –
  - Degeneration of root, stem tips and gelatinisation of roots
  - Stunted growth
  - Termination of growth in meristematic region
  - Chlorosis of younger leaves which later on become necrotic
  - Premature flower abscission etc.

Magnesium

- It is absorbed by plants as **Mg^{++} ions**.
- Element essential for the synthesis of chlorophyll.
- Magnesium is present in the **centre of the porphyrin ring of chlorophyll**.
- Magnesium is **useful for attachment of sub units of ribosomes**.
- **Interveinal chlorosis** of older leaves is due to deficiency of magnesium.
- **Deficiency of magnesium** results in
  - Marginal curling,
  - Interveinal chlorosis with anthocyanin pigmentation appearing first in older leaves, veins green
  - Reduced growth, underdeveloped phloem.

Micronutrients

Iron

- Available mostly in **ferrous form** and rarely in ferric form **(Fe^{3+})**.
- Element essential for **synthesis of chlorophyll**.
- Iron is present in **ferredoxine** and **cytochromes** responsible for electron transport system in plants.
- **Deficiency of iron** causes –
  - Marked chlorosis particularly in younger leaves, the mature leaves remain uneffected
  - Characteristic interveinal chlorotic spots develop and the principal veins remain typically green showing fine network of reticulate venation
  - Inhibits chloroplast formation
  - Stalks become short and slender.

Manganese

- Absorbed by plants as **Mn^{++} ions**.
- Manganese primarily functions as **activator of several enzymes** such as
  - Malic dehydrogenase and oxalosuccinic dehydrogenase – the enzymes of Krebs cycle
  - Nitrate reductase and hydroxylamine reductase (thus play important role in nitrogen metabolism).
- Manganese plays a role in the **photo-oxidation of H_2O** and **release of molecular O_2** during photosynthesis. It is also involved in the **synthesis of chlorophyll** and **oxidation of auxin** (indole-3-acetic acid).
- **Deficiency of manganese** results in interveinal chlorosis, grey spots or stripes, legume cotyledons with brownish spots (**marsh spot disease**) and sterile flowers.

Molybdenum

- Absorbed as **molybdate ions (Mo^{3+} or Mo^{4+})**
- It is useful for **nitrogen metabolism**. It is also a component of **nitrate reductase**.

- **Deficiency of molybdenum** causes –
  - Chlorotic interveinal mottling of mature leaves followed by necrosis and folding of leaves.
  - Inhibition of flowering
  - **Whiptail disease** (transformation of cauliflower leaf into a cylinderical structure called whiptail) of cauliflower.

Boron

- Plants absorb boron as **borate and tetraborate ions** $(BO_3^{3-}$ **or** $B_4O_7^{2-})$.
- It helps in absorption of water and calcium and in pectin synthesis.
- It is also required for pollen germination, cell differentiation and carbohydrate translocation.
- Sugar is translocated in the form of **sugar-borate complex**.
- **Deficiency symptoms of boron** are
  - Death of shoot tips because boron is needed for DNA synthesis
  - Leaves develop a thick coppery texture, they curve and become brittle
  - Root growth is arrested and flowers are not formed
  - Causes diseases like **'heart rot' of apple**, **'internal cork' of apple**, **'water cork' in turnip**, **'stem crack' of celery**.

Zinc

- Absorbed as **Zn^{++} ions**.
- It **acts as enzyme activator** particularly for **carbonic dehydrogenase, alcohol dehydrogenase** etc.
- Required for synthesis of IAA (auxin) or **its precursor tryptophan**
- **Deficiency symptoms of zinc** are –
  - Interveinal chlorosis in mature leaves beginning from margin and apex followed by necrosis
  - **Little leaf disease** in several plants
  - 'Rosette' due to shortening of internodes
  - **'White bud'** of maize
  - **'Mottled leaf'** in apple and walnut.

Copper

- Absorbed as **cuprous or cupric forms (Cu^{2+} or Cu^{+})**.
- Copper is a **structural component** of **plastocyanin** and **plastoquinone**.
- Element required for the **synthesis of vitamin-C** (ascorbic acid) and **activator of polyphenol oxidase**.
- **Deficiency symptoms of copper** are –
  - Necrosis at leaf tip and margins
  - **'Die back'** in *Citrus*
  - **'Exanthemma'** in fruit trees; this disease is characterised by die back, appearance of brown spots on leaves and fruits.
  - **'Reclamation'** in cereals and legumes; this disease is characterised by chlorosis on leaf tips and there is no seed setting.
  - **Wilting of entire plant** occurs under acute shortage of copper.

Chlorine

- Chlorine is a **component of oxygen liberation complex of photolysis.**
- Chlorine is a **constituent of amylase, plays vital role in anion cation balance.**
- The **main function of chlorine** is photo-reduction of oxygen, cell division, normal fruit production.
- **Deficiency symptoms of chlorine** show –
  - Leaf wilting, bronze colour
  - Chlorosis and necrosis
  - Stunting of roots and swollen root tips
  - Flower abscission and reduced fruiting.

Mineral indicators or bio indicator plants

Name of plant		Mineral indicated
Agrocyst	–	Leadmine
Astragalus and Stanley	–	Selenium
Impatiens balsamina	–	Zinc
Ocimum homblei	–	Copper
Gypsophila	–	Gypsum
Asplenium adulterium	–	Nickel

Non-essential elements

- **Sodium** is used by blue green algae, marine algae and C_4 plants.
- In higher plants, sodium **maintains differential permeability of cytomembrane.**
- **Silicon** is present in grasses, sedges, *Equisetum* etc.
- **Cobalt**, the component of vitamin B_{12}, is **found in few blue green algae** and *Rhizobium*.
- Some marine algae like *Laminaria* **accumulate iodine** in huge amounts.
- *Aspergillus niger* and *Lemna minor* need **gallium** for their growth.
- **Gold** is known to occur in pteridophyte, *Equisetum*.

Table : Role of elements in plants

	Element	Obtained as	Role	Deficiency symptoms
			Macronutrients	
1.	**Nitrogen**	NO_3^-, NH_4^- rarely NH_2	Cell division, growth, metabolic activities, photosynthesis	Chlorosis starting from older leaves, stunted growth due to decreased protein synthesis, smaller cells and inhibition or slow divisions, permature leaf fall, lateral buds and tillering suppressed, late flowering, purple colouration on surface of shoot axis, wrinkling of cereal grains, reduced yield.
2.	**Phosphorus**	$H_2PO_4^{2-}$, PO_4^{3-}	Energy transfer, cell division, membranes phosphorylation reactions	Stunted growth, leaves dull green or with purple and red spots of anthocyanins, chlorosis with necrosis first in older leaves or premature abscission, delayed flowering, premature fall of flower buds, poor vascular tissues and delayed seed germination.
3.	**Potassium**	K^+	Maintenance of cell turgidity, opening and closing of stomata, balancing other ions, cation-anion balance, increases hardiness, essential for photosynthesis, respiration, protein synthesis and synthesis of various other types membrane permeability	Mottled interveinal chlorosis appearing first in older leaves, marginal or apical yellowing or scorch and curling, die back, bushy habit, shorter internodes, loss of apical dominance, cereals may show lodging, loss of cambial activity, plastid disintegration and increase in rate of respiration.
4.	**Magnesium**	Mg^{2+}	Central atom of chlorophyll, stabilizes ribosomes, activator for many enzymes of photosynthesis and respiration.	Interveinal chlorosis of older leaves, appearance of brightly coloured pigments, necrosis of older leaves in acute shortage.
5.	**Calcium**	Ca^{2+}	Constituent of middle lamellae, involved in formation of nucleus and mitochondria, activator of enzymes like amylase.	Formation of multinucleate cells, chlorosis along margins of younger leaves, formation of stunted and discoloured roots.
6.	**Sulphur**	SO_4^{2-}	Constituent of amino acids methionine and cysteine. Constituent of vitamins like thiamine, biotin and coenzyme A.	Chlorosis of younger leaves
			Micronutrients	
7.	**Iron**	Fe^{2+} or Fe^{3+}	Constituent of electron carriers like ferredoxin and cytochromes, essential for synthesis of chlorophyll, activator for oxidising enzymes.	Interveinal chlorosis of younger leaves, necrosis may follow.

contd ...

8.	**Manganese**	Mn^{2+}	Activator for enzymes of photosynthesis and respiration, catalyses splitting of water during photosynthesis.	Interveinal chlorosis of younger or older leaves, followed by necrosis, disorganisation of thylakoids in chloroplasts.
9.	**Zinc**	Zn^{2+}	Involved in synthesis of auxins, activator for more than 80 enzymes.	Interveinal chlorosis of older leaves, followed by necrosis, little leaf and rosette in some plants.
10.	**Copper**	Cu^{+} or Cu^{2+}	Constituent of plastocyanin, activator for oxidising enzymes.	Young leaves become twisted and dark green in colour, exanthema in fruit trees, reclamation in cereals.
11.	**Molybdenum**	MoO_4^{2-}	Constituent of nitrate reductase, essential for nitrogen fixation and phosphorus metabolism.	Whip tail in crucifers, interveinal chlorosis of older leaves followed by necrosis, young leaves become twisted.
12.	**Boron**	H_3BO_3	Involved in translocation of sugars, essential for DNA synthesis, acts as natural inhibitor, promotes elongation of pollen tube.	Apical region of stem dies, leaves become thick and dark coloured, flowering suppressed, heart root of beet, water core of turnip, top sickness of tobacco etc.
13.	**Chlorine**	Cl^{-}	Stimulates splitting of water during photosynthesis, essential for growth of roots and for division of leaf cells.	Leaves become wilted, leaves may show chlorosis and necrosis, roots become thick and stunted.

Absorption of mineral nutrients

- It has been shown that uptake of minerals/ions involves 2 phases.
  - In the **first phase**, ions are rapidly taken into the free space or outer space of the cells (inter cellular spaces and cell wall).
  - In the **second phase**, ions are taken in slowly into the inner space of the cells (cytoplasm and vacuoles).
- Entry into the outer space does not require energy but entry into inner space required energy (**active process**).

Passive absorption

- Passive absorption refers to absorption of minerals by physical process which do not require metabolic energy.
- Any substance moves passively from a region of its higher concentration to a region of lower concentration.
- When electrolytes are absorbed, they move passively from a region of higher electrochemical potential to a region of lower electrochemical potential usually through ion channels.
- **Three theories have been discussed to explain the passive absorption of ions** – diffusion, ion exchange and Donnan equilibrium.
- **Diffusion (mass flow) –** According to this hypothesis, as the flow of water into the plant increases due to transpiration pull, the uptake of ions into the plant also increases. This occurs due to passive absorption of ions by free diffusion into the apparent free space of a tissue.
- **Ion exchange** – Both anions and cations have a tendency to get adsorbed on the surface of cell wall. These adsorbed ions exchange with the ions present in the soil solution. Ionic exchange occurs through **carbonic acid exchange** and **contact exchange.**
- **Donnan equilibrium –** Donnan equilibrium is said to be reached when the product of anions and cations in the internal solution becomes equal to the product of anions and cations in the external solution.

Active absorption

- The movement of ions against concentration or electrochemical potential gradients requires energy.
- This energy is derived from metabolism.
- Active uptake of ions is carried out by carrier mechanism for both influx and efflux.
- The activated ions combine with carrier proteins to form an ion-carrier complex, utilising metabolic energy.
- This complex moves across the membrane and reaches the inner surface.
- The complex breaks and releases ions into the cytoplasm.

NITROGEN METABOLISM

- Nitrogen occurs in environment as oxides, organic amines etc.
- Nitrogen content in the environment is 78% by volume.
- **Plant cannot absorb nitrogen in molecular form.**
- Nitrogen is **absorbed by plants in nitrate** (NO_3^-) **and ammonium** (NH_4^+) **form.**
- Cyclic movement of nitrogen in nature is called **nitrogen cycle**. It is **useful for maintaining balance in equilibrium of nitrogen in nature**.
- Nitrogen cycle consists of four processes called **nitrogen fixation, ammonification, nitrification** and **denitrification**.
- **Nitrogen fixation** is the conversion of gaseous nitrogen into inorganic nitrogenous compounds**.**
- Nitrogen fixation is of **two types** : **physical** (or **abiological**) and **biological**.
- **Physical nitrogen fixation** occurs in atmosphere in four steps –
  - Conversion of nitrogen into nitric oxide due to lightening. $N_2 + O_2 \xrightarrow{\text{Lightening}} 2NO$.
  - Oxidation of nitric oxide into nitrogen dioxide. $2NO + O_2 \rightarrow 2NO_2$
  - Nitrogen dioxide reaches the soil in the form of nitrous and nitric acid when dissolved in rain water. $2NO_2 + H_2O \rightarrow HNO_2 + HNO_3$
  - These react with alkali of soil and form nitrates (absorbable form). HNO_3 + Ca or K salts → Ca or K nitrates.
- On industrial ground **abiological fixation occurs by Haber-Bosch process** at high pressure and temperature.

$$N_2 + 3H_2 \xrightarrow[\text{200 atm}]{450°C} 2NH_3$$

- Conversion of gaseous nitrogen into nitrogenous compound by living organism is called **biological nitrogen fixation**.
- **Hellriegel and Wilforth** demonstrated the ability of leguminous plant to assimilate molecular nitrogen due to presence of microbes in root nodules.
- Biological nitrogen fixation is of **two types- symbiotic and non-symbiotic**.
- **Symbiotic nitrogen fixation** is the fixation of nitrogen as ammonia by micro-organisms living in symbiotic association with higher plants.
- *Rhizobium* in root nodules of legume plant is the best example showing symbiotic nitrogen fixation.
- **Non-legume plants like** *Casuarina*, *Myrica* **also show nodulation on their roots** which contain nitrogen fixing actinomycetes.
- Symbiotic nitrogen fixation **requires** *nod genes* **of legumes**, *nod fix* and *nif genes* **clusters of bacteria.**
- Nitrogen fixation by **free living organisms** is called **non-symbiotic fixation of nitrogen.**
- **Examples of aerobic non-symbiotic bacteria** are *Azotobacter* and *Beijerinckia*.
- *Clostridium* represents **example of anaerobic non-symbiotic bacteria.**
- *Chlorobium, Rhodospirillum* **are photosynthetic** and *Desulphovibrio* are **chemosynthetic non-symbiotic bacteria.**
- Some blue green algae also fix nitrogen non-symbiotically, for eg. *Nostoc*, *Anabaena*, *Aulosira* etc.
- The mechanism of biological nitrogen fixation was studied by using ^{15}N (radioactive nitrogen)**.**
- Main enzyme necessary for biological nitrogen fixation is **nitrogenase**.
- Eight protons and six electrons are required to reduce a molecule of nitrogen into two molecules of ammonium.
- Synthesis of nitrogenase enzyme is established by **nif gene.**
- Nitrogenase is made of two subunits. The larger component beside **C, H, O, N & S** contains **molybdenum** and **iron**. Whereas the smaller subunit has no **molybdenum**.
- Scheme for mechanism of non-symbiotic nitrogen fixation was **proposed by Burris.**
- Hydrogen is used in the **conversion of molecular nitrogen to ammonia**.

- The enzyme nitrogenase successively reduces N_2 **into dimide and hydrazine and finally to** $2NH_4^+$ **with the utilisation of ATP**.

$$\underset{\text{Nitrogen}}{N \equiv N} \rightarrow \underset{\text{Dimide}}{NH = NH} \rightarrow \underset{\text{Hydrazine}}{NH_2 - NH_2} \rightarrow \underset{\text{Ammonium}}{2NH_4^+}$$

- Hydrogen ions and electrons for reduction process is provided by reduced ferridoxin.
- Nitrogenase acts only in **anaerobic condition, under aerobic condition it undergoes irreversible damage.**
- The enzyme nitrogenase requires **ATP, Mg^{++}, an electron source** and **anaerobic conditions** for **converting nitrogen to ammonia.**
- Anaerobic condition in symbiotic nitrogen fixation is provided by leghaemoglobin present in root nodules.
- **Leghaemoglobin** is a red colour haemoglobin like pigment **which absorb oxygen and protect enzyme from oxygen.**
- This pigment is called **oxygen scavenger** or **biochemical curtain**.
- **Ammonification** (second process) is the conversion of organic nitrogenous compounds from the dead bodies of plants and animals into ammonia.
- Those bacteria which bring about the process of ammonification is called **ammonifying bacteria,** bacteria of decay or putrefying bacteria.
- **Examples of ammonifying bacteria** are – *Bacillus ramosus, Bacillus vulgaris*.
- Ammonification is a **mineralisation process.**
- Proteins of dead bodies of plants and animals is degraded by bacteria and saprophytic fungi.
- **The anaerobic decomposition of proteins** (amino acid to amine and related compounds) is called **putrefaction**.
- **Oxidative deamination** (deamination of amino acid in presence of oxygen) results in release of ammonia.
- If ammonia is not absorbed directly by plants then it is converted to nitrate through the process of **nitrification**.
- Nitrification **(third process) is the conversion of ammonia into nitrite and nitrates by soil bacteria (nitrifying bacteria).**
- *Nitrosomonas*, *Nitrosococcus*, *Nitrosomonas* convert ammonia into nitrites.
- Nitrites are converted to nitrates by the action of *Nitrobacter*.
- **Heterotrophic nitrification** is the nitrification brought about by heterotrophic bacteria (*Nocardia*) and fungi (*Aspergillus*).
- **High nitrification in aquatic habitat causes major biological oxygen demand (BOD).**
- **Assimilatory nitrate reduction** is the reduction of nitrates to ammonia within plant body.
- Conversion of nitrates and ammonia of soil to molecular nitrogen by bacteria is called **denitrification** (fourth process). This is **done by anaerobic bacteria** like *Pseudomonas denitrificans*, *Thiobacillus denitrificans*.
- Denitrification is **also called dissimilatory nitrate reduction.**
- Denitrification occurs in four steps
  $NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2\uparrow$ **(molecular form)**.
- Nitrates are reduced to nitrites by the enzyme nitrate reductase. The nitrites are reduced to ammonia by nitrite reductase. The ammonia so formed is enzymatically incorporated in amino acid.

APPLICATION OF FERTILIZER

- The key role of fertilizers and their judicious use in crop husbandry is well understood. Soil normally contain sufficient amount of essential minerals. Plant roots take up plant food elements from the soil in ionic forms.
- The positively charged ions are called cations, e.g, K^+, Ca^{++}, Mg^{++}, Fe^{+++}, Zn^{++} and so on.
- The negatively charged ions are called anions, e.g., NO_3^-, $H_2PO_4^-$, etc.
- Due to the repeated cultivation, three important elements *i.e.*, **nitrogen, phosphorus, and potassium** are depleted from fields & they need to be replenished. They are grouped as **nitrogenous fertilizers, phosphatic fertilizers, potassic fertilizers** respectively.
- Mixed fertilizers as **NPK** usually meet nutrients deficiencies in a more balanced manner and require less labour to apply than straight fertilizer used separately. Mixtures containing all the three principal nutrients (N, P & K) are called **complete fertilizers**.
- NPK fertilizers contain nitrophosphate in varying proportions like 17 : 18 : 9 or 15 : 15 : 15 (representing percentage by weight of nitrogen, phosphorus and water soluble potassium).
- Thus, the use of fertilizers restores the fertility of the soil but dosages differ according to crop, soil season and other climatic conditions.

End of the Chapter

Chapter 36

Photosynthesis

- **Photosynthesis** (Gk. *photon* = **light,** *synthesis* = **putting together**) is the most important anabolic process on earth by which green plants (autotrophic organisms) synthesize complex carbohydrates from simple substances like carbon dioxide and water with the help of light energy and purify the atmospheric air by consuming carbon dioxide and evolving oxygen.
- The process of photosynthesis can also be defined as the **transformation of photonic energy** (*i.e.*, light or radiant energy) **into chemical energy** (locked in high energy bonds of carbohydrate molecules) by the green parts of the plants.
- The **simplest equation** for photosynthesis in higher plants and algae can be –

$$6CO_2 + 12\ H_2O \xrightarrow[\text{Chlorophyll}]{\text{Light}} C_6H_{12}O_6 + 6O_2\uparrow + 6H_2O.$$

- Photosynthesis is **photoautotrophism**.
- Plants which carry out photosynthesis are called **photoautotrophs**.
- The important feature of photosynthesis is conversion of **light energy into chemical energy**.
- The process of manufacture of organic substances by certain bacteria utilising directly the chemical energy released in the oxidation of inorganic substances is called **chemosynthesis**. [*For more details refer chapter Monera*]
- Bacteria performing chemosynthesis are called **chemoautotrophs** (chemosynthetic bacteria). For eg., nitrifying bacteria.
- Organisms which manufacture their own food are called **autotrophs** and those which depend on autotrophs for their food requirements are called **heterotrophs**.
- Heterotrophs which depend completely on photoautotrophs for their survival are called **herbivores** (vegetarians).
- Heterotrophs which can survive on dead organic matter are called **saprophytes**.
- Green plants can survive in the absence of herbivores, carnivores and omnivores but cannot survive in nature devoid of saprophytes because **the raw materials required by these plants are formed by the action of saprophytes**.
- All heterotrophic organisms **depend directly or indirectly on photoautotrophs** as O_2 required for respiration of aerobic organisms is liberated during photosynthesis.
- Initially cyanobacteria were the main source of oxygen (by photosynthesis) in the atmosphere and this oxygen of the atmosphere is balanced by continuous photosynthesis and respiration.
- Photosynthesis is an **anabolic** or **constructive** process.
- Dry weight of the plant **increases** due to photosynthesis.
- Photosynthesis is an **endergonic** (occurring inside the organ) reaction.
- Ultimate source of energy for all organisms is **sunlight**.
- Photosynthesis is an oxidation - reduction process where **H_2O is oxidised** and **CO_2 is reduced**.
- Light is essential for photosynthesis. This fact was discovered by **Ingen-Housz**.
- CO_2 and H_2O are essential for photosynthesis, was proposed by **Theodore de Sassure**.
- Absorption of CO_2 during photosynthesis was proposed by **Senebier**.
- O_2 is liberated during photosynthesis and it was discovered by **Joseph Priestly**.
- Oxygen evolved in the food manufacture process

comes from CO_2. This was stated by **Senebier (1782)**.

- **Dutrochet (1937)** confirmed that **chlorophyll is essential** for the process of photosynthesis.
- **Liebig** (1840) reported that **the sole source of carbon in plant is CO_2.**
- The **seat of photosynthesis** is **chloroplast** and the first visible product, **starch**, was discovered by **Julius Sachs**.
- Photosynthesis **mainly occurs in the mesophyll cells of leaves** and to a very little extent in the green stems and floral parts (sepals). Mesophyll cells contains chloroplasts arranged along their outer margin.

CHLOROPLASTS

- Chloroplasts (**Gk** = *chloros* = **green,** *plastos* = **moulded**) are the green plastids which occur in all the green parts of the plants.
- Chloroplasts are often called **food production centres** of the cell (Assimilatory centres/ photosynthetic factories).
- Chloroplasts are the actual **sites of photosynthesis**.
- The chloroplasts contain **chlorophyll** and **carotenoid pigments** which are **responsible for trapping light energy essential for photosynthesis.**
- Majority of the chloroplasts of the green plants are formed in the mesophyll cells of the leaves. They are lens shaped, oval, spherical, discoid or even ribbon like organelles having variable length (5 - 10 mm) and width (2 - 4 mm).
- The chloroplasts are **double membrane bound organelle**.
- The space limited by the inner membrane of the chloroplast is called the **stroma**.
- A number of organised flattened membranous sacs called the **thylakoids** are **present in the stroma**. Thylakoids are **arranged in stacks like the piles of coins** called **grana**.
- The **stroma** of the chloroplasts **contains enzymes required for the synthesis of carbohydrates and proteins.**
- Role of light as a source of energy was recognised by **Robert Mayer**.
- The **photosynthetic apparatus** comprises of **photosynthetic pigments** and **light**.
- The photosynthetically active pigments are **chlorophylls**, **carotenoids** and **phycobilins** (biliproteins).
- As many as **eight major types of chlorophyll** are known to exist in the plant kingdom *viz.*, **chlorophyll *a*, *b*, *c*, *d* and *e*, bacteriochlorophyll *a* and *b*, and chlorobium chlorophyll**.

Photosynthetic pigments

- Photosynthetic pigments are located in the membranes of the thylakoids in specific areas called **quantasomes**.
- Term quantasome was coined by **Park and Biggins**.
- The various **contents of quantasome** are : (i) chlorophyll - *a*, (ii) chlorophyll - *b*, (iii) carotenoids (xanthophylls, carotene)
- The quantasomes are mainly present in **grana lamellae**.
- **Chlorophyll** is the main pigment, useful in photosynthesis.
- Chlorophyll shows **porphyrin structure**.
- Chlorophyll consists of **4 - pyrrole rings** (tetrapyrrole head) **attached to a magnesium atom at the centre** and also **phytol (tail) containing numerous carbon atoms.**
- Chlorophyll *b* is similar to chlorophyll *a* except in having a **formyl (CHO) group instead of methyl group**.
- Usually the ratio of chlorophyll *a* and *b* is **2.5 – 3.5 : 1**. It is 5.5 : 1 in heliophytes and 1.4 : 1 in sciophytes.
- The pigments which absorb light and transmit it to the chlorophyll reaction centre are **carotenoids**.
- Carotenoids **mainly absorb violet, indigo and blue wavelength of spectrum but maximum absorption occurs at blue region.**
- The carotenoids are **unsaturated polyhydrocarbons** being composed of eight isoprene (C_5H_8) units.
- Carotenoids are fat soluble hence sometimes called as **lipochromes**.
- Carotenoids are **accessory pigments present in chloroplast**.
- Carotenoids protect the chlorophyll from a lethal condition namely photo-oxidation by a light of high intensity. Hence these pigments are called **shield pigments**.
- Carotenoids are of **two types** :

- Orange to red coloured carotenoids - **carotenes**.
- Yellow coloured carotenoids - **xanthophylls** (carotenols).

- Carotenes were **first isolated from roots of carrot** hence named carotenes.
- The **lycopene** is a red pigment found in ripe tomato and red pepper fruits.
- The **β-carotene** on hydrolysis gives vitamin A hence called as **provitamin A**.
- The **most common xanthophyll in green plants** is **lutein**.
- The xanthophyll formation takes place in **dark under aerobic condition**.
- The ratio of xanthophyll to carotene in nature is **2 : 1 in young leaves**.
- **Phycobilins** comprise a **bile pigment attached to protein**.
- Phycobilins are **water soluble pigments** mostly **present in the members of red algae and blue green algae**.
- Phycobilins have a **linear tetrapyrrole**.
- **Phycoerythrin**, **phycocyanin** are the important phycobilins.
- The prefix *r* and *c* in phycoerythrin and phycocyanin **indicates the source** *i.e.*, rhodophyceae and cyanophyceae respectively.
- Electromagnetic radiation from the Sun is received by plants in the form of photons.
- A particle of light (photon) containing a packet of energy is called **quantum** (***hv***).
- The electromagnetic spectrum comprises of **cosmic rays**, **γ-rays**, **X-rays**, **ultra violet rays**, **visible spectrum**, **infra red rays** and **radio waves**.
- Visible light ranges from **350 nm - 750 nm**.
- Visible light shows **7 colours** (VIBGYOR).
- Plants usually absorb **blue or red coloured lights.**
- Energy value of light is **inversely proportional to its wavelength.**
- A ray of light incident upon a leaf behaves in **three different ways** as reflected – 12%, transmitted – 5% and absorbed – 83%.
- Only **4% of light** is absorbed by chlorophyll out of total absorbed light.
- Chlorophyll absorb **more of blue wavelength** than red (as indicated by absorption spectrum).
- A graph showing absorption of light by chlorophylls (*a, b*) at different wavelengths is called **absorption spectrum**.
- Chlorophyll - *a* shows peaks of absorption at **430 and 662 nm** of wavelengths of light.
- Chlorophyll - *b* shows peaks of absorption at **453 and 642 nm** wavelengths of light.
- A graph showing rate of photosynthesis at different wavelengths is called **action spectrum**.
- When **radiant energy reflects completely** from the surface of a substance that substance **appears white**.
- Substances appear **dark** when they absorb radiant energy completely and do not reflect it.
- Partly reflected light appears **coloured**.
- Chlorophyll absorbs all the light except **green portion**. Hence chloroplasts with their chlorophylls impart **green colour to the plant parts**. Therefore leaves appear green.
- The physical change in chlorophyll due to absorption of radiant energy is responsible for the change in chemical substances present in the **stroma**.
- Chlorophyll shows fluorescence, the property of almost immediate emission of long wave radiations by substances after attaining excited state on receipt of light energy.
- Isolated chlorophyll in pure form emits red colour and *i.e* shows **red flourescence**.
- In green plants the electrons are accepted by **electron carriers** and later transferred to the chlorophyll.
- The liberated free energy is utilised in the **synthesis of chemical energy** *i.e.*, ATP, NADPH + H^+.
- Normal energy level of electrons of chlorophyll is called **singlet or ground state**.
- Type of protein present in the stroma is **fraction 1 protein**. This protein contains an enzyme **RuBP carboxylase**.
- **Dark phase reactions** of photosynthesis take place in the **stroma**.
- **Light phase reactions** of photosynthesis occur in **grana regions**.

Pigment systems

- Light reaction of photosynthesis involves the participation of two separate pigment synthesis *i.e.*, **PS I and PS II**.

Photosystem I (PS I)

- PS I is **located on the outer surface of non - appressed parts of grana thylakoids and fret channels.**
- PS I comprises of about 200 to 400 chlorophylls, 50 carotenoids, one molecule of P_{700}.

- It is light green in colour.
- This system is not directly involved with the photo-oxidation of water and evolution of molecular oxygen. This system produces a strong reductant which reduces $NADP^+$ to NADPH.
- PS I **is involved both in cyclic and non-cyclic electron transport.**
- Pigment molecules of PS I absorb at or below 700 nm wavelength of light.

Photosystem II (PS II)

- PS II is **located on the inner surface of appressed parts of grana thylakoids.**
- PS II comprises of about 200 chlorophylls, 50 carotenoids and one molecule P_{680}.
- It is dark green in colour.
- This system is directly involved with the photo–oxidation of water and evolution of molecular oxygen.
- PS II donates electrons to PS I when $NADP^+$ is reduced.
- PS II is **involved only in non-cyclic electron transport.**
- Pigment molecules of PS II absorb at or below 680 nm wavelength of light.
- The **temperature coefficient (Q_{10})** is defined as the ratio of the velocity of a reaction at a particular temperature to that at a temperature 10°C lower.
- For a **physical process** the value of Q_{10} is slightly **greater than one**.
- For **photochemical reaction** the value of Q_{10} is **one**.
- For **chemical reaction** the value of Q_{10} is **two or more** *i.e.*, with the rise of 10°C temperature, the rate of chemical reaction is doubled.

MECHANISM OF PHOTOSYNTHESIS

- The mechanism studied for photosynthesis demonstrated the existence of two phases : **light phase (photochemical phase)** and **dark phase (biosynthetic phase)**.

Light reaction

- The reaction of light phase requires light and hence called **photochemical reaction**.
- Transfer of energy, Emerson effect, photosystem I, photosystem II, cyclic and non-cyclic photophosphorylation are the **various event and components of light phase**.
- In the light reaction two important products, **$NADPH_2$** and **ATP** are formed.
- Light reaction occurs in the **grana of chloroplast.** It was **observed by Arnon**.
- He also explained that isolated chloroplasts are capable of fixing CO_2 resulting in the formation of **carbohydrates**.
- According to Hill and Bendall, light reaction is a **two step electron transport system**.
- In the 1st step **photolysis of water** and **photophosphorylation** takes place.
- Splitting up of water and liberation of O_2 by chlorophyll in presence of light and hydrogen acceptor is called **photolysis of water**.
- Hill reaction or photolysis of water was proposed by **Robert Hill**.
- Electron acceptors or hydrogen acceptors oxidise water and hence called **Hill oxidants**.
- **Hill oxidants** are **ferredoxin**, **quinone**, **2, 6 dichloro endophenol** and **ferric salts** (ferric oxalate).
- $NADP^+$ is **natural hydrogen acceptor** in plant cells.
- Experimental proof for the liberation of O_2 from H_2O by using radioactive oxygen (O^{18}) was provided by **Ruben and Kamen (1941)**.

$$CO^{16}_2 + 2H_2O^{18} \xrightarrow[\text{chlorophyll}]{\text{light}} CH_2O^{16} + H_2O + O^{18}_2$$

- Evolution of **oxygen** takes place **from water** and **not from CO_2**, during photosynthesis. So the traditional equation of photosynthesis is changed as follows –

$$6CO_2 + 6H_2O \xrightarrow[\text{chlorophyll}]{\text{light}} C_6H_{12}O_6 + 6O_2$$

Traditional equation

$$6CO_2 + 12H_2O \longrightarrow C_6H_{12}O_6 + 6H_2O + 6O_2$$

Modern equation

- ATP, NADPH + H^+ are produced in light reaction and are used for the **reduction of CO_2**.
- Isolated chloroplast cannot carry out CO_2 reduction because enzymes necessary for CO_2 reduction are **leached out during the isolation of chloroplasts**.
- Isolated chloroplasts can carryout CO_2 reduction provided the leached substances are **externally supplied to them**.
- This was proved by **D.I Arnon** and his associates. Inorganic phosphate is converted into pyrophosphate (~P) during the transfer of electron from Cyt. b_6 to

Cyt *f* due to potential gradient. *i.e.*, ADP reacts with *Pi* and forms ATP. This is called **photophosphorylation**.

- Synthesis of ATP from ADP and *Pi* is called **phosphorylation**. Synthesis of ATP in the chloroplast in the presence of light is called **photophosphorylation**.
- Photophosphorylation was discovered by **Arnon**.
- Arnon identified **2 types of photophosphorylation** :- **cyclic photophosphorylation** and **non-cyclic photophosphorylation.**
- **Cyclic phosphorylation** involves participation of only PS I.
- This system is **not concerned with photo-oxidation of water.**
- **The electrons excited from PS I return back to PS I** so that the electron transport is cyclic.
- It is **only concerned with production of ATP.**
- It occurs under special conditions when NADPH starts accumulating.
- **Non-cyclic phosphorylation** involves the participitation of both PS I and PS II.
- The first step is photo-oxidation of water resulting in splitting of water into H^+, e^- and release of O_2.
- It involves sequence of electron transfer where $NADP^+$ is reduced by PS I, PS I is reduced by PS II and PS II is reduced by water so that the electron transport is non-cyclic.
- It is **concerned with reduction of $NADP^+$ and production of ATP.** It occurs under normal conditions.
- In the **second step reduction of $NADP^+$ takes place. $NADP^+$ reacts with electrons and hydrogen ions of water** to gives rise $NADPH^+ + H^+$.
- Emerson and his associates conducted experiments in regard to **photosynthetic yield** (evolution of O_2) on an alga namely *Chlorella*.
- A sudden decrease in photosynthetic yield (evolution of O_2) in far red light above 680 nm is called **red drop**. Red drop was discovered by **Emerson and his associates**.
- Increase in rate of photosynthesis (photosynthetic yields) due to far red light and red light of shorter wavelength supplied simultaneously is called **Emerson enhancement effect**.
- **Quantum yield** is the number of oxygen molecules produced per quantum of light. Its value is 0.125.
- **8 quanta of light are required for 1 molecule of O_2.**

Dark reaction

- Dark reaction occurs even in the presence of light but **it doesn't require light**.
- Dark reaction **depends on the light reaction for assimilatory powers**.
- Dark reaction is a **thermochemical reaction**.
- Dark reaction takes place in the **stroma of the chloroplast**.
- Dark reaction is also called **CO_2 fixation** or **carbon assimilation**.
- The mechanism of dark reaction consists of **3 phases – carboxylation**, **reduction**, **and regeneration of CO_2 acceptor**.
- Depending upon the number of carbon atoms in the first stable product of dark reaction, first photoautotrophic plants are classified into 2 types – **C_3 plants and C_4 plants**.

Calvin cycle or C_3 pathway

- Carbon assimilation in C_3 plants was explained by **Melvin Calvin** *et al* (Benson, Bassham) in *Chlorella* and *Scenedesmus* by using radioactive isotope $^{14}CO_2$.
- Techniques used by Melvin Calvin *et al* are **chromatography** and **autoradiography**.
- In honour of Melvin Calvin the sequence of reactions of carbon assimilation in C_3 plants is called **Calvin cycle**.
- Calvin was awarded with **Nobel prize in 1961**.
- Calvin cycle is also called **Calvin – Benson cycle**, **C_3 – Pathway** or **reductive pentose phosphate pathway**.
- Plants showing C_3 pathway are called **C_3 plants**.
- Calvin cycle has to take place **6 times** for the formation of a molecule of glucose because only precursor of carbohydrate (CH_2O) is formed when **1 molecule of CO_2 participates in the carboxylation**.
- **RuBP** (Ribulose bi phosphate), a 5 C compound **is the CO_2 acceptor in C_3 plants.**
- Enzyme useful for this carboxylation is **RuBP carboxylase** (RuBPase) (carboxydismutase – old name), also called RUBISCO.
- **6 molecules of CO_2** react with **6 molecules of RuBP** to form an unstable hexose compound.
- 6 molecules of unstable compound immediately converted into **12 molecules of PGA** (phosphoglyceric acid).
- In this process **$6H_2O$** are utilised.

- 12 molecules of PGA cannot undergo reduction.
- PGA is the **first stable product of C_3 plants**.
- **PGA** contains 3 - carbon atoms hence this carbon pathway is called **C_3 carbon pathway**.
- During second phase *i.e.*, **reductive phase** PGA is reduced by NADPH + H^+. Before this PGA gets **activated** by reacting with ATP.
- 12 molecules of PGA react with 12 molecules of ATP (phosphorylation) formed in light reaction to form 12 molecules of DPGA (Diphosphoglyceric acid).
- Enzyme utilised is **phosphoglyceric phospho-transferase**.
- DPGA which is in the activated state (or primed state) is **reduced to GAP** (Glyceraldehyde -3-phosphate) or 3-PGAL (3-Phosphoglyceraldehyde). This can also be written as G - 3 - P.
- Reduced **Co-enzyme - II (NADPH + H^+)** is utilised for this reduction.
- In the formation of PGA, fixation of carbon is completed but it is not reduced. Both the fixation and reduction are completed with the formation of PGAL.
- 12 molecules of DPGA react with 12 NADPH + 12H^+ to form 12 GAP (glyceraldehyde-3-phosphate). 12$NADP^+$ and 12 Pi are liberated in this reaction.
- Enzyme utilised is **triose-phosphate dehydrogenase**.

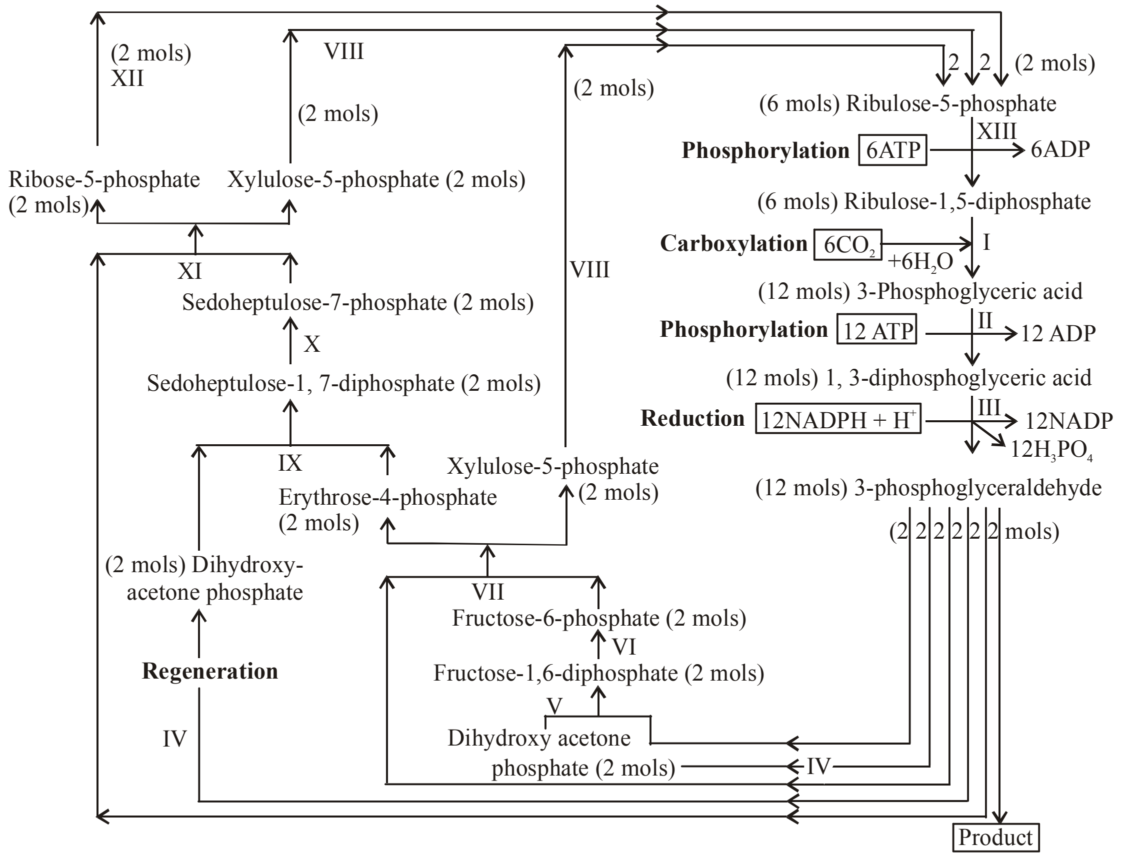


Fig : Calvin cycle : I to XIII enzymes. I - Rubisco, II - 3Phosphoglycerate Kinase, III - PGAld-dehydrogenase, IV - Triose - phosphate isomerase, V - Aldolase, VI - Phosphatase, VII - Transketolase, VIII - Epimerase, IX - Aldolase, X - Phosphatase, XI - Transketolase, XII-Isomerase and XIII - Phosphopentokinase.

- Out of 12 molecules of GAP, 5 molecules are isomerised to 5 molecules of DHAP (Dihydroxy acetone phosphate).
- Enzyme utilised is **triose-phosphate isomerase** (GAP Ketol isomerase).
- 3-PGAL exists in dynamic equilibrium with DHAP and both are together known as **triose-phosphate**.
- Third phase of Calvin cycle is the **regeneration phase**.
- During this phase **1/6th** of total PGAL is utilised to form a hexose molecule as a net gain.
- **5/6th** of the total PGAL is utilised to regenerate 6 molecule of RuBP by **utilising 6 ATP**.
- During regeneration phase first step is **condensation** of six triose molecule to form 3 molecule of **fructose 1–6–diphosphate**.
- The enzyme utilised is **aldolase**.
- In second step three fructose diphosphate molecules are **dephosphorylated to 3 molecules of fructose 6-phosphate** by the action of **fructose phosphatase**.
- Out of three fructose 6-phosphate, **1 fructose phosphate** by reversal glycolytic reaction is **converted into glucose**.
- Glucose is converted into either **sucrose or starch**.
- The remaining two molecules of fructose-6-phosphate (2/3) react with two molecules of PGAL to form **2 molecules of xylulose 5-phosphate** and **2 molecules of erythrose 4-phosphate**. This reaction is catalysed by **transketolase**.
- Two molecules of erythrose 4-phosphate react with 2 molecules of DHAP to form 2 molecules of **sedoheptulose diphosphate**. This reaction occurs in the presence of **transaldolase**.
- Two molecules of sedoheptulose monophosphate are formed from sedoheptulose diphosphate by the action of **phosphatase**, this is **dephosphorylation**.
- Two molecules of **sedoheptulose monophosphate** and 2 molecules of **PGAL** react to **form 2 molecules of xylulose 5-phosphate** and **2 molecules of ribose 5-phosphate**. This reaction is catalysed by **transketolase**.
- **Four molecules** of **xylulose 5-phosphate** (formed earlier) isomerise into four molecules of **ribulose 5-phosphate**. The enzyme utilised is **phosphoketopentoisomerase.**
- Two molecules of ribose 5-phosphate (formed earlier) isomerise into 2 molecules of ribulose 5-phosphate by the action of phosphoribose isomerase. Thus **6 molecules of ribulose monophosphate** (Ru-5-phosphate) are formed.
- These six molecules of ribulose 5-phosphate are converted to six molecules of **ribulose biphosphate** by **phosphopentokinase**.
- **6 ATP** are **utilised in phosphorylation reaction.**
- Overall reaction of **Calvin cycle** is –
  RuBP + 6 CO_2 + 18 ATP + 12 NADPH + H^+ $\rightarrow$ 6 RuBP + Glucose + 6 H_2O + 18 ADP + 12 $NADP^+$.
- One molecule of glucose is formed from 6 CO_2 by utilising **18 ATP** and **12 NADPH + H^+**.

Hatch & Slack pathway or C_4 cycle

- **C_4 acid** (dicarboxylic acid) is formed due to carboxylation was shown by **Kortschak *et al* in sugarcane.**
- In 1960, **Hatch and Slack established the above idea by conducting experiments on leaves of maize and grasses.**
- C_4 pathway is called **Hatch & Slack cycle**. It is also known as **co-operative photosynthesis**.
- Hatch-Slack cycle occurs in chloroplasts of **mesophyll cells** and **bundle sheath cells**.
- **Primary acceptor of CO_2** in C_4 plants is **phosphoenol pyruvic acid (PEP)**.
- Carboxylation is catalysed by **PEP carboxylase** (PEP case).
- Carboxylation taking place with the help of PEP case is called **β-carboxylation**.
- **First stable product** in C_4 plants is **OAA (oxaloacetic acid)**.
- OAA is **reduced to malic acid**. Enzyme useful for the reduction is NADP specific **malic dehydrogenase**.
- **OAA, malic acid and aspartic acid are the dicarboxylic acids.** Hence C_4 pathway is also called **C_4 dicarboxylic acid cycle**.
- Malic acid comes out of the mesophyll cells and enters the bundle sheath cells through plasmodesmata.
- Normally malic acid **undergoes oxidative decarboxylation**.
- Carbon of C_4 acid reaches RuBP and undergoes carboxylation by carboxydismutase to form PGA.
- The residue of C_4 acid (containing 3 carbon atoms) is converted into **pyruvic acid**.

- As liberated CO_2 is accepted by **RuBP** so, in C_4 plants Calvin cycle occurs in the **chloroplasts of bundle sheath cells.**
- Pyruvic acid enters the mesophyll cells and then it is **phosphorylated to PEP** by **pyruvate dikinase**.
- C_4 plants **show Kranz type of anatomy** *i.e.*, two types of chloroplasts.
- **Chloroplasts of mesophyll cells** are **grana rich** and they **do not produce starch**.
- **Chloroplasts of bundle sheath cells lack grana** but **they are starch rich**.
- The leaves of C_4 plants requires at least 5ATP and 2 NADPH to fix one molecules of CO_2. Thus, the pathway requires total 30 ATP and 12 NADPH molecules to synthesize one molecule of glucose.
- The C_4 plants can absorb CO_2 even from a much low CO_2 concentration when the C_3 plants fail to avail it.
- Thus, the C_4 plants can perform a high rate of photosynthesis even when the stomata are nearly closed.
- The C_4 cycle requires more light energy to fix CO_2 as compared to C_3 plants.
- They also maintain a high rate of photosynthesis under conditions of water shortage where the C_3 plants would stop photosynthesis.
- Thus, the C_4 plants are better adapted to tropical and desert areas where sun light is more intense and the growing season is longer.
- The **rate or photosynthesis remains higher due to absence of photorespiration.**
- They are about twice as efficient as C_3 plants in converting solar energy into production of dry matter.

Crassulacean acid metabolism (CAM)

- In the members of Crassulaceae, Cactaceae, Agavaceae, Orchidaceae, Portulacaceae, CO_2 fixation occurs **during night only**.
- In succulents belonging to the above families the **stomata remain closed during day** time in order to reduce transpiration and **open during night** (scotoactive opening).
- All such plants are called c**rassulacean acid metabolisms plants** (CAM plants).
- In **CAM plants also** OAA is formed due to **carboxylation** as in C_4 plants.
- Like C_4 plants, OAA is reduced to malic acid in CAM plants also. Malic acid is **accumulated in the vacuole**.
- Absorption of CO_2 during night and its storage as organic acid (malic acid) is called **acidification**.
- During day time malic acid undergoes **oxidative decarboxylation** and CO_2 is released.
- Liberation of CO_2 from an organic acid during day time is called **deacidification**.
- The diurnal acidification and deacidification during the night and day time respectively is called CAM.
- All reactions of CAM **occur in mesophyll cells**.
- Chloroplasts are absent in bundle sheath cells of **CAM plants**.
- CAM pathway is **important for the survival of succulents**.

PHOTOSYNTHETIC FACTORS

- **Law of minimum** was **proposed by Liebeg (1843).**
- Law of limiting factors (to explain the influence of external factors on photosynthesis) was proposed by **F.F.Blackman (1905)**.
- When a process is conditioned as to its rapidity by a number of separate factors the process is limited by the **pace of the slowest factor**. This is called the **law of limiting factor**.
- The factor which is at the minimum level is called **limiting factor**.
- When the concentration of the limiting factor is increased to a certain extent the rate of process also increases.
- Factors which influence the rate of photosynthesis are of two kinds - **external factors** (environmental factors) and **internal factors.**
- The **important environmental factors** are – (i) light, (ii) CO_2 conc., (iii) O_2 conc., (iv) temperature, (v) H_2O, (vi) mineral salts.
- Light intensity at which rate of photosynthesis is equal to the rate of respiration is called **compensation point**.
- **If light intensity is increased above compensation point** rate of photosynthesis **increases**.
- The degradation of chlorophyll molecule due to high light intensity is called **photo-oxidation**.
- Photo-oxidation of chlorophyll under very high light intensity is called **solarization**.
- **Rate of photosynthesis is maximum** in **red light** and **then in blue light**.

- Rate of photosynthesis is **minimum in green light**.
- Photosynthesis also occurs in artificial light when it is **provided in sufficient quantities**.
- Plants which can grow in shade are called **sciophytes**.
- Sciophytes have very sensitive and efficient photosystems to receive **diffused light**.
- Plants which can grow in direct sunlight area are called **heliophytes**.
- Rate of photosynthesis is **more in intermittent light** (light in flashes) **than in continuous light.**
- If **CO_2 concentration is increased** from **0.03% to 1%** the **rate of photosynthesis also increases**.
- When CO_2 conc. is **more than 1%** the rate of **photosynthesis decreases** due to **closure of stomata**.
- CO_2 reacts with water to form **carbonic acid** when it is in high concentration.
- **The most common limiting factor for photosynthesis** is **CO_2**. **Light occupies the next place**.
- O_2 is the **byproduct** of photosynthesis.
- Rate of photosynthesis decreases in **high concentration of O_2**.
- The inhibitory effect of O_2 on photosynthetic rate is called **Warburg effect**.
- In C_3 plants high O_2 conc. leads to the occurrence of photorespiration; as a result net yield of **photosynthesis decreases**.
- Temperature has maximum influence on dark phase of photosynthesis. Hence dark phase is called a **thermochemical reaction**.
- Minimum, optimum and maximum ranges of temperature (cardinal points) depend on **type of a plant** and its **geographical distribution**.
- For **tropical plants** minimum temperature is **0°C**. In maximum temperature photosynthesis decreases due to **denaturation of enzymes**.
- Algae of hot springs can carry out photosynthesis at **70°C**.
- With an increase in temp from **0°C to 35°C** rate of photosynthesis increases twice for rise of 10°C. Therefore $Q_{10} = 2$.
- Water donates **electrons and cations** ($2H^+$) to $NADP^+$.
- Plants utilise **less than 1% of water absorbed** by them in photosynthesis.
- **Mg** is **associated with the synthesis of chlorophyll molecule**.
- Electron carriers namely **ferredoxin** and **plastocyanin** contain **iron**, and **copper** respectively.
- **Mn^{++} and Cl^-** ions are **useful for photolysis of water.**
- **Rate of photosynthesis decreases when there is deficiency** of elements like **Mg^+, Mn^+, Cl^-**.
- Radiant energy is converted into chemical energy by chlorophyll.
- Chlorophyll–less mutant plants are called **albinos**.
- Albinos cannot survive long due to the **non-production of carbohydrates**.
- **Accumulation of carbohydrates decreases** the rate of photosynthesis (due to non-availability of space for new molecules).
- As the leaf expands the stomata will be opened to the external atmosphere. Rate of **photosynthesis increases due to the entry of CO_2**.
- Necessity of CO_2 for photosynthesis can be demonstrated **by Moll's half leaf experiment**.
- Necessity of light for photosynthesis can be demonstrated **by light screen experiment**.
- Necessity of chlorophyll for photosynthesis can be demonstrated **by *Croton* leaf experiment**.
- Liberation of O_2 during photosynthesis can be demonstrated by ***Hydrilla* funnel experiment**.
- Presence of starch can be tested **by iodine test**.
- Osmotically inactive form of photosynthetic product is **starch**.

IMPORTANCE OF PHOTOSYNTHESIS

- Photosynthesis is the fundamental synthetic process present in green plants. It is an **anabolic or constructive process.**
- All organisms depends directly or indirectly on photosynthesis **for their food and energy needs.**
- Entire oxygen of the atmosphere is derived from photosynthesis. It is **useful for respiration of organisms.**
- Photosynthesis is **helpful in maintaining percentage of O_2 and CO_2** constantly in the atmosphere.
- It is the **only biochemical process in which light energy is first converted into chemical energy** and then **stored as potential energy in carbohydrates**.
- Molecular O_2 released from photosynthesis is also utilized in **making ozone (O_3)** in the outer layer of

atmosphere. The ozone layer acts as screen and helps in stopping the highly destructive ultraviolet (UV) rays from reaching the earths.

- The carbohydrates produced during photosynthesis are used by plants and animals to synthesize organic acids proteins, fats, nucleic acids, hormones, pigments, vitamins, alkaloids and other metabolites.
- Photosynthesis consumes atmospheric carbon dioxide which is being continuously added by the respiration of organisms and burning of organic fuels. Thus, this process acts as **purifier of atmosphere.**

PHOTORESPIRATION

- Light induced CO_2 liberation from a C_2 compound (glycolic acid) of dark phase is called **photorespiration**.
- Photorespiration occurs in **green cells** only.
- Photorespiration is **absent in C_4 plants** and is **present in C_3 plants**.
- Photorespiration involves three cell organelles – **peroxisomes**, **chloroplasts** and **mitochondria**.
- This process is considered to nullify the result of photosynthesis as **no ATP** and **$NADPH_2$ is produced**.
- During photorespiration **loss of carbon takes place in the form of CO_2.**
- When the concentration of $O_2$is more than that of CO_2 then RuBP oxygenase adds O_2 to RuBP.
- RuBP is converted into **one molecule of PGA** and one molecule of **phosphoglycolic acid**.
- Phosphoglycolic acid is **dephosphorylated** to glycolic acid.
- Glycolic acid then enters the **peroxisome**.
- Glycolic acid acts **as a substrate** for photorespiration.
- Glycolic acid **undergoes oxidation** to form glyoxylic acid and hydrogen peroxide. Enzyme is **glycolic oxidase**.
- Enzyme useful for the breakdown of H_2O_2 into water and oxygen is **catalase**.
- Glyoxylic acid is converted into **glycine** by **transamination** in the presence of enzyme **glyoxylate aminotransferase**. Glycine then enters the mitochondrion.
- Two molecules of glycine by loosing one molecule of CO_2 are converted into **serine**. Enzyme involved is **glycine decarboxylase**.
- In mitochondria two glycine molecules react to produce 1 molecule of serine, CO_2 and NH_3.
- **Liberation of CO_2 occurs** in the mitochondrion.
- Serine is deaminated to **hydroxypyruvate** in **peroxisome** by **transaminase** and glyceric acid is also formed.
- Photorespiration is also called **glycolate pathway**. Formation of PGA from two carbon intermediate, glycolic acid is called **glycolate pathways**.
- Glyceric acid is transported out of peroxisome into chloroplast where it forms 3PGA by ATP.The PGA is used in photosynthetic carbon reduction cycle.

End of the Chapter

Chapter 37

Respiration in Plants

- All the cellular activities are grouped into two categories - **anabolism** (biosynthetic activities of the cell) and **catabolism** (breaking up processes of the cell).
- The anabolic activities are **endergonic** (energy dependent), while catabolic activities are usually **exergonic** (energy producing).
- The sum total of catabolic and anabolic reactions occurring at any time in a cell is called **metabolism**.
- **Respiration** is an **exergonic** and **catabolic physico-chemical process** which involves the exchange of environmental oxygen and body carbon dioxide through a liquid medium and the oxidation of glucose inside the mitochondria to produce energy which is partly stored in the high energy bonds (~) of ATP molecules as biologically useful energy.
- The reaction for respiration is –
  $\mathbf{C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + Energy.}$
- Biological useful energy is in stored forms and is must because –
  - Released energy may not be required immediately.
  - Sites of endergonic processes may be away from the sites of exergonic processes.
  - It provides a quick source of energy when required, so **ATP is commonly called energy currency.**
- The dry weight of a plant **decreases** due to respiration.
- Respiration is a **biological oxidation** process. It resembles oxidation in certain respects and differs with it in releasing energy in a stepwise manner.
- All living organisms (except viruses) **respire**.
- Carbon present in the living cells undergoes combustion in presence of atmospheric oxygen and is exhaled out in the form of CO_2. Hydrogen is present in the form of water vapour. This was stated by father of modern chemistry **Lavoisier**.
- Respiration is a **type of metabolism** which includes the following **four important points**.
  - Energy is liberated through **biological oxidation** from the food collected by the organism and the energy will be utilised by that living system.
  - **End products** are not important. **Types of energy and their utilization** is very important.
  - In aerobic respiration energy of the food is **totally liberated due to complete biological oxidation of substrate**. A part of energy is liberated in anaerobic respiration due to **partial oxidation of the substrate**.
  - Biological oxidation depends upon **factors present in the living cells**.
- The organic substances (*i.e.*, carbohydrates, fats, proteins, etc.) are broken down to release energy by the process of **cellular respiration.**
- Cellular respiration may be divided into two cateogries depending upon the availability of atmospheric oxygen – **aerobic** (**presence of oxygen**) and **anaerobic respiration** (**absence of oxygen**).
- The breakdown of respiratory substrates provides carbon skeleton for the synthesis of a large number of other essential plant products, such as **polysaccharides**, **proteins**, **fats**, **nucleic acids**, **pigments**, **cytochromes** etc.
- Thus, the same respiratory process which acts as catabolic pathway for respiratory substrates also acts as anabolic pathway for the synthesis of various intermediary metabolic products and secondary metabolities.
- Thus, it is called as **amphibolic pathway** rather than as a catabolic pathway.

RESPIRATORY SUBSTRATES

- Any organic substance which can be oxidised in respiration is known as **respiratory substrate**.

- Respiratory substrates are - **carbohydrates** (starch, sucrose, fructose and glucose), **proteins, fats** and **organic acids**.
- All organic substances (excepting glucose) should necessarily undergo **digestion** before their participation in respiration.
- A respiratory substrate which does not require digestion and which can directly participate in respiration is **glucose**.
- The ratio of the volume of CO_2 liberated to the volume of oxygen absorbed per molecule during respiration is called **respiratory quotient** (RQ).
- The value of RQ indicates the type of **respiratory substrate.**
- **RQ value for carbohydrates** is **1 or unity** as amounts of CO_2 and O_2 are equal because carbohydrates contain equal amounts of carbon and oxygen.
- Fats are **poor in oxygen**. So they need more O_2 for their oxidation. Therefore **RQ value for fats** is **less than 1**.
- **RQ value for proteins** will be approximately **0.8 or 0.9**. Because proteins **contain more oxygen** when compared to fats and **less O_2** when compared to carbohydrates.
- As RQ value for fats and proteins is **less than 1** so **more oxygen is absorbed** and **less CO_2 is liberated** in oxidation of fats and proteins.
- **RQ value in succulents is zero**. In succulents *Opuntia* (Cactaceae), *Bryophyllum* (Crassulaceae) carbohydrates are partially oxidised to malic acid. CO_2 is taken back and is fixed by RuBP carbroxylase in Calvin cycle.
- **RQ value for organic acids** is **more than 1**. Because they are rich in oxygen, more CO_2 is liberated and less O_2 is absorbed in oxidation of organic acids.
- RQ value is **infinite** during **anaerobic respiration** because there is no utilisation of O_2 in this process.
- Carbohydrates are converted into fats during **maturation of certain seeds**. During this conversion the liberated oxygen will be **utilised for respiration**.
- The value of RQ in different parts of the plant falls between **0.97 and 1.17** (near about 1 which is the RQ for carbohydrates). From this it is clear that mostly **sugars are the respiratory substrates in plants**.
- Since germinating seeds contain only one type of reserve food their RQ value indicates the **nature of the food actually stored in the seeds**.
- RQ value is measured with the help of double respiroscope.
- **External factors affecting respiration** are – oxygen concentration, CO_2 concentration, mineral and water availability etc. Respiratory substrate also effect respiration.
- **At low temperatures** (below 0°C) the rate of **respiration is minimum.** Hence fruits and vegetables are stored at **low temperature for preservation**.
- **Depending upon the substrates employed**, respiration is of **two types** – **floating respiration** & **protoplasmic respiration**.
- **Floating respiration** is that respiration which employs energy foods' as substrates (Two energy foods are carbohydrates and fats).
- **Protoplasmic respiration** is that respiration which employes proteins as respiratory substrate. As proteins are rarely stored in the cells, protoplasmic respiration uses cellular proteins. This disturbs metabolism and cellular machinery causing permanent injury and even death of the cells.

COMPENSATION POINT

- **Compensation point** is the point reached in a plant when the rate of photosynthesis is equal to the rate of respiration.
- This means that the carbon dioxide released from respiration is equivalent to that which is taken up during photosynthesis.
- The compensation point is reached as light intensity increases.
- Respiratory rate increases with an increase in temperature from **0 to 40°C**. But the **optimum temperature for respiration** is **25-35°C** (at which most of the metabolic activities of plants takes place).
- **At high temperature** (above 50°C) the **respiratory rate** decreases because of the **denaturation of enzymes**.
- Photosynthesis occurs in the presence of light and **helps in the preparation of respiratory substrate**.

AEROBIC RESPIRATION

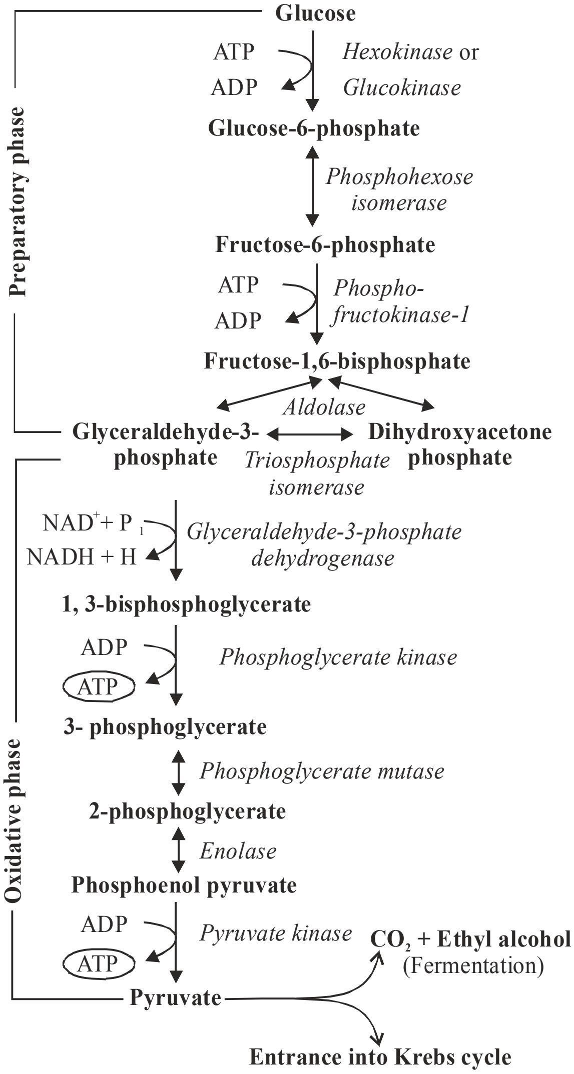
- Complete biological oxidation of the respiratory substrate with the help of atmospheric oxygen is known as **aerobic respiration**.
- Organisms which carry out aerobic respiration are called **aerobes**.
- The process of aerobic respiration can be represented by the following equation –
$C_6H_{12}O_6 + 6O_2 + 6H_2O \rightarrow 6CO_2 + 12H_2O + 673Kcal$
- 686 Kcal (2870 kJ) is energy released per mole of glucose.
- There are **two types of aerobic respiration** – **common pathway** and **pentose phosphate pathway**.
- It is known so because one of its step (glycolysis), is common to it as well as to anaerobic respiration.
- Common pathway occur in three steps - **glycolysis**, **Krebs cycle** and **terminal oxidation** (electron transport chain and oxidative phosphorylation).

Glycolysis or Embden - Meyerhof Parnas or emp pathway

- The breakdown of a sweet substance namely glucose (glycogen) into two molecules of pyruvic acid is called glycolysis.
- **Glycolysis** is **common phase** in both aerobic and anaerobic respiration.
- Glycolysis occurs in all living organisms and in all types of respiration. Hence James called it as **core respiration**. This is also known as **fundamental respiration**.
- **Site of glycolysis** is **cytoplasm** (cytoplasmic matrix of a living cell).
- The **reduction of the glucose** during glycolysis produce compounds for the synthesis of protein, fats and nucleic acid.
- **Most of the steps** of the glycolysis are **reversible**.
- Glycolysis may be divided into two phases, a **preparatory phase** and **an oxidative phase**.
- In the preparatory phase **breakdown of glucose** and **low energy phosphorylation occurs**, and **energy is used**. In the oxidative phase **high energy phosphate bonds are formed** and **energy is stored**.
- All reserve substances first undergo **hydrolysis** and are finally converted into glucose.
- In majority of the organisms **glucose acts as the respiratory substrate**.
- In glycolysis **one molecule of glucose** is converted into **two molecules of pyruvic acid**.
- The sequence of reactions in glycolysis was traced out by **Embden - Meyerhof- Parnas**. Hence glycolysis is also called **EMP pathway**.
- Glucose is to be **excited** before it is biologically oxidised through glycolysis.
- Excitation of glucose (oxidative phosphorylation) takes place by **transphosphorylation**.
- Glucose is phosphorylated to glucose-6- phosphate by **hexokinase and ATP**.
- Glucose-6-phosphate is converted into its isomer fructose-6-phosphate (*isomerisation*) by **hexose phosphofructokinase**.
- If **fructose** is there in hydrolytic products of carbohydrates it is also phosphorylated to fructose-6-phosphate by **fructose phosphotransferase** just like glucose.
- Fructose-6-phosphate is phosphorylated to fructose - 1,6 - biphosphate by **phosphofructokinase and ATP**.
- Though fructose 1-6 - biphosphate is in the excited state it is not suitable for biological oxidation. Therefore, the chemical bond between third and fourth carbon atoms is to be broken down by **ketosephosphate aldehylase (Aldolase)**.
- The products of fructose, 1,6- biphosphate are glyceraldehyde - 3 - phosphate **(GAP)** and dihydroxyacetone phosphate **(DHAP)**.
- (a) GAP and DHAP are **trioses** and **isomers**.
(b) GAP and DHAP are **interconverted** into one another by **GAP ketol isomerase** (triose phosphate isomerase).
- The substance which is suitable for biological oxidation and which undergoes first biological oxidation in respiration is **GAP**.
- GAP is **phosphorylated** and also **biologically oxidised to 1,3- diphosphoglyceric acid**.
- Consumption of inorganic phosphate (phosphoric acid, H_3PO_4) in this biological oxidation is most important since this phosphate is involved in **ATP synthesis in the next reaction**.
- This first biological oxidation reaction is catalysed by **GAP NAD oxidoreductase**.
- NAD^+ (Nicotinamide Adenine Dinucleotide) **acts as coenzyme in above oxidation.**
- NAD^+ is the **universal hydrogen acceptor**.
- H_2 is liberated due to biological oxidation.

- NAD$^+$ accepts **one proton** and **2 electron** and it should be written as NADH and the remaining proton will be free in the cytoplasm.
- The **influence of GAP NAD oxidoreductase** can be **inhibited by iodoacetate.**
- Enzyme useful for the transformation of 3-phosphoglyceric acid into 2- phosphoglyceric acid is **phosphoglyceromutase**. Phosphate at 3rd carbon atom is shifted to 2nd carbon atom by the enzyme, and the process is called **intramolecular shift**.
- Enzyme useful for the conversion of 2-PGA to phosphoenol pyruvic acid is **enolase**. One molecule of water is eliminated.
- Enzyme useful for dephosphorylation of PEP into pyruvic acid is **phosphopyruvic phosphotr-ansferase** (pyruvate kinase).
- The influence of enolase can be inhibited by **NaF** (sodium fluoride).
- Mg^{2+} ions act as cofactors for **phosphotransferases and enolase**.
- The **end product of glycolysis** is **pyruvic acid**.
- In all, there are **four phosphorylations** during glycolysis. Two phosphate groups are supplied by **ATP** and two by **phosphoric acid.**
- **No. of ATP used for phosphorylation of glucose** in glycolysis is **2 (1st and 3rd reactions)**.
- No. of ATP formed during glycolysis is **4 (2 ATP for each GAP)**.
- **Net gain of ATP** during glycolysis is **2(4 – 2 = 2)**
- If fructose-6-phosphate is oxidised through glycolysis **net gain of ATP is 3 (4 – 1 = 3)**.
- No. of *Pi* utilised during glycolysis is **2**.
- No. of NAD$^+$ reduced during glycolysis is **2** (one NAD$^+$ for each GAP).
- **Summary equation of glycolysis** –

  $C_6H_{12}O_6$ + 2ADP + 2Pi + 2NAD$^+$ $\longrightarrow$
  (Glucose)
  $2CH_3COCOOH + 2ATP + 2NADH + 2H^+$
  (Pyruvic acid)
- Glycolysis involves oxidation without the direct use of oxygen. The oxidation is actually a process of **dehydrogenation.**
- Pyruvic acid **does not directly enter** the Kreb cycle.
- It enters the Kreb cycle in the form of **acetyl CoA.**
- The conversion of pyruvic acid into acetyl CoA takes place by **pyruvic oxidase**.
- Both **decarboxylation and dehydrogenation** occur in this complex reaction and this together is called **oxidative decarboxylation**.
- This is the **first oxidative decarboxylation** in respiration.
- One carbon of $CH_3COCOOH$ (pyruvic acid) is liberated in the form of CO_2.
- The essential cofactors for pyruvic oxidase are **TPP** (thiamine pyrophosphate), **Mg^{++} ions, lipoic acid** (LA) **CoA.** and **NAD$^+$.**
- The residue of pyruvic acid is **acetyl CoA.**
- The **connecting link between** glycolysis and Krebs cycle is **acetyl CoA** (2 carbon fragment).



Flow chart : Pathway of glycolysis from glucose to pyruvate.

Table : Major steps, enzymes involved, substrate and end products of glycolysis

	Steps	Substrates	Enzymes/Cofactor	End products
1.	Phosphorylation	Glucose + $\boxed{\text{ATP}}$	Hexokinase Mg^{+2}	Glucose-6-phosphate
2.	Isomerization	Glucose-6-phosphate	Phosphohexose isomerase Mg^{+2}	Fructose-6-phosphate
3.	Phosphorylation	Fructose-6-phosphate $\boxed{\text{+ATP}}$	Phosphofructokinase Mg^{2+}	Fructose, 1, 6, diphosphate
4.	Splitting	Fructose 1, 6 diphosphate Dihydroxyacetone 3-phosphate	Aldolase Triose phosphate isomerase	3-PGAL (3, phosphoglyceraldehyde) and Dihydroxy acetone-3 phosphate (DHAP) Glyceraldehyde 3-phosphate Thus 2 molecules of 3 PGAL are produced.
5.	Each 3 PGAL undergoes: Dehydrogenation and Phosphorylation	Glyceraldehyde-3-phosphate + NAD	Glyceraldehyde phosphate dehydrogenase	1, 3, diphosphoglycerate + $NADH_2$
6.	Dephosphorylation	1, 3 diphosphoglycerate	Phosphoglycerate kinase, Mg^{2+}	3 phosphoglycerate + $\boxed{\text{ATP}}$
7.	Isomerization	3 phosphoglycerate	Phosphoglyceromutase	2 phosphoglycerate
8.	Dehydration	2 phosphoglycerate	Enolase, Mg^{2+}	Phosphoenol pyruvate (PEP)
9.	Dephosphorylation	Phosphoenol pyruvate	Pyruvate kinase Mg^{2+}, K^+	Pyruvate + $\boxed{\text{ATP}}$
In **step 1**, **3 ATP** is utilised whereas in **step 6**, **9 ATPs** are produced.				

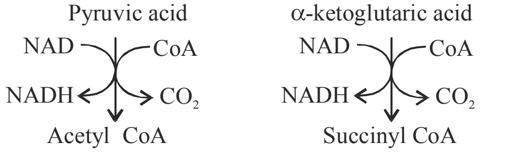
Krebs cycle or tricarboxylic acid cycle or TCA cycle

- Kreb cycle is the second step (basically the third step after glycolysis and intermediate step) in plant respiration.
- Krebs cycle occurs in the **mitochondrial matrix**.
- In honour of Krebs, cyclic chemical changes occurring in the matrix of the mitochondrion together are called **Krebs cycle**.
- The condensation of acetyl CoA in presence of a molecule of water and OAA is carried out by **oxaloacetic : citric acid ligase** (condensing enzyme, citrate synthetase, citrogenase).
- **First organic acid** formed during Krebs cycle is **citric acid**. Hence Krebs cycle is also called **citric acid cycle**.
- The second event of Krebs cycle is **regeneration of OAA** (Oxaloacetic acid) from citric acid.
- Tricarboxylic acids formed during Krebs cycle are **citric acid, cis-aconitic acid, isocitric acid** and **oxalosuccinic acid**.
- Krebs cycle is also known as **tricarboxylic acid cycle (TCA cycle) as citric acid**

$$\left(\begin{array}{l} CH_2COOH \\ | \\ COHCOOH \\ | \\ CH_2COOH \end{array}\right) \text{ is a } 3-C \text{ compound.}$$

- Conversion of citric acid into cis-aconitic acid and cis aconitic acid into isocitric acid are catalysed by **aconitase**.
- First reaction is **dehydration** and second one is **hydration**.
- Biological oxidation of isocitric acid to oxalosuccinic acid takes place by **isocitrate - oxalosuccinic oxidoreductase**. NAD^+ is reduced to NADH.

- **Decarboxylation** of oxalosuccinic acid into α-ketoglutaric acid occurs by the above enzyme and in the presence of **Mn^{++} ions**, one carbon of acetyl CoA is liberated in the form of CO_2 in this reaction.
- A five carbon compound formed during Krebs cycle is **a-ketoglutaric acid** which is the **first dicarboxylic acid formed.**
- **Conversion of α - ketoglutaric acid into succinyl** CoA occurs in the same manner as that of pyruvic acid into **acetyl CoA**, **the enzyme is succinyl oxidase**.



- Both **decarboxylation** and **dehydrogenation** (oxidative decarboxylation) occur in this reaction. This is the **second oxidative decarboxylation.** This is the only oxidative decarboxylation in Krebs cycle.
- Succinyl CoA is an energised compound. Succinyl CoA is hydrated to succinic acid liberating CoA.
- Energy liberated in this hydration reaction is useful in **synthesizing GTP from GDP + Pi** (GTP - guanosine triphosphate). Enzyme useful for this reaction is **succinyl thiokinase**.
- High energy compound directly formed during Krebs cycle is **GTP**.
- The third phosphate of GTP is transferred to ADP to give rise to ATP. GTP + ADP $\longrightarrow$ GDP + ATP This is **substrate level phosphorylation**.
- Enzyme useful for the biological oxidation of succinic acid to fumaric acid is **succinic fumaric oxidoreductase** (succinic dehydrogenase).
- Coenzyme FAD (Flavin adenine dinucleotide) is reduced to $FADH_2$ during this oxidation.
- **Fumarase** is useful for the conversion of fumaric acid to malic acid. A molecule of water is utilized in this reaction.
- Enzyme useful for the biological oxidation of malic acid into oxaloacetic acid is **malic - oxaloacetic acid oxidoreductase** (**malic dehydrogenase**).
- Coenzyme - I (NAD^+) is reduced in this reaction.
- The food collected by a living organism undergoes **biological oxidation** in respiration through **glycolysis** and **krebs cycle**.
- One glucose molecule gives two molecules of pyruvic acid. We get $6CO_2$, 8NADH, $2FADH_2$ and 2ATP molecule in Krebs cycle.

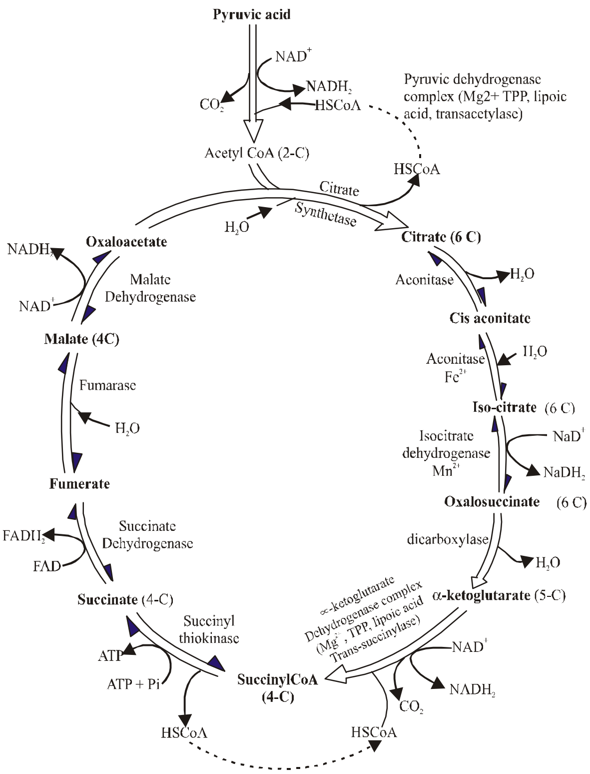


Figure : Schematic representation of Krebs cycle

Importance of krebs cycle

- Production of ATP.
- Krebs cycle is useful for the **formation of proteins**.
- Pyruvic acid is converted into alanine, a-Keto glutaric acid into glutamic acid, OAA into aspartic acid. Polymerisation of such aminoacids results in the **formation of proteins**.
- Krebs cycle is useful for the **conversion of fats into carbohydrates through glyoxylate cycle**. Main enzymes useful in this cycle are isocitritase and malic synthetase.
- Chlorophyll is synthesised from **succinyl CoA**.
- The **intermediate substances of Krebs cycle** are useful in intermediary metabolism and also act as precursors and structural units of life.

Table : Major steps, enzymes involved, substrates and end products of Kreb's cycle

S.N.	Steps	Enzyme	Substrates	Endproducts
1.	Condensation	Citric acid synthetase	(2C) Acetyl CoA and Oxaloacetate (4C)	Citric acid + CoA
2.	Dehydration	Aconitase	Citrate	Cis-aconitic acid + H_2O
3.	Rehydration	Aconitase	Cis-aconitate	Isocitric acid
4.	Dehydration (–2H)	Isocitrate dehydrogenase	Isocitrate (NAD^+, Hydrogen acceptor)	Oxalosuccinic acid + NADH + H^+
5.	Decarboxylation (–CO_2)	Oxalosuccinate decarboxylase	Oxalosuccinate	α-ketoglutarate + CO_2
6.	Dehydrogenation-II and carboxylation-II (–2H, –CO_2)	α-ketoglutarate dehydrogenase complex (involving four coenzymes, at least three enzymes and magnesium ion)	α-ketoglutarate + CoA + NAD^+	Succinyl CoA + NADH + H^+ + CO_2
7.	Phosphorylation of ADP	Succinate thiokinase	Succinyl CoA + GDP/ADP	Succinic acid + GTP + CoA
8.	Dehydrogenation-III	Succinic dehydrogenase	Succinate + FAD	Fumarate + $FADH_2$ (enzyme bound)
9.	Hydration (+H_2O)	Fumarase	Fumerate	Malate
10.	Dehydrogenation-IV (–2H)	Malate dehydrogenase	Malate (NAD/NADP)	Oxaloacetic acid + NADH +

Electron transport chain and Oxidative phosphorylation

- An **electron transport chain or system** is a series of coenzymes and cytochromes that take part in the passage of electrons from a chemical to its ultimate acceptor.
- **Reduced coenzymes** participate in electron transport chain.
- Electron transport **takes place on cristae of mitochondria** [oxysomes (F_o-F_i particles) found on the inner surface of the membrane of mitochondria].
- The electron transport chain is **comprised of four complexes and two mobile carriers** *i.e.* coenzyme *Q*, a non protein part of the chain except this all the members chain are proteins and cytochrome *C*.
- **Complex I** consists of flavoproteins of NADH dehydrogenase (FP_N).
- **Complex II** consists of flavoprotein of succinic dehydrogenase.
- Between complexes II and III is the **mobile carrier – coenzyme Q (CoQ) or ubiquinone (UQ)**.
- **Complex III** consists of cytochrome *b* and cytochrome c_1. Associated with cytochrome *b* is nonhaeme iron of Complex III ($FeNH_R$).
- **Complex IV** consists of cytochrome *a* and cytochrome a_3 and bound copper that are required for this complex reaction to occuzr.
- The electrons either follow the pathway of complexes I, III and IV or II, III and IV.
- NADH formed in glycolysis and citric acid are oxidised by NADH dehydrogenase (complex I) and the electrons are transferred to ubiquinone.
- Ubiquinone also receives electrons during equivalents *via* FADH through the activity of succinate dehydrogenase (Complex II).
- The reduced ubiquinone is then oxidised by transfer of electrons of cytochrome c *via* cytochrome bc_1 complex (Complex III).
- Cytochrome *c* **acts as a mobile carrier between complex III and complex IV**.
- Complex IV refers to cytochrome *c* oxidase complex containing cytochromes *a* and a_3 and two copper centres.
- When the electrons are shunted over the carriers *via* complex I to IV in the electron transport chain, they are coupled to ATP synthetase (complex V) for the formation of ATP from ADP and Pi.

- Oxygen functions as the terminal acceptor of electrons and is reduced to water along with the hydrogen atoms.
- Reduced coenzymes (coenzyme1, II and FAD) do not combine directly with the molecular O_2. **Only their hydrogen or electrons** are transferred through various substances and **finally reach O_2**.
- The substances useful for the transfer of electron are called **electron carriers**.
- Enzyme useful for the oxidation of co-enzyme is **NADH dehydrogenase**.
- Flavo proteins receive **hydrogen from co-enzyme** I or II and get reduced.
- CoQ receives **hydrogen from flavoproteins** and gets reduced. CoQ also receives hydrogen from reduced FAD and gets reduced.
- The splitting of hydrogen into $2H^+$ and $2e^-$ takes place at **CoQ** (also known as **ubiquinone**; **U.Q**).
- Protons are liberated into the **surrounding medium**.
- Only **electrons** are transferred through cytochromes (Cyt *b*, Cyt c_1,c_2, *a*, a_3) and finally reach molecular O_2.
- Atoms of iron exist in **2 forms** – ferric and ferrous. Electrons are received by **ferric form**.
  $2Fe^{+++} + 2e^- \longrightarrow 2Fe^{++}$
  Ferric form　　　Ferrous form
- Enzyme useful for terminal oxidation is **cytochrome oxidase or terminal oxidase.**
- Both cytochrome *a* and a_3 form a system called **cytochrome oxidase**.
- **Copper** is also present in Cyt a_3 **in addition to iron**.
- The molecular oxygen that has accepted electrons now receives the protons that were liberated into the surrounding medium to give rise to a **molecule of water**.
- The electrons are transferred from one electron carrier to another electron carrier because of the **differences in redox potentials among the carriers**.
- The tendency of electron carrier to receive or donate electrons is known as **redox potential**.
- Electrons **lose some amount of energy** during their transfer through electron carriers.
- The liberated energy is utilised for the synthesis of **ATP from ADP** and **Pi**.
- **Synthesis of ATP** (from ADP and inorganic phosphate) during oxidation is called **oxidative phosphorylation**.
- ATP-synthetase becomes active in ATP formation only where there is a **proton gradient** having higher concentration of H^+ or protons on the F_0 side as compared to F_1 side (chemiosmotic hypothesis of Peter Mitchel, 1961, Nobel Prize in 1978).
- 2 mols. of $NADH_2$ produced in glycolysis in cytoplasm have to go inside mitochondria for oxidative phosphorylation but mitochondrial membrane is not permeable to $NADH_2$ and hence the electrons or H-atoms of $NADH_2$ go inside mitochondria with the help of **electron shuttles**.
- **Two types of shuttles** are common – **malate aspartate shuttle** and **glycerol phosphate shuttle**.
- **Malate asparate shuttle** - When this electron shuttle occurs, transfer of electrons from $NADH_2$ in cytoplasm occurs to NAD inside the mitochondria. This is more efficient and **results in production of 38 ATP molecules**.
- In **glycerol-phosphate shuttle** the transfer of electrons from $NADH_2$ in cytoplasm occurs to FAD inside mitochondria and it results in production of **36 ATP molecules**.
- Oxidative phosphorylation of respiration is of **two kinds** – **substrate level phosphorylation** (SLP) and **chain level phosphorylation** (CLP).
- The oxidative phosphorylation occurring at the level of respiratory chain is called **chain level phosphorylation**.
- **3 ATP and 1 H_2O are formed** by the oxidation of a molecule of reduced Coenzyme I or II, between pyridine nucleotides and flavoproteins, between cyt *b* and cyt c_1, between cyt *a* and a_3.
- **2ATP and 1 H_2O are formed** by the oxidation of a molecule of reduced FAD through electron transport between cyt *b* and cyt c_1, between cyt *a* and a_3.
- Chain level phosphorylation **takes place in oxysomes**.
- No. of ATP formed by oxidation of glucose during glycolysis is **10** (substrate level phosphorylation = 4, chain level phosphorylation = 6).
- No. of **ATP utilised** during glycolysis **is 2**.
- Net gain of ATP through **glycolysis is 8** (When glucose is completely oxidised).
- Number of ATP formed by complete oxidation of each molecule of pyruvic acid is **15**. Therefore for 2 molecules of pyruvic acid is **30**.

- Number of ATP formed during **SLP = 2** and **CLP = 28**.
- No. of ATP formed by complete oxidation of a molecule of glucose (180 gm) is **40**.
- No. of ATP utilised during respiration is **2**.
- Net gain of ATP during aerobic respiration is **38**.
- No. of ATP formed through SLP during aerobic respiration = 6 (4 + 2)
- No. of ATP formed through CLP during aerobic respiration = 34 (6 + 28)
- As a result of biological oxidation of co-enzymes **chemical energy reserve is formed in a living cell**.
- Energy liberated by the removal of terminal phosphate from ATP is **8 k cal**.
- Most of the ATP molecules are stored in mitochondria hence mitochondria are often called as **power houses of the cell**.
- ATP is utilised in **driving various metabolic activities** (**absorption of salts** and **other metabolic activites**).
- Krebs cycle and respiratory chain are useful for the **biological oxidation of carbohydrates** (eg. starch), **fats** and **proteins**.
- **Carbohydrates, fats** and **proteins** enter the Krebs cycle in the form of **acetyl CoA**.

HEXOSE MONOPHOSPHATE PATHWAY (HMP) OR PENTOSE PHOSPHATE PATHWAY (PPP)

- It is alternate method of aerobic respiration which **occurs in the cytoplasm of mature plants cells** and accounting for 60% of total respiration in liver cells and also occur in adipose tissue and lactatic mammary glands.

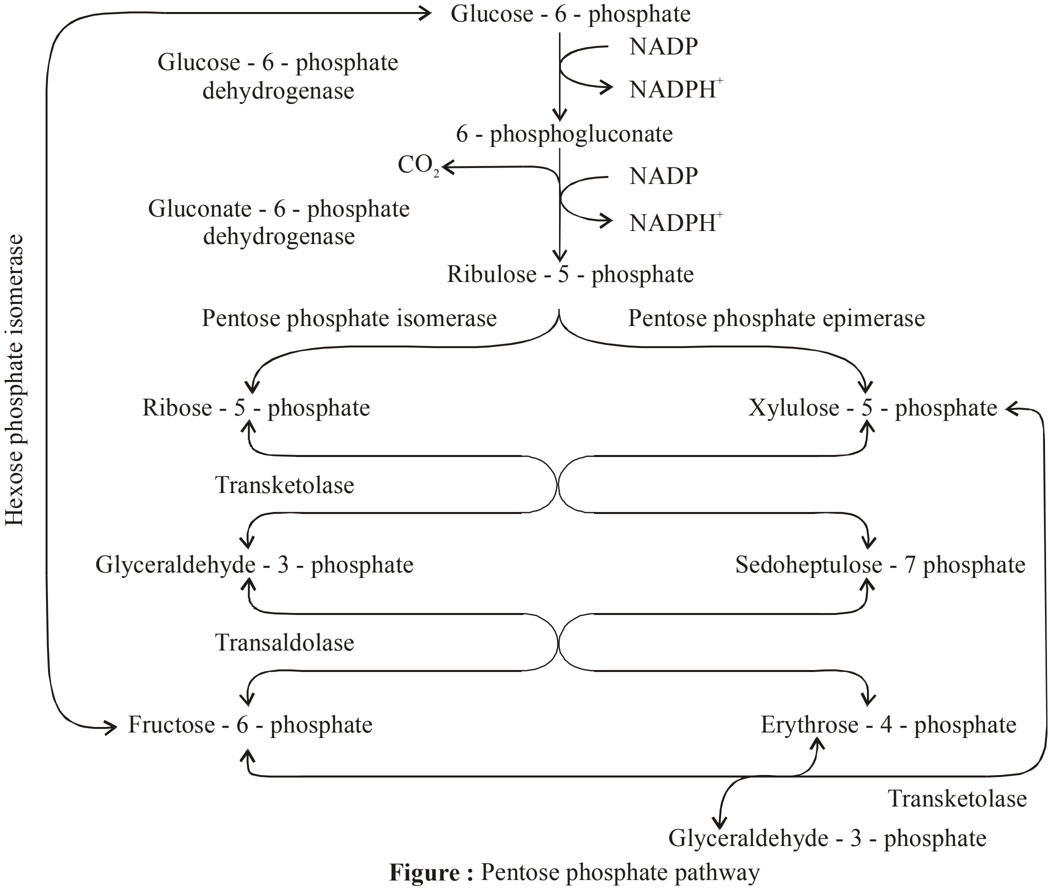


Figure : Pentose phosphate pathway

- The **pentose pathway** is also known as the **phosphogluconate pathway**. Since, this pathway metabolizes glucose 6-phosphate by reactions that bypass the reactions of glycolysis, it is also known as **hexose monophosphate shunt (HMP shunt)**.
- The **first enzyme in this pathway,** *i.e.* glucose 6-phosphate dehydrogenase was **discovered by Otto Warburg** in 1931. Later the complete cycle was elucidated by **Fritz Lipmann, Frank Dickens and Bernerd Horecker**.
- Normally glucose during aerobic respiration forms CO_2 and H_2O.
- The glycolytic pathway is not the only route available for the oxidation of sugars in plant cells. **Oxidative PPP or HMP** by sharing common metabolites can also do this work.
- In PPP, glucose - 6 - phosphate (6C) formed in glycolysis or photosynthates formed during photosynthesis are oxidised to form **6 - phosphoglyconate**.
- This step requires the enzyme **glucose - 6-phosphate dehydrogenase** to release NADPH.
- 6 - phosphogluconate in presence of enzyme 6 - phosphogluconate dehydrogenase forms 1 molecule of ribulose - 5 - phosphate.
- It can further form glycolytic intermediates like glyceraldehyde - 3 - phosphate and fructose - 6 - phosphate.
- **All reactions** of PPP **occur in cytoplasm of cell**.
- It is a multifunctional pathway which is primarily meant to generate reducing power in the form of **NADPH** which serves as a **hydrogen and electron donar** in a number of reductive biosynthetic pathways, especially of fatty acids and steroids.
- It **occurs in the extramitochondrial cytoplasm which has all the enzymes of HMP.**
- In this, **hexoses** are converted into **pentoses**, especially ribose - 5 - phosphate.
- It is **also called direct oxidative pathway** because in this C-1 of glucose is oxidised first. (In glycolysis, C – 3 and C – 4 are first oxidized).
- The co- enzyme used in oxidative reactions of HMP is $NADP^+$ which is reduced to NADPH + H^+ (In glycolysis, H - acceptor used is NAD^+).
- 12 pairs of hydrogen atoms are eventually transferred to oxygen in this pathway, **yielding 38 ATP**. Of these, 1 ATP must compensate for the ATP used in converting one molecule of free glucose to glucose 6-phosphate. Hence the **net yield is 35 ATP** which compares favourably with the 38 ATP obtainable from glycolysis and TCA cycle.

ANAEROBIC RESPIRATION

- Partial biological oxidation of glucose molecule without utilising oxygen is called **anaerobic respiration**.
- Anaerobic respiration is a **temporary process** in higher plants and **permanent process** in micro organism *i.e.* bacteria and *Yeast.*
- Anaerobic respiration **takes place in cytoplasm**.
- Net equation for anaerobic respiration is
  $\underset{\text{Glucose}}{C_6H_{12}O_6} \rightarrow 2CO_2 + \underset{\text{Ethyl alcohol}}{2C_2H_5OH} + 17.8 \text{ K cal} + 56/\ 22 \text{ K cal}$
- With the formation of pyruvic acid, respiration in anaerobes can be considered **complete** because pyruvic acid will not undergo biological oxidation instead it undergoes decarboxylation.

Glycolysis
$C_6H_{12}O_6 + 2NAD^+ + 2ADP + 2Pi \longrightarrow$
$2CH_3COCOOH + 2NADH + 2H^+ + 2ATP$
Pyruvic acid decarboxylation
$2CH_3COCOOH \longrightarrow 2CO_2 + 2CH_3CHO$
Acetaldehyde reduction
$2CH_3CHO + 2NADH + 2H^+ \rightarrow 2C_2H_5OH + 2NAD^+$

- **End products of anaerobic respiration** are **$2CO_2$** (carbon dioxide) and **$2C_2H_5OH$ (ethanol)**.
- Anaerobic respiration is **intracellular respiration.**
- Anaerobic respiration is **harmful to plants because of the production of ethyl alcohol (ethanol).**
- Fermentation of sugars takes place by some micro-organisms. This was first stated by **Louis Pasteur**.
- **Buchner** accidentally discovered that, the juice extracted from the yeast cells has the ability of bringing out fermentation. This discovery enabled the study of fermentation without the involvement of living system.
- In microorganisms, the term **anaerobic respiration is replaced by fermentation.** This term was coined by **Cruickshank (1897)**.
- **Fermentation** means preparation of wine from sugars or sugary substances on an industrial scale.
- **Gay Lussac** is the discoverer of fermentation. He indicated that alcohol is formed due to a chemical change of glucose.
- Depending upon the end product the fermentation

is of various types *viz* **alcoholic fermentation, lactic acid fermentation, citric acid fermentation** etc.

- Alcoholic fermentation is brought about by **yeast cells** (*Saccharomyces*) sp.
- Enzyme useful for alcoholic fermentation is **zymase.**
- Yeast cells **cannot ferment starch** because they lack **amylase**.
- Alcoholic fermentation resembles the anaerobic respiration of higher plants but **differs** from it in two aspects – **no glycolysis** and **no ATP formation.**
- Alcoholic fermentation is useful in alcohol industry and bakery.
- **Lactic acid fermentation** is brought about by bacterium *Lactic acidi* (anaerobic), *B.acidi lactici* (aerobic).
- *Saccharomyces cerevisiae* is **Brewer's yeast. Wine yeast** is *Saccharomyces ellipsodiens* which perform alcoholic fermentation.
- Lactic acid fermenation is used in **dairy industry**.
- **Butyric acid fermentation** is brought about by *Clostridium butyricum* (a bacterium). This fermentation turns butter **rancid.**
- **Acetic acid fermentation** is brought about by a bacterium *Acetobacter aceti.*
- It is useful in **vinegar industry**.
- **Citric acid and oxalic acid fermentation** is brought about by *Aspergillus niger* (Fungus).
- **Organisms carrying on fermentation** are *Yeast*, *Clostridium*, *Acetobacter*, *Aspergillus*.

Some important points

– Not only animals but plants also exchange CO_2 with O_2. It was proved by **Ingen-housz**.
– **Sachs** confirmed that all **exergonic reactions** form a component of respiration. Sachs divided the entire process of respiration into **two types**.
– **Slites** and **Leach** explained that all reactions in which complex organic substances are broken down into simpler ones are respiratory in nature.
– The book entitled **cellular respiration** was written by **Meldrum** on the basis of a concept that molecules of cells are combusted through oxidation.
– All **respiratory intermediates are the** ***precursors*** for the synthesis of protoplasm.This was **clarified by James.**
– Shifting from anaerobic respiration to aerobic respiration due to availability of O_2 is called **Pasteur effect**.
– Anaerobes which can tolerate the presence of oxygen are called **facultative aerobes**. (They continue their anaerobic respiration), eg : yeast.
– Anaerobes which cannot survive in atmospheric oxygen are called **obligate anaerobes**. Eg : *Bacillus botulinus*.
– **Mg^{++}** and **K^{+}** act as **co-factors** of the enzymes.
– Increase in rate of respiration due to high salt concentration is called **salt respiration or anion respiration**.
– Water acts as the medium for respiratory enzymes and also participates in respiration. Hydration of tissues **increases** the rate of respiration.
– The water formed in a metabolic process is called **metabolic water**.
– Rate of respiration in measured by **Ganong's respirometer**.
– Fermentation can be demonstrated by **Kuhne's Vessel**.
– Liberation of heat is demonstrated by **Dewar's flask experiment**.
– Chemical useful for absorption of CO_2 during respiration is **KOH** (potassium hydroxide).
– **Mercury** is used in anaerobic respiration experiment because it **does not react with CO_2**.
– During 24 hours there is a time when plants neither give carbon dioxide nor oxygen. This is the time of **twilight**.
– Anaerobic respiration was first reported by **Kostychev**.
– Endoparasites respire **without oxygen**.

End of the Chapter

Chapter 38

Nutrition & Digestive System

NUTRITION

- The process by which living organisms obtain those substances which are required for their growth and maintenance and for meeting their energy needs is called **nutrition**, and the substances are called **nutrients of foods**.
- Organisms have **two modes of nutrition** : autotrophic and heterotrophic.
- In **autotrophic nutrition,** green plants, some bacteria and protists utilise energy of sunlight for preparing organic food in their own body from simple inorganic materials. These organisms are called **phototrophs or autotrophs**.
- Some bacteria use energy released by the oxidation of certain chemical substances for the preparation of food. They are called **chemotrophs**.
- In **heterotrophic nutrition** animals obtain organic food materials by consuming bodies or products of other plants or animals, such organisms are called **heterotrophs**.
- **Heterotrophic nutrition** is of **four types**– holozoic, saprozoic, parasitic and symbiotic.
- In **holozoic nutrition**, the solid food is ingested (taken in), digested and then absorbed into the cells.
- Holozoic animal may be **herbivores** (plant eaters, e.g. cow, rabbit), **carnivores** (flesh eaters, e.g. dog, tiger), **omnivores** (both plant and animal eaters, e.g. cockroach, man), **insectivores** (insect eaters, e.g. toads, lizards), **frugivores** (fruit eaters, e.g. monkeys, birds), **sanguivores** (feed on blood of vertebrates, e.g. female *Anopheles* mosquito, leeches), **detrivores** (feed on decaying organic matter, e.g. earthworms) and **fluid feeders** (feed on fluids from plants, e.g. butterflies, male mosquitoes).
- In **saprozoic nutrition**, organisms obtain nutrients from decaying organic materials after digesting the same with the help of enzymes. A few animals (e.g. spider, housefly, etc.) secrete digestive enzymes directly onto their food, which are dead or decaying matters and then suck the digested food.
- In **parasitic nutrition** liquid food material is obtained by the parasite from the body of host, e.g. *Plasmodium*, *Ascaris*.
- In **symbiotic nutrition** often two organisms live in association and derive nutrition from each other, e.g. *Escherichia coli* in human intestine synthesizes vit. B_{12} and in return obtain simpler food from human intestine.
- **Holozoic nutrition** involves **four steps**. These are – **ingestion** (feeding of the food), **digestion** (breaking down of complex organic molecules into simple molecules by hydrolysis), **absorption** (uptake of simple diffusable molecules by the digestive tract) and **egestion** (passing out of indigestible material through the anus).
- In different animals **ingestion occurs** by different process on the basis of which they are classified into **fluid feeder animals, filter feeder animals** and **macrophagous animals.**
- Ingestion occurs in **fluid feeder animals** by **diffusion** (eg. parasitic protozoans), **pinocytosis** (eg. sanguivorous animals like leech, mosquitoes) etc.
- **Filter feeder animals**, also called **microphagous animals** are those animals which takes small sized food particles.
- Ingestion occur in microphagous animals by **maintaining a water current which bring microscopic organisms.** Examples are **pseudopodial feeder** (*Amoeba*), **ciliary feeder**

(*Paramecium*), **flagellar feeder** (sponges), **mucoid feeder** (*Nereis*) and **tentacular feeder** (*Hydra*).

- **Macrophagous animals** feed on large sized food particles and have different structure to capture and ingest the food. Eg. (i) Tentacles with batteries of cnidoblasts in coelenterates. (ii) Eversible and sticky tongue (eg. frog, toad, wall lizard) to capture insects with differently adapted teeth, like well developed incisors in rabbit and well developed canines (tearing teeth) in carnivores (eg. lion, tiger etc.)
- **Digestion**, essentially a **hydrolytic process**, is carried out by various enzymes using water molecules for cleavage.
- The enzymes which bring about digestion are called **hydrolases**.
- Digestion may be **intracellular** (within the cell) or **extracellular** (in digestive cavity).
- The unicellular animals like *Amoeba* and porifers (sponges) digest the food within the cells and show **intracellular digestion**.
- The **cnidarians** (*e.g. Hydra, Aurelia etc.*) have sac like coelenteron or gastrovascular cavity, which is lined by various type of endoderm cells. The food is partially reduced to small fragments by **extracellular digestion** by the enzymes secreted by the gland cells of endoderm. The small fragments of the food are ingested by nutritive cells and complete the digestion **intracellularly**.
- The free living platyhelminthes (*e.g. Planaria*) also employ **both types of digestion** *i.e.* intracellular and extracellular.
- Nutritional requirements are basically supplied in the form of nutrients which may be organic and inorganic.
- **Food** is any substance (especially solid) that can be taken into the body of an animal and plant to maintain its life by providing one or more nutrients for supply of energy and materials.
- The **major constituents of food** are **carbohydrates, proteins**, **fats, vitamins**, **minerals** and **water**.
- If all these components are present in optimum proportion and quantity for maintaining the body in perfect state of health, activity and development then the food is called **balanced diet**.
- **According to their utility** in the body, these **nutrients** are **divided into four categories** – **energy producers** (carbohydrates, fat); **body builders** (proteins), **metabolic regulators** (vitamins and minerals and H_2O) and **hereditary substances** [nucleic acids (DNA, RNA)].

Table : Main component of food and their sources.

Carbohydrate	Flour, rice, potatoes, corn, vegetables, bread etc.
Protein	Milk, eggs, meat, fish, beans, peas, nuts, pulses and cereals etc.
Fats and Oils	Groundnut oil, coconut oil, sunflower oil, ghee, butter, milk, cheese, meat, egg, fishes like cod and herring.
Water	Liquids (water, juices, milk) and some fruits like lettuce, orange, melons.
Vitamins	Balanced diet provide all essential vitamins for body health.
Minerals	Dairy products, vegetables, fruits, meat, chicken etc.

- Balanced diet should have **protein 1/5, fat 1/5** and **carbohydrate 3/5**.
- Carbohydrates **provide energy and heat**.
- **1 gm of carbohydrate** yield **4 kcal** of energy on oxidation in the body. It is called its **physiological fuel value**.
- Carbohydrates are **more suitable for the production of energy in the body than proteins and fats**, because carbohydrates contain relatively more oxygen and require less molecular oxygen for their oxidation.
- Athletes, labourers doing heavy work and mountaineers should live on high carbohydrate diets.
- **Protein** are **essential for body growth and repair**.
- **Basic unit** or **smallest structural unit** of proteins are **amino acids.**
- Amino acids absorbed from the food are used to synthesise **structural proteins** (collagen, elastin keratins), **enzymes** and **hormones**, (pepsin, trypsin, insulin), **haemoglobin**, **skin pigment**, **purines**, **pyrimidines** and **blood proteins**.
- The **physiological fuel value of protein** is **4 kcal**.
- The dietary requirement of proteins **rises during pregnancy and lactation, growth and tissue repair**.
- Nutritionally **amino acids are of two types**– **essential** (not synthesized in body and must be included in diet) and **non-essential** (can be synthesized in body from carbohydrate metabolites).
- **Essential amino acids** are **8 in number**

(methionine, threonine, tryptophan, valine, leucine, isoleucine, lysine and phenylalanine) and **non essential amino acids** are **12 in number** (alanine, proline, glycine, aspartic acid, tyrosine, serine, cysteine, asparagine, glumatic acid, glutamine, arginine and histidine).

- **Semi-indispensible amino acids** are formed slowly and are required only during periods of rapid tissue growth. Eg. arginine and histidine.
- Twenty **amino acids**, linked together by **peptide bonds**, make all different proteins required by the body.
- If amino acids are used for energy liberation (as during starvation), ketones are formed. The phenomenon is called **ketosis** or **acidosis**.
- Fats are used as **stored food to be used in the production of energy.**
- Calorific value of **fat** is **9.45 kcal** *means* 1gm of fat yield 9.45 kcal energy on oxidation in the body.
- An **essential fatty acid (EFA)** is one which must be included in the diet because it cannot be made in the body.
- **Linoleic acid** and **alpha linolenic acid** are the two most essential fatty acids.
- **Saturated fatty acid (general formula $C_nH_{2n}O_2$)** do not possess double bonds in their carbon chains, eg. palmitic acid.
- **Unsaturated fatty acid (general formula $C_nH_{2n-2x}O_2$)** possess one or more double bonds in their carbon chains.
- **Linoleic acid and linolenic acid** are both **poly unsaturated fatty acids (PUFAs)** and **help in** – forming the structure of membrane, transport, breakdown and excretion of cholesterol, normal development and functioning of retina and brain.
- **Free fatty acid (FFA)** circulate in blood in combination with **albumin**.
- **Lumin** discovered vitamins and the term vitamin was coined by **Casimir Funk (1912).**
- **Vitamins** are **non-energy producing organic substances** which are vitally essential in traces for proper use of macronutrients in cell metabolism and hence for proper growth and function.
- **On the basis of solubility**, vitamins are divided into **2 main categories - water soluble vitamins** (vitamin B complex and vitamin C) and **fat soluble vitamins** (A, D, E and K).
- **Fat soluble vitamins** are absorbed in the alimentary canal without any breakdown.
- **Vitamin D** (steroid vitamin) is synthesized in skin cells in sunlight from 7-dehydrocholesterol (*i.e.* provitamin D_3).
- Vitamin often acts as **coenzymes.**
- During prolonged fasting **first carbohydrates are used up, followed by fat and proteins towards end.**
- Apart from organic chemicals, human body needs inorganic chemical elements, called **minerals.**
- Depending on the necessity, **minerals can be divided** into – **macroelements** (required in amount more than 1 gm) and **microelement** (required in trace amount less than 1gm).
- Both macroelements and microelements (minerals) are **found in milk, cereals, fresh fruits and vegetables, sea food etc**.
- **Basal metabolic rate** (BMR) is the minimal caloric requirement needed to sustain life in a resting individual. For normal adult it is **1600 Kcal/day**.
- **Routine metabolic rate** (RMR) is the energy requirement of a moderately active person. RMR is **2800 Kcal** for adult males and **2200 Kcal** for adult females.
- **Sprue**, caused by **deficiency of folacin** (folic acid) is **characterised** by ulceration of mouth, inflammation of bowel, inability to absorb (especially fats), diarrhoea, weakness and anaemia.
- **Anorexia nervosa** is sometimes referred to as **'slimmers's disease'** (literally means "loss of appetite through nervous causes).
- **Disorders of nutrition** are of **two types**– malnutrition and overnutrition.
- **Malnutrition (PEM – protein malnutrition)** is primarily **due to an inadequate intake of food (particularly protein**) both in quantity and quality and infections etc, which increases requirements for calories, proteins and other nutrients, while decreasing their absorption and utilization. It **generally affects infants and children**.
- Two very commonly occurring diseases due to protein malnutrition are – **kwashiorkar** and **marasmus**.
- **Symptoms of kwashiorkar** are retarded growth of body and brain, protruding belly, oedema, slender legs, bulging eyes and diarrhoea.
- **Symptoms of marasmus** are mental retardation, lean and weak body, dry thin and wrinkled skin as

Table : Important vitamins, their functions & deficiencies.

Name	Functions	Deficiency
Vitamin A or *Retinol*	Regulates epithelial growth of tissue, promotes vision by regenerating visual purple, a precursor for synthesis of rhodopsin.	**Xerophthalmia** (dry cornea), **nyctalopia** (night blindness, means no vision in dim light), **dermatosis** (dry scaly skin), **keratomalacia.**
Vitamin D or *Calciferol Antirachitic*	Regulates calcium and phosphorus metabolism; also for normal growth of bones and teeth.	**Osteomalacia** in adults (weak bones, pelvis get bent and deformed), **rickets** in children (bent long bones and painful swelling on wrist, elbows etc.).
Vitamin E or *Tocopherol Antisterility*	Antioxidative, essential for reproductive metabolism, muscular growth.	**Muscular atrophy, sterility** in fowls and rats.
Vitamin K or *Antihaemorrhagic*	Essential for formation of prothrombin which helps in coagulation and maintains time of coagulation of blood.	**Haemorrhage -** due to defective blood coagulation.
Vitamin B complex **B_1 (Thiamine)** or *Aneurin* or *Antineuritic*	Essential for growth, carbohydrate metabolism digestion, nervous system, decarboxylation of pyruvic acid and coenzyme activities.	**Beri-beri**, **polyneuritis**, **gastro-intestinal disorders**.
Riboflavin (B_2) or **Vitamin G**	Essential for tissue oxidation, healthy skin, muscles, carbohydrate and fat metabolism, normal vision.	**Cheilosis** (cracking of skin at sides of mouth), **ariboflavinosis** (blurred vision, cataract, eye sores), **loss of hairs, tongue sores.**
Nicotinic acid, B_3 (or *Niacin* or *Antipellagric*) or **Vitamin PP**	Essential for fat, carbohydrate and protein metabolism, healthy skin, coenzymatic functions of cellulose.	**Pellagra** (characterised by dermatitis, diarrhoea, dementia and death), **polyneuritis** (mental disorders), **gastro-intestinal disorders** etc.
Folic acid, B_9 (Vitamin M)	Essential for growth, formation of blood cells, DNA and also acts as co-enzyme.	**Megaloblastic anaemia** (low Hb count), nutritional disorders, retarded growth
Vitamin B_6 or *Pyridoxine*	Essential for decarboxylation of amino acids, metabolism of tryptophans and fatty acids.	**Dermatitis**, **anaemia**, **mental disorders, nausea.**
Pantothenic acid (B_5)	Essential for anabolism in form of co-enzyme A, skin growth.	**Dermatitis, nervous disorders, retarded growth, burning feet syndrome.**
Biotin, B_7 (Vitamin H)	Essential for growth and carbohydrate metabolism.	**Skin lesions, loss of appetite, weakness etc.**
Vitamin B_{12} or Cyanocobalamine or Cobalamine	Essential for formation of erythrocytes, maintains nervous activities.	**Pernicious anaemia** (due to production of haemoglobin free immature RBCs as a result of deficient intrinsic factor), **hyperglycaemia.**
Vitamin C or *Ascorbic acid*	Formation of erythrocytes, help in integrity of capillaries, heart, muscles, bones, teeth, gums etc.	**Scurvy** (characterised by wound healing and growth retardation), **anaemia**, malformation of teeth, bones and gums, reduces coagulations time of blood.

Table : Important minerals required in animal bodies.

Mineral elements	Significance	Effects of deficiency
MACRO ELEMENTS		
Calcium (Ca)	Required for formation of teeth and bones, blood clotting, functions of nerves and muscles	Weak teeth and bones; retarded body growth.
Phosphorsu (P)	Required for formation of teeth and bones and acid-base balance; component of ATP, DNA, RNA	Weak teeth and bones; retarded body growth and physiology.
Sulphur (S)	Component of many amino acids	Disturbed protein metabolism.
Potassium (K)	Required for acid-base balance, water regulation and function of nerves.	Low blood pressure, weak muscles; risk of paralysis.
Chlorine (Cl)	Required for acid-base balance; component of gastric juice	Loss of appetite; muscle cramps.
Sodium (Na)	Required for acid-base and water balances and nervous functions	Low blood pressure, loss of appetite; muscle cramps.
Magnesium (Mg)	Cofactor of many enzymes of glycolysis and a number of other metabolic reactions dependent upon ATP	Irregularities of metabolism, principally affecting nervous functions.
Iron (Fe)	Component of haemoglobin and cytochromes	Anaemia, weakness and weak immunity.
Iodine (I)	Important component of thyroxine hormone	Goitre, cretinism.
MICRO ELEMENTS		
Flourine (F)	Maintenance of bones and teeth	Weak teeth, larger amount causes mottling of teeth.
Zinc (Zn)	Cofactor of digestive and many other enzymes	Retarded growth, anaemia, rough skin, weak immunity and fertility.
Copper (Cu)	Cofactor of cytochrome oxidase enzyme. Necessary for iron metabolism and development of blood vessels and connective tissues	Anaemia, weak blood vessels and connective tissues.
Manganese (Mn)	Cofactor of some enzymes of urea synthesis and transfer of phosphate group	Irregular growth of bones, cartilages and connective tissues.
Cobalt (Co)	Important component of vitamin B_{12}	Anaemia.
Selenium (Se)	Cofactor of many enzymes; assists vitamin E	Muscular pain; weakness of cardiac muscles.
Chromium (Cr)	Important for catabolic metabolism	Irregularities of catabolic metabolism and ATP production.
Molybdenum (Mo)	Cofactor of some enzymes	Irregular excretion of nitrogenous waste products.

subcutaneous fat disappear, thin limbs, indigestion, diarrhoea etc.

- **Marasmus** is due to **deficiency of protein and calories**. It **occurs in children between 6 months and 3 years of age** and **kwashiorkar** is **common in infants under 1 years of age** whose diets are **deficient of proteins**.
- **Over nutrition** means excessive intake of particular nutrient which produces adverse symptoms. Eg. **obesity** and **hypercholesterolemia**.
- **Obesity** occurs due to greater intake of food calories than the requirement of body. It is **more common in persons** having higher intake of sweets, carbohydrates rich food, fried articles, fat rich food and absence of roughage of food.
- Obesity is **characterised** by large accumulation of fat in tissues, bulky; overweight body which leads to high blood pressure and heart problems and which are prone to diabetes, hypertension and other disorders.
- **Hypercholesterolemia** occurs due to excessive intake of saturated fats like butter, ghee, vegetable oil, red meat and egg and reduced biotin intake.
- **Symptoms of hypercholesterolemia** are tremendously increased blood cholesterol level, stiffening of blood vessels due to cholesterol deposition, high blood pressure and various cardiac disorders.

DIGESTIVE SYSTEM

- Digestive system comprises **alimentary canal** and **accessory digestive glands** which play an important role in digestion.
- **Alimentary canal** is a long coiled tube having muscular wall and glandular epithelium extending from mouth to anus.
- Alimentary canal is divided into **4 main parts: bucco-pharyngeal cavity, oesophagus, stomach** and **intestine**.
- **Buccopharyngeal cavity** (the space between the jaws) is divided into **three parts** : **vestibule, buccal cavity** and **pharynx.**
- **Vestibule** is the **space between gums and lips**.
- **Buccal cavity** is the space bounded dorsally by palate, ventrally by throat (with tongue) and laterally by alveolar processes of jaws having teeth.
- **Palate** forms the roof of the buccal cavity and separates buccal cavity from nasal chamber.
- Palate is differentiated into **hard** and **soft palate**.
- **Hard palate** is supported by bony processes and having palatal rugae to grip the food during mastication.
- **Soft palate** takes part in **swallowing**.
- **Uvula**, a hanging flap closes the internal nares during swallowing of food bolus.
- **Tongue** is a thick muscular protrusible structure, attached to the floor of buccal cavity by means of soft ligamentous fold called **frenulum**.
- Tongue helps in **ingestion, chewing** and **swallowing of food.**
- **Four types** of lingual papillae are– **filliform, fungiform, foliate** and **circumvallate**.
- **Filliform** (without taste buds) located near centre and most of the upper surface of the tongue.
- **Fungiform** contains few (8-10) taste buds.
- **Foliate (absent in man)** is found in rabbit and other mammal.
- **Circumvallate** contains approximately 200 taste buds.
- A number of tubular mucous glands are present over the tongue. They are called **Weber's gland**.
- The basal region of tongue contains two tonsils or **lingual tonsils**.
- Tonsils contain **lymphoid tissue.**
- **Tonsillitis** is inflammation of tonsils.
- **Teeth** are hard structures **meant for tearing, cutting, crushing and holding food**.
- Tooth is mainly made of ivory like substance called **dentine.**
- In root region dentine is covered by bone-like **cement** and **peridontal membrane** and in crown part, dentine is covered by **enamel** (**hardest**, **white**, **shining**).
- Internally tooth has a **pulp cavity** with connective tissue, nerve fibres, lymph and blood vessels.
- On the outside it contains **odontoblast** (dentine producing) with protoplasmic outgrowth present in canaliculi of dentine. A narrow **pulp canal** is present at the base.
- Human teeth are **thecodont** (teeth embedded in the alveoli), **heterodont** (presence of different types of teeth), **bunodont** and **diphyodont** (appearence of two sets of teeth in the life span).
- **Milk, deciduous or temporary teeth** begin to appear at the age of **6 - 11 months**. They are completed by the age of two years. There are **20 milk teeth**.

- **Permanent teeth** begin to appear between the age of **6 - 12 years**. Milk teeth are lost. Last molars come out late after 18 years of age. They are called **wisdom teeth.**
- Teeth are **ecto-mesodermal in origin**.
- Permanent teeth of man are of four types – **incisors (8)**, **canines (4), premolars (8)** and **molars (12)**.
- Dental formula for permanent teeth is– $i\frac{2}{2}c\frac{1}{1}pm\frac{2}{2}m\frac{3}{3}$ or $\frac{2+1+2+3}{2+1+2+3}\times\frac{2}{2}=\frac{16}{16}$ or 32.
- **Dental formula** is the number of teeth in one half of upper jaw divided by teeth of one half of the lower jaw.
- **Caries** is decay of teeth due to degeneration of enamel and formation of cavities.
- **Pyrrhoea** is infected gums and tooth sockets.

Types of teeth

- **Acrodont teeth** is a part of bone, not embedded in sockets, e.g., reptiles (except crocodiles), amphibians.
- **Thecodont teeth** is embedded in sockets, e.g., mammals, crocodiles.
- **Monophyodont** means one set of teeth, e.g., *Platypus*, toothed whale.
- **Diphyodont** means two set of teeth - milk teeth (temporary) and permanent, e.g. mammals.
- In **polyphyodont** condition, teeth can be replaced many times, e.g. frog.
- In **isodont** or **homodont** condition, all teeth are similar, e.g., toothed whale.
- **Heterodont** (more than one type): Four type of teeth occur in humans - **incisors** (cutting), **canines** (tearing), **premolars** (grinding) and **molars** (grinding, not present in milk dentition).
- **Pleurodont** types of teeth is fixed by sides to lateral surface of jaw ridge, e.g., reptiles.
- **Bunodont** teeth have low cusps, e.g., humans.
- **Lophodont** type of teeth have transverse ridges, e.g., elephant.
- **Solenodont** type of teeth have crescent shaped cusps, e.g., sheep.
- **Secodont** type of teeth have pointed cusps, eg. carnivores.

- **Diastema**, characteristics of ruminants, is a gap between incisor and premolar **due to absence of canines on account of herbivorous diet**.
- **Pharynx** is a posterior most part of buccopharyngeal cavity lies between soft palate and 6th cervical vertebra.
- Pharynx is distinguishable into **three parts : nasopharynx, oropharynx** and **laryngo-pharynx.**
- **Nasopharynx** lies behind the nasal chamber and has internal nares, eustachian canal and pharyngeal tonsils.
- **Oropharynx** (lined by non–keratinized stratified squamous epithelium) lies behind buccal cavity and **is the passage for food bolus**.
- **Laryngopharynx,** lowest part of pharynx, has two apertures : **glottis** and **gullets**.
- **Glottis**, lead into trachea, guarded by cartilaginous flap, **epiglottis** which is made up of elastic cartilage.
- **Gullets** lead into oesophagus or food pipe. It is normally closed.
- **Tonsil** occurs both in oropharynx and laryngopharynx.
- **Oesophagous** is a long narrow, muscular tubular structure which connects pharynx with stomach.
- It **conducts the food** to stomach by **peristalsis**.
- **Stomach** is widest and distensible **J-shaped part** of alimentary canal, placed obliquely behind the diaphragm.
- It is differentiated into **three parts : cardiac, fundic** and **pyloric.**
- **Cardiac stomach** receives the oesophagus through cardiac aperture, guarded by a **cardiac sphincter**.
- Cardiac sphincter **prevents regurgitation of food**.
- **Gastric rugae,** the longitudinal fold of the inner mucosa of empty stomach **increases the surface area of digestion**.
- **Fundic** is the **main stomach** because it **produces gastric juices including HCl**.
- **Pyloric part** or **pylorus** (narrow part) is differentiated into **antrum**, **canal** and **sphincter**.
- **Pyloric sphincter** regulates passage of food into intestine.
- The regulation of food from stomach is more **common in infants** due to their less developed cardiac sphincter.
- Stomach helps in **mechanical churning** and **chemical digestion** of food. It also **acts as food reservoir**.

Stomach of ruminants

- Stomach of ruminants are differentiated into **four chambers** : large **rumen** (paunch), **reticulum** (honey comb), **omasum** (psalterium) and **abomasum** (rennet).
- Rumen, reticulum and omasum are **modified parts of oesophagus** and **secrete no digestive juice**.
- **Rumen** is used for churning, breaking of food, fermentation of cellulose by symbiotic micro-organisms.
- **Omasum** is located to the right of rumen and **used for mechanical churning** and **breaking of food** and **absorption of fluids**.
- **Reticulum** is the **smallest part** which **helps in cellulose digestion**.
- **Abomasum** is the glandular part which **function as true stomach.**

- **Intestine** is divided into **large** and **small intestine**.
- **Small intestine** is divided into **three parts** - proximal **duodenum** (shortest and wider part), middle **jejunum** (thicker and vascular) and distal **ileum** (thinner than jejunum and less vascular).
- **Small intestine** is the **longest part** of **alimentary canal**.
- Small intestine has circular folds called **plicae circulares** and **villi** (contain **lacteals) which increases absorptive surface area**.
- **Lacteals** are minute blind ended lymph vessel where digested fats are absorbed and transported to the bloodstreams through the thoracic duct.
- Cells lining the villi have brush border or **microvilli**.
- **Peyer's patches** are lymphoid aggregate present in the submucosa of ileum and **involved in production of B-lymphocytes** and **protect the intestine from infection**.
- Small intestine is the **main region where digestion and absorption of food occur.**
- **Sphincter** of **Oddi** guards the opening of common bile and pancreatic duct into the duodenum.
- **Ampulla of Vater** is the **region of duodenum** where common bile duct and pancreatic duct opens jointly.
- The semidigested acidified food that enters the duodenum is called **chyme.**
- The distal end of the ileum is dilated into a small bulb like structure called **sacculus roduntus.**
- **Large intestine** is formed by **three parts : caecum, colon** and **rectum.**
- **Caecum** in human is a pouch like small junction between ileum and colon.
- An **ileocaecal valve** is **present in the caecum**.
- Externally caecum bears a blind tube, having lymphoid tissue called **vermiform appendix** (7 to 9 cm long and 1 cm diameter).
- Infection of the vermiform appendix is called **appendicitis**.
- Rupture of appendix is called **peritonitis.**
- Caecum and vermiform appendix are **vestigial in function.**
- **Vermiform appendix** is **functional in ruminants** and **caecum is prominent in herbivorous animals**.
- **Colon** is the **largest part** which has four segments: **ascending**, **transverse**, **descending** and **sigmoid**.
- Colon has longitudinal bands called **taeniae coli** and small pouches named **haustra.**
- Colon is **concerned with conservation of water, sodium or other minerals** and **formation of faeces**.
- **Rectum** leads into **anal canal** which opens out by **anus** present at base of trunk and guarded by **anal sphincter muscle**.
- **Enlargements of rectal veins** causes severe painful condition called **piles** or **haemorrhoids**.
- The **chief function of large intestine** is the **absorption of water** and **elimination of solid waste**.
- **Digestive glands** are those glands which secrete digestive juices for the digestion of food.
- Digestive juices **contain digestive enzymes** which are divided into following categories on the basis of their substrate: **amylolytic** or **carbohydrase**; **proteolytic**; **lipolytic** and **nucleolytic**.
- Digestive glands includes **salivary gland**; **gastric gland**; **liver**; **pancreas** and **intestinal gland**.
- Salivary glands are of **three types** – **parotid, submaxillary** and **sublingual.**
- **Parotid** or **Stenson's duct** open in vestibuli just outside the second upper molars.
- **Submaxillary** or **Wharton's duct** opens near the lower central incisor.
- **Sublingual** or **Rivinian ducts** open under the tongue.
- **Mumps** is a **viral infection** (*Myxovirus*) **of parotid glands**.
- In man, **infraorbital gland** (present in rabbit beneath the eye) is **absent**.

Table : Types of digestive juices

Digestive juices	Digestive gland (Secreted by)	Secreted into
Saliva	Salivary glands	Mouth
Gastric juice	Gastric gland	Stomach
Bile	Liver	Duodenum
Pancreatic juice	Pancreas	Duodenum
Intestinal juice (also called succus entericus)	Intestinal gland	Small intestine

- **Saliva** is a complex mixture and a **hypotonic solution** that is secreted continuously from the salivary glands under the control of ANS.
- Daily secretion of **saliva** is about **1 to 1.5 litres** and operates at **6.7 pH** (slightly acidic, almost neutral).
- **Secretion of saliva** is a **reflex action**.
- Saliva is formed of about **95.5% water, 0.2% minerals** and **0.3% organic compounds** like mucin and a starch splitting enzyme **ptyalin** (salivary amylase).
- **Mucin** is a glycoprotein and it helps in lubricating the food in its passage down by giving it a slimy consistency.
- Mucin is **mainly produced by the sublingual and submaxillary gland** whereas **enzyme is mainly from parotids**.
- **Lipase** is secreted by the **Ebner's glands** on the dorsal surface of tongue. It is also called **lingual lipase** which is active even at the acidic pH of stomach.
- **Gastric glands** are numerous simple, branched or unbranched tubular gland which are **formed by infolding of the epithelium.**
- **Three types** of gastric glands are – **cardiac gland** (secrete alkaline mucus); **pyloric gland** (secrete alkaline mucus) and **fundic gland**.
- Fundic gland possess four types of enzyme secreting cells: **chief** or **peptic** (zymogen) **cells**, **oxyntic cells**, **goblet cells** and **argentaffin cells**.
- Secretion of gastric glands is called **gastric juices**.
- **Daily secretion of gastric juices** is **2-3 lt.**
- Secretion of gastric juice is under **nervous as well as hormonal control**.
- **Gastrin** stimulates gastric gland of stomach to secrete large amount of gastric juices. It relaxes pyloric sphincter and closes cardiac sphincter.
- **Intestinal glands**, formed by surface epithelium of small intestine, occurs as **Crypts** of **Lieberkuhn** and **Brunner's gland.**
- **Brunner's glands** mostly occur in duodenum and opens into crypts of Lieberkuhn.
- The secretion of both glands are collectively called **intestinal juice** or **succus entericus**.
- Intestinal juice is **slightly alkaline** (pH 7.5) and contains mucus, inorganic salts, and many enzymes like enterokinase, intestinal lipase, maltase, sucrase, nucleopeptidase, isomaltase etc.
- **Enterocrinin**, an intestinal hormone produced by duodenum and jejunum, **stimulates secretion of intestinal juice**.
- Crypts have different types of enzyme secreting cells: **paneth cell** for lysozyme and **argentaffin cells** for hormones.
- **Argentaffin cells** (or enterochromaffin cells) produce **secretin** and peristaltic stimulant called **5-hydroxytryptamine** (serotonin).
- **Liver** is the **largest** and **multilobulated gland** of about 1.5 kg weight and nearly 1/40 of total body weight.
- Liver is differentiated into small left lobe and large right lobe separated by falciform ligament.

In **rabbit**, liver is made up of **5 lobes**: **Ist lobe** (caudate); **IInd lobe** (right central, largest); **IIIrd lobe** (left central); **IVth lobe** (left lateral) and **Vth lobe** (spigelian, smallest).
In **frog**, liver is **trilobed** and **liver of man** is **bilobed**.

- **Glisson's capsule,** characteristic of liver, is a thin layer of dense connective tissue which surrounds the liver lobule enclosing branches of portal vein, the hepatic artery, the bile duct and lymphatic capsule.
- **Kupffer cells** of liver sinusoids **acts as phagocytes** which eat up the dead cells and bacteria by phagocytosis.
- **Gall bladder** is a pear shaped yellow green sac like structure lies on the inferior surface of the right lobe.
- Gall bladder **stores bile,** which is secreted by liver cells and collected by bile capillaries.
- Bile produced by liver makes the **media alkaline having pH 7.8 - 8.6**.

Table : Hormonal control of digestive secretion.

	Hormone	Secreted by	Action
1.	**Gastrin**	Pyloric epithelium on entry of food (bolus)	Stimulates the release of gastric juice and churning movements of stomach
2.	**Enterogastrone**	Duodenal epithelium on entry of acid chyme	Stop secretion of gastric juice
3.	**Cholecystokinin (CCK)**	Duodenal epithelium on entry of acid chyme	Causes release of bile from gall bladder, also brings about the release of enzymes in the pancreatic juice.
4.	**Secretin**	Duodenal epithelium on entry of acid chyme	Cause release of sodium bicarbonates in the pancreatic juice, also stimulates production of bile by liver.
5.	**Duocrinin**	Duodenal epithelium on entry of acid chyme	Causes release of mucus from Brunner's gland into intestinal juice.
6.	**Entrocrinin**	Duodenal epithelium on entry of acid chyme	It brings about release of enzymes from the crypts of Leiberkuhn into intestinal juice.
7.	**Pancreozymin**	Duodenal mucosa	Stimulate secretion of pancreatic enzyme.

- Bile contains **92% water**; **6% bile salts**; **0.3% bile pigments** [bilirubin (yellow); biliverdin (green)] **0.3% to 1.2% fatty acids**; **0.3-0.9% cholesterol** and **0.3% lecithin**. Lecithin compound **decreases surface tension and helps in fat emulsification**.
- **Bile salts** contain NaCl, sodium bicarbonate (both inorganic) and sodium glycholate and sodium taurocholate (both organic).
- Medicines contain bile salts used for dissolving gall stones.
- Bile capillaries unite to form **hepatic duct**.
- **Bile duct** also known as **choledocus duct**, is formed by joining of **cystic duct** (arise from gall bladder) and **common hepatic duct** from different liver lobes.
- In man, **bile duct** first opens into Ampulla of vater and the latter is surrounded by sphincter of Oddi muscle.
- The **process of bile secretion** is called **choleresis**.
- Presence of stones in gall bladder and bile duct is called **cholelithiasis** and **cholecystolithiasis** respectively.
- **Gall stones** are formed by bile salts and calcium, whose formation is promoted by high cholesterol level.
- Surgical removal of gall bladder is called **cholecystectomy.** It is **commonly done by laproscopy**.
- In human, removal of gall bladder **disturbs fat digestion leading to steatorrhea** (loss of increase amount of fat in faeces).
- Liver produces an anticoagulant heteropolysaccharide called **heparin** which prevents blood clotting inside the blood vessel.
- Liver produces two proteins - **prothrombin** and **fibrinogen** which helps in clot formation.
- Liver act as **haemolytic organ.** It also acts as an **erythropoietic organ** in the embryo. In adults this function is taken over by bone marrow.
- **Sphincter of Boyden** is a strong sphincter of smooth muscle surrounding the bile duct before its joining with pancreatic duct.
- **Liver cirrhosis** is loss of liver architecture which is replaced by fibrous and fatty tissue.
- **Hepatitis** is inflammation or infection of liver.
- **Jaundice** is raised bilirubin in blood and its deposition in various body parts.
- **Pancreas** is a compound elongated organ situated in the limbs of the U shaped duodenum.
- **Pancreas** contain **two different kinds of glandular tissue** - an **exocrine part** (secretes pancreatic juice) and an **endocrine part** (secretes hormones-insulin and glucagon).
- Pancreatic secretion (pancreatic juice) is **stimulated by cholecystokinin** and **secretin** both.
- **Complete digestive juice** is **pancreatic juice** as it possesses amylolytic, lipolytic and proteolytic enzymes.
- Pancreatic juice is colourless watery fluid, slightly

alkaline (pH 7.5–8) due to presence of **sodium bicarbonate**.

- Among the mammals, because of the rennin **only man** can digest the lactose found in the milk.
- **Duct of Wirsung** is main pancreatic duct. Accessory duct is called the **duct of Santorini**, which may take pancreatic juice directly into the duodenum.

Hepatopancreas is digestive gland found in many invertebrates (e.g. prawn) which performs the functions of both liver and pancreas.

- **Coprophagy** means feeding on own faeces. It is found in rabbit.

DIGESTION AND ABSORPTION

- **Digestion** is the process of breaking down of complex and insoluble organic substances (carbohydrates, fats, proteins) into simpler and soluble substances like glucose, amino acids and fatty acids so that they can easily be absorbed into the body.
- Digestion is the process by which **food substances are broken down by mechanical and chemical means**.
- **Mechanical digestion** comprises mastication or chewing, liquefaction of food by digestive juices, swallowing and peristalsis.
- Major utility of breaking up of food into small bits during chewing is to **increase the surface area of food. It helps the enzymatic action.**
- **Chemical digestion** includes the enzymatic action on food.
- In hydrolysis of nutrients, a **small amount of energy is released as heat.**
- **Four main types of digestive enzymes** are : carbohydrases, proteinases, lipases and nucleases.
- **Carbohydrase** includes amylase (polysaccharides to disaccharides) and disaccharidases (maltase, sucrase and lactase).
- **Proteinases** can be endopeptidase and exopeptidase.
- **Endopeptidase** cleaves a polypeptide chain at specific sites between aminoacids, eg. chymotrypsin.
- **Exopeptidase** cleaves amino acids from the ends of a polypeptides chain. Eg. carboxypeptidase which break down protein in the small intestine.
- **Lipase** (steapsin) acts on ester bonds of fats on triglycerides.
- **Nuclease** hydrolyses nucleic acid into nucleotides and finally into nitrogenous bases, pentose sugar and phosphate group, *e.g.*, DNAase and RNAase.
- **Digestion starts from the mouth** where masticated food is mixed with saliva.
- Tongue rolls up the masticated moistened food into small ball called **bolus**.
- Contraction of pharynx pushes the bolus into oesophagus. The phenomenon is known as **swallowing** or **deglutition**.
- **Peristalsis** is a series of waves of contraction that pass from one end to the other and is meant for pushing food.
- **Vomiting** is **reverse peristalsis** (also called **amstalsis**) for ejection of harmful substances from gut.
- **Regurgitation** is the back flow of food from stomach to oesophagus. It is found in ruminants.
- Peristalsis **occurs usually in oesophagus**, **stomach** and **intestine**. **Least peristalsis** occurs in **rectum**.
- Saliva has **no proteolytic enzyme** so **no digestion of protein takes place in buccal cavity.**
- **Ptyalin** or **salivary amylase** (present in saliva) converts starch and glycogen into limit dextrins, maltose and isomaltose.
- Salivary amylase **functions at or near neutral pH** in humans and pig. It is **absent in herbivores**.
- Saliva contains an **antibacterial enzyme (lysozyme)** which dissolves the cell wall of gram positive bacteria and kills them.
- There is **no digestion in oesophagus**. Oesophagus **conducts the food from mouth into stomach**.
- **Stomach** is the **chiet site of protein digestion**.
- Food mixed with gastric juice in the stomach is called **chyme**.
- Chyme is thick liquid made of partially digested food and stomach juices; made in the stomach and moves into the small intestine for further digestion.
- Enzyme secreting cells of fundic gland are – **chief cells (zymogenic or peptic or serous cells)**, **parietal cells**, **globlet cells** and **argentaffin cells**.
- Besides **pepsinogen**, peptic cells also secrete **prorennin** and a weak enzyme **gastric lipase**.
- Pepsinogen is activated into pepsin by HCl.
- **Rennin** (also called **rennet or chymosin**), changes milk soluble protein **caesin** into insoluble semifluid **calcium paracaesinate**. This is called **curdling of milk**.

Table : Digestion in humans

Digestive glands and juice	Enzyme	Optimum pH	Substance acted upon	End products	Controlling factor
Salivary glands (Saliva)	Salivary amylase or ptyalin	Neutral 7.00 6.7-6.8	Starch	Maltose	Nervous reflex and adrenaline hormone
Gastric glands (Gastric juice)	1. *Pepsin* 2. *Rennin* 3. *Lipase*	Acidic 1.5 to 2.00 1.5 to 2	Proteins Caeseinogen of milk Fat	Peptones and peptides Paracaesein and casein Fatty acid and glycerol	Nervous reflexes and gastrin hormones from mucosa of stomach
Liver (Bile juice)	No digestive enzyme	Alkaline 7.1 to 8.3	Fat	Emulsified fat: chylomicrons	Secretin & cholecystokinin hormones from intestinal mucosa.
Pancreas (Pancreatic juice)	1. *Trypsin* 2. *Chymotryspin* 3. *Carboxypeptidase* 4. *Amylase* 5. *Lipase*	7.5-8.0 7.5-8 7.5-8 7.5-8 7.5-8	Proteins Proteins & peptides Polypeptides & Peptones Starch Fat	Peptides Amino acids Amino acids Maltose Fatty acid and glycerol	Secretin and Pancreozymin hormones secreted from mucosa of small intestine
Intestinal glands (Intestinal juice or Succus entericus)	1. *Erepsin* 2. *Lipase* 3. *Sucrase* 4. *Maltase* 5. *Lactase*	7.6 7.6 7.6 7.6 7.6	Polypeptides Fats Sucrose (Cane sugar) Maltose (Malt sugar) Lactose (milk sugar)	Amino acids Fatty acids & Glycerol Glucose & fructose Glucose Glucose & Galactose	Secretin hormone from mucosa of small intestine

- Amount of **rennin decreases with age**, so **absent in adult man**.
- **Gastric lipase** is **active in infants** which changes milk fat tributyrin into fatty acids as glycerols.
- **HCl** secreted from **oxyntic cells makes the gastric juice acidic** (**pH 2.0 - 3.7**), which is **essential for conversion of pepsinogen (inactive) to pepsin (active)**.
- **Pepsin** is a protein splitting endopeptidase.

$$\text{Protein} \xrightarrow[\text{pH } 1-3.5]{\text{Pepsin}} \text{Proteoses} + \text{Peptones}$$

- The **most important functions of HCl** is to activate both pepsinogen and prorennin and killing of micro-organisms like bacteria ingested with food and drinks.
- The **total achlorohydria** means lack of HCl secreted in stomach.
- Mucus secreted by **goblet cell protects stomach wall against HCl action** and **protein digesting enzymes**.
- The gastric juices **do not contain carbohydrolase** (carbohydrate splitting enzyme), so there is **no digestion of carbohydrate in stomach**.
- **Intrinsic factor** (or **Castle's intrinsic factor**) is **secreted from oxyntic cells of stomach**, which **helps in vitamin B_{12} absorption**.

- **Serotonin** secreted by **argentaffin cells** is a smooth muscle stimulant.
- **Gastrin** secreted by **gastric G cells stimulates HCl production**.
- **Food in the small intestine** is in the form of liquid emulsion called **chyle.**
- Chyle is **mixed with three digestive fluids** namely **bile, pancreatic juice** and **intestinal juice**.
- **Bile** contains **no digestive enzymes**, **yet play an important role in fat digestion and absorption**.
- Bile **helps in release of enterokinase enzyme**.
- Liver **regulates the blood sugar level** either by **glycogenesis** or by **glycogenolysis** and **also control lipogenesis**.
- The **liver stores food** in the form of **glycogen**.
- The **presence of bile in the small intestine** is also **necessary for the absorption of the fat soluble vitamins A, D, E and K.**
- **Emulsification** is the breaking of large fat droplets into a fine **emulsion by bile juice (bile salts) of the liver.**
- The bile salts **emulsify the fat** for **proper lipase activity**.
- **Pancreatic juice** is alkaline (7.5 - 8.5 pH), colourless liquid having four types of enzyme : **proteolytic proenzyme** (trypsinogen, chymotrypsinogen and procarboxypeptidase); **nucleases** (DNAase and RNAase); **steapsin** or **pancreatic lipase** and **pancreatic amylase**.
- Pancreatic juice **takes part in the digestion of proteins, carbohydrates and fats**.
- **Steapsin (pancreatic lipase)** is the **principal fat digesting enzyme.**
- Steapsin **converts fats** into **fatty acids, monoglycerides and glycerol**.
- **Pancreatic amylase** hydrolysis starch, glycogen, and dextrin into limit dextrin, maltose and isomaltose.
- **Nucleases** hydrolyse nucleic acid into nucleotides.
- **Trypsin** acts in **alkaline medium** (pH 7 to 9), in which most proteins are negatively charged.
- Trypsin changes **chymotrypsinogen** to **chymotrypsin** and **procarboxypeptidase** to **carboxypeptidase**.
- **Chymotrypsin changes caesin of milk** into **paracaesin**.
- Trypsin **changes peptones and proteins into peptides**.
- **Carboxypeptidase** changes larger peptide into smaller peptides and amino acids.
- **Pancreatic juice** has two more lipolytic enzyme - **phospholipase** and **cholesterolesterase**.
- **Secretin** and **pancreozymin** hormones are secreted from mucosa of small intestine and **regulates pancreatic activities.**
- The **secretion** of both the **Brunner's glands** (occur mostly in duodenum) and **crypts of Leiberkuhn** are collectively known as **intestinal juice** (or **succus entericus**).
- The important enzymes in **intestinal juice or succus entericus** are – enterokinase, erepsin, disaccharidases, intestinal lipase, polynucleotidase and nucleosidase.
- **Enterogastrone** produced in duodenum **inhibits the secretion of HCl**.
- **Erepsin** includes both aminopeptidase and carboxypeptidase, it hydrolyses all small peptides and dipeptides of chyme into aminoacids.
- **Secretin** and **cholecystokinin** hormones are released from certain cells of intestinal mucosa under the influence of HCl, fat and products of protein breakdown in the chyme.
- Germs entering the stomach along with food are killed in alimentary canal where **pH is 3**.
- The **chief function of large intestine** is the absorption of water and elimination of solid wastes.
- **Protein digestion** occurs in stomach, duodenum, jejunum and ileum. It is **completed** in **ileum**.
- **Digestion of all major nutrients of food** is **completed in small intestine**.
- **Absorption of digested food** mainly occurs in **ileum of small intestine**.
- **Absorption** is a process by which nutrients are circulated throughout the body by blood and lymph and supplied to all body cells according to their requirements.
- Absorption occurs through **simple diffusion**, **facilitated diffusion** and **active transport**.
- **Maximum absorption** takes place in **ileum**.
- Fatty acids and glycerol are **absorbed by lacteals** in villi. They are taken in lymph vessels.
- **Amino acids** and **glucose** are carried by **hepatic portal vein**.

- Some nutrients such as fructose and mannose are absorbed from intestine by facilitated diffusion. The process is more rapid than simple diffusion.
- **Water is absorbed by osmosis** from the intestinal lumen to intestinal cells.
- With the accumulation of faceal matter, colon develops a strong peristaltic movement, which produce the urge for defaecation.
- **Defaecation or egestion** is the elimination of undigested food through the anus.
- **Appetite** (feeding) **centres** and **satiety centres** (stopping of ingestion) are located in **hypothalamus**.
- **Anorexia** is loss of appetite.
- **Vomiting centres** are located in **medulla oblongata**.
- **Diarrhoea** is watery stool, or increased frequency, or both, when compared to a normal amount. Diarrhoea may be acute (short-term), which is usually related to bacterial or viral infections, or chronic (long-term), which is usually related to a functional disorder or intestinal disease.
- **Symptoms of diarrhoea** may include: cramping abdominal pain, bloating, nausea, urgent need to use the restroom, fever bloody stools etc.
- **Hepatitis** is the inflammation of the liver, resulting in liver cell damage and destruction.
- **Lactose intolerance** is a condition caused by a lack of an enzyme called lactase, which, in turn, causes the body to be unable to digest lactose, a sugar found in milk products.
- **Symptoms of lactose intolerance** are nausea, cramps, bloating, gas, diarrhoea.
- **Alactasia** is inherited condition causing the lack of the enzyme needed to digest milk sugar.
- **Constipation** is a condition in which the stool becomes hard and dry.
- **Continence** is the ability to hold in a bowel movement or urine.
- **Crohn's disease** is a chronic form of inflammatory bowel disease that usually affects the lower small intestine (called the ileum) or the colon, but it can affect the entire gastrointestinal tract. It is **also called regional enteritis and ileitis**.
- **Heartburn** is a painful, burning feeling in the chest caused by stomach acid flowing back into the oesophagus.
- **Peptic ulcer** is sore in the lining of the oesophagus, stomach, or duodenum; usually caused by the bacterium *Helicobacter pylori*. An ulcer in the stomach is a gastric ulcer; an ulcer in the duodenum is a duodenal ulcer.

End of the Chapter

Chapter 39

Breathing & Exchange of Gases

- **Respiration** is the **catabolic process** which involve exchanges of environmental oxygen and body's carbon dioxide through liquid medium to utilize the oxygen for the oxidation of glucose in the mitochondria to produce the energy.
- Respiration may be **aerobic** (which **involves intake of oxygen** and liberation of carbon dioxide) and **anaerobic** (which **does not use oxygen** in the breakdown of respiratory substrata), also called **fermentation** in micro-organisms like yeast and some bacteria.
- Anaerobic respiration is **also occurs in intestinal parasites** (such as tapeworm, liver fluke etc) and **mammalian RBC's** and **under O_2 deficiency in skeletal muscles**.
- **Erythrocytes perform only anaerobic respiration** as they do not have mitochondria.
- The respiration (aerobic) in higher animals is brought about in 2 phases – **external respiration** (or **breathing or ventilation**) in which intake of O_2 from the surrounding medium and elimination of CO_2 into that medium; and **internal respiration** (or **tissue or cellular respiration**) in which oxidation of nutrients in the cells producing CO_2 and energy.
- In **direct respiration**, gases are directly exchanged between body cells and from the environment without involving blood, *e.g.,* insects, worms, coelenterates.
- In **indirect respiration**, a respiratory surface is present for exchange of gases.
- Respiration (**involuntary process**) is the **combined process of inspiration** (breathing air into the lung) **and expiration** (expelling out of air from lung).
- The **respiratory system** is composed of the **nasal passages**, the **olfactory epithelium**, a **conducting airway** which **includes the nasopharynx, larynx trachea, bronchi** and **bronchioles** and the **respiratory portions of the lungs**.
- Respiratory system is **endodermal in origin**.
- The **basic functions of the respiratory system** are –
  - To absorb oxygen from the atmosphere into the blood for use in cellular respiration
  - To eliminate from the blood into the atmosphere the carbon dioxide produced by cellular respiration

Table: Different types of respiration in different animals

Types of respiration/ Respiratory organ	Animals
• Cell surface respiration	Protozoans sponges, coelenterates
• Cutaneous respiration	Earthworm, leech, frog
• Branchial respiration	Prawn, *Unio*, fish etc
• Tracheal respiration	Insects and myriapods
• Book lung, book gill, buccopharyngeal respiration	Spider, *Limulus,* frog respectively
• Body wall, gills (ctenidia) & pulmonary sac	Mollusca
• Tube feet	Echinoderms
• Pulmonary respiration	Reptiles, birds, mammals
• Cloacal respiration	Some turtles
• Lining of epithelium of cloaca, gut etc.	Fishes
• Pelvic gills	American lung fish *Lepidosiren*
• Opercular gills	Fishes like *Acipenser, Lepidosteus, Polypterus*
• Pseudobranchs	Spiracle of elasmobranchs
• Pharyngeal diverticula	*Amphipnous, Channa*
• Branchial diverticula	*Clarias & Anabas*
• Swim bladder	Lung fishes

- To help maintain the normal pH (hydrogen ion concentration) of the blood by adjusting the concentration of carbon dioxide in the blood.

- These three functions are **regulated primarily by regulating pulmonary ventilation**, the **total volume of gas exchanged between the lungs** and **the atmosphere**.
- **Pulmonary ventilation** is regulated by adjusting the rate and depth of breathing.
- The **prime respiratory organ** in vertebrates is **lung**. Mammalian lungs principally act as '**suction pump**'.
- **Nasal cavities** (containing ciliated and goblet cells) **modify incoming air and moistened** it before it enters lung.

> **Smoke paralyses the cilia** and continued smoking destroys the cilia/ciliated cells, which are then replaced by goblet cells. This causes the accumulation of excess mucus in the lungs together with particles, tar and carcinogen.

- **Nasopharynx** connects the nasal cavities to the larynx and the rest of the respiratory system.
- Pharynx serves as a **common passage for both air and food.**
- **Larynx** (or **voice box**) is composed of cartilages, ligaments, muscles and a mucosal surface and **prevents indigested solids and liquids from entering the respiratory system** and also contains the vocal cords which produce speech sounds.
- **Larynx** is called **Adam's apple in man**.
- An inflammation of the larynx is called **laryngitis.**
- The **pitch of sound is determined by** the tension on the vocal cords. The **greater the tension, the higher the pitch**.
- **Main cartilages of larynx** are– **thyroid cartilage** (most prominent, C-shaped), **cricoid cartilage** (shape like a signet ring), **arytenoid cartilage** (at the anterior of which **cartilage of Santorini** is attached) and **epiglottis** (a leaf shaped cartilage).
- **Epiglotts** is the structure (**containing elastic cartilage**) that prevents the entry of food into respiratory tract during swallowing.
- **Trachea** (or **wind pipe**) which carries air between the larynx and the bronchi are **supported by incomplete rings of C-shaped cartilage (hyoid bone) in its wall**.
- Mucous gland present in ciliated epithelium of trachea protects the respiratory system for infections by holding the bacteria and dust particles coming in system with air.
- Trachea (lower part) **branches into two bronchi**, one to each lung and these branch within lungs into many smaller **bronchioles**.
- Bronchi (**air passages**) **have a pseudostratified ciliated columnar epithelium** containing numerous goblet cells, macrophages and fibroblast.
- Bronchioles are of **three types** - **large bronchioles** (having simple columnar epithelium of ciliated cells), **terminal bronchioles** (most distal simple bronchioles) and **respiratory bronchioles** (having alveoli in their walls).
- **Bronchiolar (clara cells) cells** are the characteristic of the bronchioles.
- The **chief difference between bronchi and large bronchioles** is that **bronchioles lack cartilage.**
- Mammalian lungs are **paired**, **soft**, **pinkish** and **highly elastic structure** lying in the pleural cavities of the thorax.
- The covering of the lung is called **pleura**.
- The outside of each lung is covered by a thin membrane called the **visceral pleural membrane.**
- **Parietal pleural membrane** lines the inner wall of the thoracic cavity.
- The space between two membranes (visceral and parietal) is called **pleural cavity** which is normally very small as the pleural membranes are in close contact.
- A small space called **mediastinum** lies in between the two lungs.
- The **right lung** is divided into **three lobes** and **left into two**. Right lobes are superior, middle and inferior; and left lobes are superior and inferior.
- The **left lung is smaller than right** and has a concavity, the **cardiac notch**, where the heart lies.
- Mammalian lungs are **composed of millions of alveoli** (made of simple squamous cells) **that provide a huge surface area for gas exchange.**
- Number of alveoli in human pulmonary system is **300 - 400 million** with surface area of **100 sq.mt.**
- Within the lungs each bronchus or bronchi subdivides many times into smaller tubes called **respiratory bronchioles** of lesser diameter without cartilaginous ring.

- Each respiratory bronchiole divides to form **alveolar ducts** terminating into small dilated **air sacs** or **infundibulum**.
- Walls of air sac form hollow air cells or **alveoli** which are **the ultimate unit of bronchial tree to participate in gaseous exchange**.
- Wall of alveoli is thin membrane and lined by 2 types of epithelial cells –
  - **Type I cell** - Flat cells with large cytoplasmic extension and are primary lining cell.
  - **Type II cell** (granular pneumocyte) - Thicker and contains numerous lamellar inclusion bodies. These cells **secretes surfactant**.
- **Surfactant** is a lipid surface tension lowering agent which **prevents alveoli from collapsing during respiration**.
- The ability to secrete surfactant doesn't develop untill around the eight or ninth month of pregnancy so there frequently is a problem in premature babies with the lack of surfactant causing the alveoli to stick together when the body exhales.
- **Dipalmatoyl lecithin**, a predominant phospholipid in multilamellar bodies, is an active component of the pulmonary surfactant.
- Alveoli is **surrounded by a network of capillaries of the pulmonary artery and veins**.
- Air enters into the lung in this way -

Inhaled air ↓

Right and left bronchi ← Trachea ← Glottis ← Larynx ← Mouth / Nose or nasal chamber

↓

Bronchioles → Alveoli

- The **diaphragm** is a thin musculomembranous dome shaped muscle that **separates the thoracic and abdominal cavities.**
- The diaphragm is the **main muscle of respiration and its action is only partly under control of will**.
- The diaphragm is **supplied with phrenic nerves.**
- The **contraction of diaphragm assists** in **inspiration, micturition** (passing of urine), **defaecation** (the passing of faeces) and **parturition** (childbirth).
- **Breathing** is a **physical process** whereas **respiration** is a **biochemical event** in which energy is released in the form of ATP.
- Breathing is **periodically filling and emptying of lung**.
- Rate of breathing is **40 -60/ min** in neonates, **14 - 18 min** in adolescents, **12 -14/ min** in human adults and **18 - 22/ min** in children.
- **Inspiration** is the **active process** as it is the result of muscle contraction. It **involves external intercostal muscles and diaphragm.**
- During **inspiration,** the diaphragm and the intercostal muscles contract. The diaphragm moves downwards increasing the volume of the thoracic (chest) cavity, and the intercostal muscles pull the ribs up expanding the rib cage and further increasing this volume.
- This **increase of volume lowers the air pressure in the alveoli to below atmospheric pressure**. Because air always flows from a region of high pressure to a region of lower pressure, it rushes in through the respiratory tract and into the alveoli. This is called **negative pressure breathing,** changing the pressure inside the lungs relative to the pressure of the outside atmosphere.
- **Expiration** is a **passive process** as it is the result of relaxation of muscles. This returns the thoracic cavity to its original volume, increasing the air pressure in the lungs and forcing the air out.
- During **forced breathing or heavy exercise** an active process is involved requiring internal intercostal muscles.
- Inspiration is for about **2 secs** and expiration for **3 sec**.
- **Dead space** encloses the air not involved in gaseous exchange as it is enclosed in the respiratory passage such as nasal chamber. It **reduces the amount of fresh air that enters the lungs**.
- **Cough** is a **forcible expiration usually proceeded by a prolonged inspiration.**
- **Hiccough** is a **noisy inspiration caused by muscular spasms of the diaphragm** at regular intervals.
- **Gaseous exchange take place** by physical process of **diffusion** (a process in which substance moves from a higher to a lower concentration).
- In order to provide sufficient oxygen and to get rid of sufficient carbon dioxide there must be
  - A **large surface area** for gaseous exchange
  - A **very short diffusion path** between alveolar air
  - Blood **concentration gradients** for oxygen

and carbon dioxide between alveolar air and blood.

- The gaseous exchange takes place between external environment and blood through respiratory organs.
- The **site of gaseous exchange in lungs** is **alveoli**.
- The **gaseous exchange** is the diffusion of oxygen from alveolar air into the blood and diffusion of CO_2 from blood to alveolar air.
- The percentage of **oxygen** in inhaled air is about 21 and oxygen content of the air we expire is about 16.
- **Carbon dioxide** amount in atmosphere is 0.04%, carbon dioxide of the air we expire is about 3.6%.
- Water has **poor solubility for O_2** therefore **blood plasma is poor carrier**. 98.5% of oxygen is transported by blood with the help of the respiratory pigment haemoglobin present in RBCs.
- In breathing, lungs are neither completely filled with air nor completely emptied and this condition is known as **pulmonary volume**.
- **Tidal volume** is the volume of air inspired and expired involuntarily in each normal breath. It is about **500 ml**.
- **Inspiratory reserve volume** (IRV) is the **volume of air inspired over and above the tidal volume** by **deepest voluntary inspiration**. It is about **3000 ml**.
- **Expiratory reserve volume** (ERV) is the **amount of air expired over and above the tidal volume by forceful voluntary expiration**. It is about **1100 ml**.
- **Residual volume** (RV) is the **volume of air that remains in the lungs after the most forceful expiration**. It is about **1200 ml**.
- **Inspiratory capacity** is the total amount of air a person can inspire by maximum distension of his lung. It is **equal to total volume and inspiratory reserve volume**. It is about **3500 ml**.
- **Functional residual capacity** (= RV + ERV) is the amount of air that remains in lungs after normal expiration. It is about **2300 ml**.
- **Vital capacity** (= IRV + TV + ERV) is the maximum amount of air which can be expelled forcefully from lungs after first filling with a maximum deep inspiration. It is about **4600 ml**.
- **Total lung capacity** is the maximum amount of air lungs can hold *i.e.*, the total of TV, IRV, ERV and RV of air. It is about **5800 ml**.
- Pulmonary volume and pulmonary capacity vary in different persons according to **size** and **build of body**.
- **Pulmonary ventilation** is the **product of tidal volume and respiratory rate**.
- **Oxygen is transported in the blood in two ways** – (i) by mixing with haemoglobin (97%) as oxyhaemoglobin, and (ii) by dissolving in plasma (3%).

Carbon monoxide poisoning

Haemoglobin has much more about 250 times more affinity for carbon monoxide than for oxygen. In the presence of carbon monoxide, it readily combines to form a stable compound called carbonmonoxyhaemoglobin (COHb). The oxygen combining power decreases and as a result tissues suffer from oxygen starvation. It leads to asphyxiation and in extreme cases to death. The person needs to be administered with pure oxygen-carbon dioxide mixture to have a very high pO_2 level to dissociate carbon monoxide from haemoglobin. Carbon monoxide poisoning occurs often in closed rooms with open stove burners or furnaces or in garages having running automobile engines.

- **Haemoglobin** is a protein composed of four polypeptide chains and four organic compounds called heme groups which possess an atom of iron.
- Haemoglobin molecule is made of two **α-chains** which has 141 amino acids and two **β-chains** with 146 amino acids each.
- **Heme** is the **respiratory carrier part** of the haemoglobin molecule.
- Each **heme** unit contains a central iron atom which is in the ferrous (Fe^{2+}) state and it is this iron atom that combines with oxygen.
- The chemical formula of **oxyhaemoglobin** is $Hb(O_2)_4$.
- The metal constituent of haemoglobin is **iron**.
- The relationship **between oxyhaemoglobin saturation** and **oxygen tension** is called **oxygen haemoglobin dissociation curve**.
- Each of the four Fe^{2+} ion in the haemoglobin molecule can bind with one molecule of O_2. So oxyhaemoglobin carries 1 – 4 molecules of oxygen.

- Haemoglobin affinity for O_2 is **inversely related to the P_{50}** which is the O_2 tension that produces a 50% saturation of haemoglobin with O_2.
- **Bohr effect** refers to the **displacement of the haemoglobin saturation curve** and **the subsequent increase in P_{50}** that is caused by an increase in CO_2 tension. In this O_2 affinity of haemoglobin decreases with the fall of blood pH.
- The **oxygen carrying capacity of blood is 20 ml/ 100ml.**
- CO_2 carrying capacity of blood is **3.7ml / 100 ml** of blood.
- **Carbon dioxide is transported** in the blood **in three ways** –
  - **7% dissolved in the plasma** (**as carbonic acid**)
  - **23% bound to haemoglobin (as carbaminohaemoglobin)**
  - **70% as bicarbonate in the plasma** following an enzyme - catalysed reaction in red blood cell **(commonest one).**
- Changes in carbon dioxide concentration are directly related to changes in hydrogen ion concentration (pH) by the carbonic acid-bicarbonate buffer reaction:

$$\underset{\text{Carbon dioxide + water}}{CO_2 + H_2O} \xleftrightarrow{\text{(Carbonic anhydrase)}} \underset{\text{Carbonic acid}}{H_2CO_3} \longleftrightarrow \underset{\text{Hydrogen ion + bicarbonate ion}}{H^+ + HCO_3^-}$$

Since more carbon dioxide is eliminated during hyperventilation, the hydrogen ion concentration of the blood declines (pH increases and the blood becomes more alkaline).

- To maintain electrostatic neutrality of plasma many chloride ions diffuses from plasma into RBC and carbonates ions from RBC to plasma. The chloride content of RBC increases when oxygenated blood becomes deoxygenated is called **chloride shift** or **Hamburger shift**.
- **Haldane effect** is the **increased CO_2 uptake** because of removal of O_2 from haemoglobin. It **minimize the increase in CO_2 tension** that occurs in the venous blood which inturn causes venous blood to be less acidic than it would be otherwise.
- Haldane effect is a **way of buffering the CO_2 molecules** which has the potential to form carbonic acid after being hydrated.
- Bohr effect **shifts the O_2 -Hb dissociation curve to right** and **promotes oxygenation of haemoglobin in lungs**.
- **Carboxyhaemoglobin (COHb),** formed when carbon monoxide combines with haemoglobin, **decreases the functional haemoglobin concentration** as a result of which tissues suffer from oxygen starvation and leads to asphyxiation (suffocation) and in extreme cases to death.
- Haemoglobin has much more about **250 times affinity for CO than oxygen**.
- **Foetal haemoglobin** has a **greater affinity for O_2 than adult haemoglobin** as it binds 2,3 DPG less avidly by γ polypeptide chains than that in HbA and this assist it to load oxygen in the placenta while maternal haemoglobin is unloading oxygen thereby enabling the foetal body cells to utilise O_2.

Table : Respiratory pigments

	Name of the respiratory pigment	**Metal present**	**Colour**	**Features**
1.	Haemoglobin	Iron	Red	Plasma of some annelids (*e.g.* earthworm and *Neries*)
2.	Haemocyanin	Copper	Blue	Plasma of crustaceans (*e.g.* prawn), some snails (*Pila*), cephalopods (*e.g. Sepia*)
3.	Haemoerythrin	Iron	Red	Blood cells of some annelids (*e.g.* polychaete *Magelona*)
4.	Chlorocruorin	Iron	Green	Plasma of some annelids (*e.g.* polychaete sabella)
5.	Pinnaglobin	Manganese	Brown	Plasma of some molluscs (*e.g. Pila*)
6.	Echinochrome	Iron	Red	Coelomic fluid of sea urchin (echinoderm)
7.	Vanadium	Vanadium	- - -	Blood of many tunicates (urochordates). *Ciona* contains vanadium pigment in the plasma Special green blood cells called vanadocytes of Ascidia.

2,3 DPG

2,3 - DPG (diphosphoglycerate) is present in the red cells of adult blood. It competes for oxygen binding sites in the haemoglobin molecule. As it binds to the β - chain of haemoglobin A (especially deoxy HbA) it causes the right shift of dissociation curve resulting in higher P_{50}.

- **Dissociation curve for myoglobin** of muscle is **hyperbolic**.
- **Respiratory quotient** or

$$RQ = \frac{\text{volume of } CO_2}{\text{volume of } CO_2 \text{ utilized}}.$$

- **Methaemoglobin** is usually present at the time of asphyxiation (condition caused by increase in CO_2 concentration in tissue).
- At high altitude, **RBC of human blood will increase in number** in response to the air being less dense. More number of RBC's are needed to trap O_2 from rarefied air having low PO_2 (partial pressure of O_2).
- **Respiratory centre** (RC) regulates normal breathing (movement of diaphragm and intercostal muscles) and also automatically adjusts the breathing rate to varying requirements of body during stress conditions.
- The respiratory centre is **sensitive to the increased carbon dioxide or increased acidity in the cerebrospinal fluid** and **an increased P_{CO_2} in the blood acts** because CO_2 rapidly diffuses from the blood to the cerebrospinal fluid.
- **Respiratory centre is located** in the **medulla oblongata** and **pons varolii**.
- Respiratory centre can be divided into an **inspiratory** and **expiratory centre** in the medulla, an **apneustic centre** and **a pneumotaxic centre**.
- Respiratory centre comprises 3 groups of specialized nerve cells (neurons) – **doral respiratory group** (located in dorsal position of medulla), **ventral respiratory group** (in ventrolateral part) and a **pneumotaxis centre** in dorsal part of pons.
- **Pneumotaxis centre acts as an inhibiting nerve centre** and is **connected to both inspiratory and expiratory parts** of respiratory centre.
- **Ventral respiratory group** issues signals for both inspiration and expiration when high level of pulmonary ventilation are required in deep breathing.
- **Dorsal respiratory centre** does not issue any impulse for expiration therefore it is referred to as inspiratory centre.
- **Stretch receptor** present in walls of bronchi and bronchioles transmits signals through vagus nerves to the dorsal group of respiratory centre to "switch off" inspiratory signals.
- **Hering breuer reflex** serves as a protective mechanism for preventing excessive lung inflation.
- The **bronchial** tree is **connected to the brain through the vagus nerve**.
- **COPD** (chronic obstructive pulmonary disease) is a general term of several lung diseases that **includes chronic bronchitis, emphysema** and **chronic asthma**.
- The two **primary causes of COPD are cigarette smoking and alpha 1 antitrypsin deficiency**. Air pollution and occupational dusts may also contribute to COPD, especially if the person exposed to these substances is a smoker.
- **Bronchitis** is an inflammation of the bronchi causing them to over secrete mucus, which in turn causes coughing to get it up.
- **Emphysema** is an inflammation or abnormal distention of the bronchiole or alveolar sac resulting into the loss of elasticity.
- Emphysema is a **non-reversible pulmonary disease causing extreme shortness of breath and eventual death**. In this disease, the bronchial tubes of the lungs become blocked with mucus plugs and infection, inhibiting passage of air into and out of the alveoli (air sacs). The disease is characterized by destruction of these sacs which lose their elasticity, swell and rupture thereby interferring with the exchange of oxygen and carbon dioxide in the breathing process. Emphysema is often caused by smoking.
- **Tuberculosis** is a specific infectious disease caused by *Mycobacterium tuberculosis*. The **disease primarily affects lungs** and **causes pulmonary tuberculosis**. It can also affect intestine, meninges,

bones, joints, lymph glands, skin and other tissue of the body.

- TB is **spread by coughing**. The earliest symptoms of active TB are fever, night sweats and weight loss. Later there is cough and blood may appear in phlegm (sputum).

The TB skin test is based upon the type IV hypersensitivity reaction (also called delayed or cell mediated hypersensitivity). Delayed hypersensitivity is a function of helper T lymphocytes, not antibody. If a previous TB infection has occurred, then there are sensitized lymphocytes that can react to another encounter with antigens from TB organisms. For the TB skin test, a measured amount of tuberculin purified protein derivative (PPD) is injected subcutaneously to form a small wheal, typically on the forearm. In 48 to 72 hours, a positive reaction is marked by an area of red induration that can be measured by gentle palpation (redness from itching and scratching doesn't count).

- **Sputum, skin test of tuberculin** (mantoux test) and **X-rays** are carried out to diagnose tuberculosis. **BCG** (Bacillus calmette guerin) **vaccine gives considerable protection against the disease**.
- **Antituberculosis drugs** are streptomycin, para amino salicylic acid (PAS), rifampicin, ethambutol etc.
- When TB affects animals like cattle then this is known as **bovine tuberculosis** which may sometimes be communicated to man (*via* milk).
- **Asthma** is an allergic reaction that causes constriction of the bronchiole muscles, thereby reducing the air passages thus the amount of the air that can get to the alveoli.
- **Pneumonia** is an infection of the alveoli. It can be caused many kind of both bacteria (eg. *Streptococcus pneumoniae*) and virus.
- Tissue fluids accumulate in the alveoli reducing the surface area exposed to air.
- **Occupational lung disease** are caused due to exposure to harmful substances like gas, fumes or dust present in the environment where a person works. E.g. **silicosis** (exposure to silica), **asbestosis** (exposure to asbestos dust). **Fibrosis** is caused due to proliferation of fibrous connective tissue of upper part of lung.
- The occupational diseases express symptoms after exposure of 10 - 15 years or more. Such diseases can not be cured, but can be prevented by adopting following measures –
  - Minimising the exposure of harmful dust.
  - Use of protective gears and clothing by the workers.
  - Regular health check up.
- **Lung cancer** is technically known as bronchogenic carcinoma and is **caused due to uncontrolled multiplication of the basal cells of the bronchial epithelium**.
- Lung cancer **develops in lung tissue in the following steps**:
  - First, a thickening and callusing of cells lining the bronchi appears.
  - Cilia are lost so it is impossible to prevent dust and dirt from settling in lungs.
  - Next, cells with atypical nuclei appear in callused lining.
  - A tumor consisting of disordered cells with atypical nuclei develops as cancer *in situ*.
  - When some tumor cells break free and penetrate other tissue (metastasis), cancer spreads.
  - Tumor may grow until bronchus is blocked, cutting off air supply to lungs.
  - Entire lung collapses; trapped secretions become infected causing pneumonia or lung abscess.
- The only treatment is surgery (pneumonectomy) where a lobe or whole lung is removed.

End of the Chapter

Chapter 40

Locomotion & Movement

- **Locomotion** is the ability to move in a particular direction in its environment, which requires a propulsive force acting against a supporting structures.
- For various functions like shifting from an unfavourable conditions, to get food, to find partner, for laying eggs or giving birth, living organisms move from one place to another place. This type of movement is called locomotion.
- In **living organism movement is autonomic** which occurs self stained whereas in **nonliving organism movement is induced** which occurs by external force.
- Locomotion includes –
  - **running** (e.g., horse, *Ostrich*)
  - **walking** (e.g., cattle)
  - **jumping** (e.g., Baboon)
  - **somersaulting** (e.g., *Hydra*, leech)
  - **crawling** (e.g., snakes)
  - **climbing** (e.g., squirrel)
  - **flying** (e.g., birds, butterfly), and
  - **swimming** (e.g., fishes, *Paramecium*)
- Some animals are **sedentary** *i.e.,* they are **fixed at one place**, e.g., sponges, several coelenterates (e.g., corals, *Obelia*), *Herdmania* and many echinoderms.
- Locomotion **cannot occur without movements of body parts**.
- Movement of body parts is **performed by all organisms including plants**.
- Animals are able to move their body parts by the movement of **external body parts** or **internal organs**.
- **Movement of external body parts** includes the movement of limbs, head, trunk, jaws, tentacles, eye balls, pinna of the ear (to collect sound) etc.
- **Movements of internal organs** are peristalsis and peristaltic movement, movement of diaphragm, ribs, movement or uterine wall (for giving birth) etc.
- The scientific study of body movements is known as **kinesiology**.
- Animal exhibit **three basics types of movements.** These are **- amoeboid, ciliary** and **muscular**.
- **Amoeboid movement** occurs by means of temporary protoplasmic outgrowths (called **pseudopodia**) due to flow of protoplasm in any direction, e.g., *Amoeba*, macrophages and leucocytes.
- **Ciliary movements** occurs with the help of cilia, e.g., *Paramecium*.
- **Muscular movement** is caused by the property of contractibility of muscles, which is used effectively for locomotion.
- Movements in vertebrates are performed by two types of independent systems – **muscular system & skeletal systems**.
- **Movement of internal organs** are **controlled by muscular system** while **locomotion and movement of most external body parts** are **brought about by coordination of both the system**.

MUSCULAR SYSTEM

- A system of different muscles present in body specialised to perform various movements inside the body as well as its external part is called **muscular system**.
- In humans, the muscles are of **three types** – **skeletal**, **smooth** and **cardiac muscles**.
- **Skeletal muscles** are attached to the bones by tendons and **help in the movement of the parts of skeleton**. These muscles are **under the control of conscious mind** and are **called voluntary muscles**.
- Under the microscope, skeletal muscles exhibit transverse strips and hence are designated as **striated muscles**.

- **Smooth muscles** are **non-striated** and i**nvoluntary muscle**. These are **found inside the wall of the hollow internal organs** (e.g. alimentary canal, blood vessels, reproductive tract).
- **Cardiac muscles** are **also striated** and a**re not under voluntary control**. These **occurs exclusively in the wall of heart**.
- Study of components, structure and functioning of muscular tissue is known as **myology/sarcology**.
- Human body has about **640 types of muscle**.
- **According to function** or **movement** muscles are classified into **flexor**, **extensor**, **adductor**, **abductor**, **pronator**, **supinator**, **elevator**, **depressor**, **rotator**, **sphincter**, **dilator**, **invertor** and **evertor**.
- **Prime movers** muscles acts most powerfully during any given movements.
- **Flexors muscles** bend one part of a limb on another at a joint, eg. biceps. It **brings the forearm towards the upper arm**.
- **Extensor muscles** extends or straightens a limb, eg. triceps.
- **Adductor muscles** brings a limb towards the mid line of the body, e.g., lattissmus dorsi.
- **Abductor muscles** pulls a limb away from the midline of the body, e.g. deltoides of shoulder.
- **Pronator muscles** turns the palm downwards or backwards, e.g. pronator teres.
- **Supinator muscles** turns the palm upward or to forward, e.g. supinator.
- **Elevator muscles** rises a part of the body, e.g. massetor.
- **Depressor muscle** lower a part of the body, e.g., depressor mandibularis moves down the lower jaw to open the mouth (**pectoralis major is the depressor muscle for the wings of the birds**).
- **Rotator muscle** rotates a part of the body, e.g., pyriformis which raises and rotates the thigh.
- **Sphincter muscle** decreases the size of an opening e.g., pyloric sphincter.
- **Dilator muscle** increases the size of an opening, e.g., iris.
- Turn the sole inward and outwards are called **invertor** and **evertor** respectively.
- **Synergists muscles act together** to produce movement.
- **Antagonistic muscle** are those muscles which **act in opposition to other muscle**. Eg. the bicep muscle extended from shoulder to radius bends or flexes the arm at elbow whereas triceps extending from ulna to shoulder straightens the arm.

Important muscles

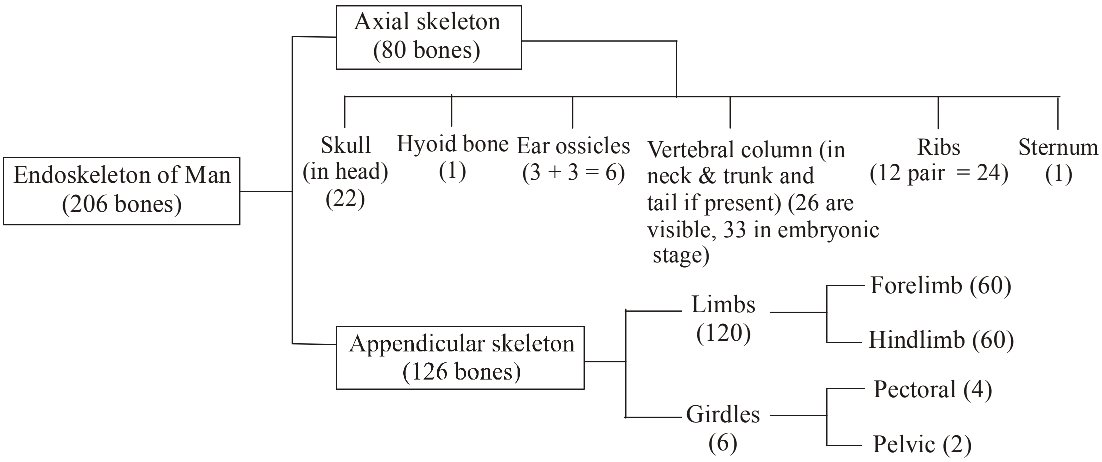
Largest muscle	–	Gluteus maximum (buttock)
Smallest muscle	–	Stapedius of stapes
Strongest muscle	–	Massetors of jaws (lower)
Longest (or Tailor) muscle	–	**Sartorius** (run from the hip to knee), Quadriceps Femoris.
Boxer's muscle	–	Serratus anterior

- **Striated muscle** (also called **skeletal muscle**) are mostly attached to bones and **takes part in moving them like levers**.
- **The molecular components** of skeletal muscles are – (i) contractile proteins, (ii) enzymes, (iii) fats and carbohydrates, (iv) organic phosphates; and (v) ions.
- Important **non-protein organics** are ATP, phosphocreatine, creatine, urea and glycogen.
- **Potassium** is the **most abundant mineral element** in muscle.
- **Myofibrils** (proteinaceous fibrils) are the **contractile elements of muscle fibre**.
- **Sarcomere** are the **contractile units of myofibrils**.
- Each muscle fibre is elongated and **syncytial (multinucleate)**. Its membrane is called **sarcolemma** and its cytoplasm is called **sarcoplasm**.
- Skeletal muscle fibre shows transverse striations in the form of regular alternate dark **A band (anisotropic)** and **light I (isotropic) bands**.
- **At the centre of I band**, a fine dense **Z-line** (or **Krause's membrane**) is present **which divides the myofibrils into sarcomeres**.
- Sarcomere is the **area between two Z-line**.
- **H-zone** is found **at the centre of A band and M Line or Hensen's line**.
- **Myosin** is a **major protein present in the thick filament of skeletal muscle fibre**.
- **Actin** is the contractile protein of muscle **present in thin filament**.
- The myosin molecule consists of head and a tail components. The **head part conform a cross bridges with actin and has contractile as well as ATPase activity**.
- **Sliding filament theory** of muscle contraction was proposed by **A.F. Huxley & H.E. Huxley in 1954**.
- According to this theory, **during muscle contraction, actin filaments slide inward on the myosin filament of A-band** with the help of cross bridges to reduce the length of the sarcomeres.

- **Release of calcium ions** from sarcoplasmic reticulum **trigger the muscle contraction process**.
- The calcium ions result in movement of troponin and tropomyosin on their thin filaments, and this enables the myosin molecule heads to 'grab and swivel' their way along the thin filament, this is the driving force of muscle contraction.
- **Contraction of a muscle is caused by actomyosin** which is formed in the presence of calcium ions and energy (obtained from ATP), actin and myosin.
- In **resting muscles**, ATP combines anaerobically with creatine to form creatine phosphate.
- When **muscle contracts** creatine phosphate breaks down to produce ATP.
- During muscle contraction **conversion of pyruvic acid to lactic acid proceeds anaerobically and chemical energy is changed into mechanical energy**.
- **During muscle contraction** –
  - Both I and H zones progressively **shorter and eventually disappear**.
  - Length of A band **remains unchanged**,
  - Distance between two lines **shortens** and size of sarcomere **decreases by 60-70%**.
- Energy for contraction of muscle fibre is provided by **ATP** (produced by **creatine phosphate** & **respiratory breakdown of glycogen/glucose**).
- Biochemical and electrical changes occurring during muscle contraction were explained by **Albert Szent-Gyorgi** in **1942**.
- Based upon the sarcoplasmic contents, situation of nuclei & number of formed elements, two types of fibres are recognised in striated muscle – **white fibre** & **red fibres**.
- **White muscle fibre** are **fast muscle fibre** which lack myoglobin and have fewer mitochondria.
- These muscle **perform fast work for short duration** as a result of which **these muscle fibre get fatigued quickly**. Eg. eye ball muscle, flight muscle of sparrow.
- **Red muscle fibre** are **slow muscle fibre** possessing red haeme protein (called myoglobin) and abundant mitochondria.
- These muscle can **perform slow sustained work over long period without getting fatigued**. Eg. extensor muscle of back & flight muscle in kites.
- **Sharpey's fibre** are calcified bundles of white & yellow fibres perforating and holding periosteal bone lamellae.
- **Threshold stimulus** is the **minimum strength of stimulus** required to initiate muscle contraction.
- **Oxygen debt** is the **requirement of extra oxygen during recovery phase of muscle** over a period of resting stage.
- The **extra oxygen required during recovery phase** is for regeneration of oxymyoglobin, restoration of depleted ATPs & CP and oxidation of lactic acid.
- **Cori cycle** was **discovered by Cori & Cori.**
- Cori cycle is the passage of lactic acid produced in muscle into liver where 80% of it is changed to glycogen/glucose for continued supply to muscle.
- The force produced during contraction of muscle is called **muscle tension**.
- **Muscle fatigue** is a **failure of muscle to respond a fresh stimulus** after a prolonged previous activity.
- Muscle fatigued is **caused due to accumulation of lactic acid**, consumption of stored glycogen. ATP changes in neuromuscular junction which is sensitive to lactic acid.
- **Rigor mortis** is a condition in which non-availability of ATP molecules, enzymes and oxygen results in non-separation of actin & myosin filaments leading to body stiffening after death.
- **Refractory period** is the interval during which a muscle fibre fails to respond to a second stimulus.
- It is **0.002 - 0.005 sec.** in a skeletal muscle fibre & **0.1–0.2 sec.** in a cardiac muscle fibre.
- A single isolated contraction of a muscle fibre in response to a single stimulus and relaxation is called **muscle twitch**.
- **Latent period** is the interval between the application of appropriate stimulation and contractions.
- It is **0.01 sec.** in skeletal muscle and upto **30 sec.** in visceral muscle.
- The duration for which the muscle remains in contracted state is called **contraction period.**
- It is **0.04 sec.** in skeletal muscle & upto **20 sec.** in a visceral muscle.
- **Relaxation period** is the interval required for the contracted muscle to regains its original relaxed/ elongated state.
- It is **0.05 sec.** for a skeletal muscle & **2.3 sec.** for visceral muscle.
- The ability of muscles to get stretched is called **tensility**.

SKELETAL SYSTEM

- The **skeletal system** (bones and joints), working interdependently with the skeletal muscle system (or voluntary or striated muscles), **provides basics functions that are essential to life**. These are -
  - **Protection** - protects the brain & internal organs
  - **Support** - maintains upright posture
  - **Blood cell formation** - haematopoiesis
  - **Mineral homeostasis**
  - **Storage** - stores fats & minerals
  - **Leverage** - a lever is a simple machine that magnifies speed of movement or force. The **levers** are **mainly the long bones of the body** and the **axes** (**fulcrum**) are the **joints where the bones meet**.
- Skeletal systems are commonly divided into **three types - external (an exoskeleton)**, **internal (an endoskeleton)**, and fluid based (a **hydrostatic skeleton**), though hydrostatic skeletal systems may be classified separately from the other two since they lack hardened support structures.
- **Exoskeleton** is the hard protective and supportive framework present on the outside of the body.
- Exoskeleton is **found in both invertebrates** (e.g., shell of snails, bivalves, corals, sclerites of insects) and **vertebrates** (e.g., claw, nails, horns, feather, scales etc.)
- Exoskeleton can be **epidermal** or **mesodermal**.
- **Epidermal/ectodermal exoskeleton** occurs in mammals, birds and many reptiles.
- **Mesodermal/dermal exoskeleton** occurs in fishes (scales) and some reptiles (crocodiles, turtles and tortoises).
- **Endoskeleton** consists of those hard parts which are present inside the body of the animal.
- The **functions of endoskeleton** are support, protection, muscle attachment, movement, blood cell formation and mineral reservation etc.
- **Hydrostatic skeletons** are similar to a water-filled balloon. Located internally in cnidarians (coral, jellyfish, etc.) and annelids (leeches), among others, these animals can move by contracting the muscles surrounding the fluid-filled pouch, creating pressure within the pouch that causes movement.
- Animals such as earthworms use their hydrostatic skeletons to change their body shape as they move forward from long and skinny to short and stumpy.
- The **human skeleton** is made of individual or joined bones (such as skull), supported and supplemented by structure of ligaments, tendons, muscles, cartilage & other organs.
- A **ligament** is a short band of tough fibrous connective tissue composed mainly of long, stringy collagen fibres.
- Ligaments **connect bones to other bones** to form a joint. Some ligaments limit the mobility of articulations, or prevent certain movements altogether.
- **Tendon** is a fibrous, strong, connective tissue that **connects muscle to bone**. **Damage to a tendon** can **result in the inability to flex or extend at a joint**.
- **Cartilage** is a type of dense connective tissue.
- Cartilage is composed of cells called **chondrocytes** which are dispersed in a firm gel-like ground substance, called the matrix.
- Cartilage **contains no blood vessels** and **nutrients are diffused through the matrix**.
- Cartilage is **found in the joints**, **the rib cage**, **the ear**, **the nose**, in the **throat** and **between intervertebral discs**. There are three main types of cartilages: **hyaline**, **elastic** and **fibrocartilage**.
- **Types of bones** are spongy bones, compact bones, diploid bones, cartilage bones, sesamoid bone, investing or dermal or membranous bone and visceral bone.
- **Bones are classified according to shape and size** into (i) **long bones**, which make up the limbs. (humerus, tibia etc.), (ii) **short bones,** which are grouped together to strengthen our skeleton (meta carpels), (iii) **flat bones,** which protect our body and provide a place for muscles to attach (scapula), and (iv) **irregular bones** (vertebrae, tarsals of ankle).
- **Spongy bones** (cancellous bones) have bony matter as bar or trabeculae and space filled with red bone marrow.
- Spongy bone **occur at the ends of long bones vertebrae, sternum** and **ribs**.
- **Function of long bones** in mammals is to **provide support and to produce RBC's and WBC's**.
- **Epiphyseal plates** at the extremities of long bones **help in elongation of bones**.
- In birds, the spongy bone have air filled spaces and called as **pneumatic bones**.
- **Compact bones** have compact / dense matrix and occur in the form of lamellae. E.g. clavicles and



scapulae of pectoral girdle, innominates of pelvic girdle, arm bones and leg bones.

- **Diploid bones** have both compact (on surface) and spongy (inside) region, e.g., femur, humerus, flat bones of skulls and ribs.
- **Cartilage bones** or **replacing bones** are produced by endochondral ossification (*i.e.,* internal ossification of cartilage). E.g., limb bones, vertebrae girdle bones (except clavicle), occipital and sphenoid.
- **Sesamoid bones** are produced through ossification of tendons, e.g., patella.
- **Investing bones** are formed by transformation of connective tissues, e.g., clavicle, face bones.
- **Visceral** or **heterotypic bones** occur separate from the rest of the skeleton. E.g., os cordis (heart of deer), os penis (penis of rodents, bats and some carnivores) etc.
- The total number of bones in adult human is **206.**
- **Human skeleton** (**endoskeleton**) is divided into **two main parts - axial** and **appendicular skeleton**.
- The **axial skeleton** is present on the median longitudinal axis of the body. It consists of **80 bones** in adult man.
- Axial skeleton consists of **skull, vertebral column, sternum** and **ribs**.
- **Appendicular skeleton** is situated at the lateral sides, which is actually extends towards from the principle axis. It consists of **126 bones** in adult man.
- Appendicular skeleton consists of **pectoral** and **pelvic girdles**, and **bones of arms** and **legs**.
- Skeleton of head is called **skull** which rests upon the upper end of vertebral column.
- **The bony structure of skull consists** of the following parts: (i) bones of cranium (ii) ear ossicles (iii) hyoid bone, and (iv) bones of the face.
- **Cranium** (or **brain box**) is formed by **8 bones**, these are: **1 frontal bone, 2 parietal bones, 2 temporal bones, 1 occipital bone, 1 sphenoid bone** and **1 ethmoid bone**.
- Newborns have temporary holes in the cranium called **fontanelles**. They are present as long as the brain growth occurs *i.e.*, the anterior fontanelles closes at 18 months.
- Cranium bones contain **sinuses**. Sinuses are air spaces lined with mucous membrane that reduce weight of skull and give resonant sound to the voice.
- Two mastoid sinuses drain into middle ear; **mastoiditis** inflammation can lead to deafness.
- Occipital has **foramen magnum** for passage of spinal cord and two occipital condyles for the fixation with atlas vertebra.
- **Ear ossicles** are three small bones - the **incus** (anvil), **malleus** (hammer) and **stapes** (stirrup) that transmit (and amplify) vibrations of the tympanum across the middle ear to the oval window which transfers them to the inner ear.
- **Hyoid bone** (horse shoe shaped bone) is situated in the wall of the upper part of the throat just above the larynx (it is not a bone of skull proper).
- Hyoid **support tongue and provides insertion to some tongue muscle**. It consists of an elliptical main part (or body) and the two processer called greater and lesser cornia.
- The **skeleton of face** consists of **14 bones**. These are : 2 **zygomatic bones, 2 maxilla, 2 nasal bones,**

2 lacrimal bones, 1 vomer, 2 palatine bones, 2 inferior nasal chamber, 1 mandible (the **only movable bone in the skull of man**).

- **Functions of skull** are to protect the brain, to protect the special sense organs, provide rigid walls of a respiratory passage, for cutting and masticating its food with the help of jaws etc.
- The **bone common to cranium and face** is **frontal**.
- The skull bones fit together by **sutures**.
- **Sella turcica** is the depression in sphenoid bone of skull that lodges pituitary body.
- **Vertebral column** is a string like vertebrae which lies in the middorsal line of the neck and trunk.
- **Function of vertebral column** is to carry weight of body during motions as well as standing and it gives flexibility to the animal during movement of head.
- Vertebral column permits movement, and **protect the spinal cord**.
- The **number of bones** in vertebral column is **33** but vertebrae consists of **26 bones** because 5 sacral vertebrae fused to form one sacrum, and 4 coccygeal vertebrae fused to form one coccyx.
- Human vertebral formula is $\mathbf{C_7T_{12}L_5S_5Cd_4}$.
- **Cervical vertebrae** are present in the neck, **thoracic vertebrae** in the chest, **lumbar vertebrae** in abdomen, **sacrum vertebrae** between the innominate bones of the pelvic girdle and **coccyx/ caudal vertebrae** are present in tail region.
- **Atlas**, the **first cervical vertebra** has reduced centrum, rudimentary neural spine and concave superior articular facets to provide nodding movement of head.
- The **second cervical vertebra axis** is characterised by **odontoid process**.
- Odontoid process fits into **canal of atlas** to provide head with sideways rotation.
- **Lumbar vertebrae** are **largest**, **heaviest** and **strongest** as they bear weight of the abdominal viscera.
- Vertebral column serves as a strong beam from which **viscera are suspended by mesentries in the body cavity**.
- Vertebral column **displays four curves** to enhance balancing powers and firmness for upright posture of the body.
- These **curvatures** are **cervical, thoracic, lumbar** and **pelvic (= sacral)**.
- Between the centre of adjacent vertebrae there are elastic pads of fibrocartilage, the **intervertebral discs which provide mobility to the vertebrae, check undue frictions and take up shocks**.
- Displacement of the vertebrae from its normal position due to displacement or degeneration of a part of intervertebral disc is called **slip disc**.
- **Sternum** is a flat bone present just under the skin in the middle of the front of the chest.
- Sternum **protects the internal organs of thoracic region, provide surface for muscle attachment** and **helps in respiratory mechanism**.
- Sternum is **longer in male than female**.
- Sternum of man consists of three portions **manubrium, body** and **xiphoid process**.
- **Ribs** which form the bony lateral walls of thoracic cage are usually **12 pairs** but occasionally there may be 11, 13 or even 14 pairs.
- The **first 7 pairs of ribs** which reach the sternum directly are known as **true rib**; the **8th, 9th and 10th pair of ribs** which are attached indirectly to the sternum or attached to coastal cartilage of seventh rib are known as **false rib** and the **last pairs (11th and 12th)** of ribs fall for short of the sternum and are known as **floating ribs**.
- Floating ribs are **so called** because these ribs are imperfectly formed and do not reach the sternum.
- **Thoracic cage or rib cage** is formed of thoracic vertebrae, sternum and ribs.
- **Pectoral (shoulder) girdle** consists of **4 bones**–2 clavicles and 2 scapulae.
- **Clavicles** or **collar bones** is a slender S shaped bone that articulate with the manubrium of the sternum.
- **Scapula** is a **large triangular**, **flat bone** which presents a shallow articular surface known as **glenoid cavity**.
- **Coracoid process** is a knob like inwardly bent fused scapula blade.
- Glenoid cavity articulate with **head of humerus** and it **also help in the attachment of the arm muscles**.
- The **primary function of the pectoral girdle** is to provide an attachment point for the numerous muscles that allow the shoulder and elbow joints to move. It also provides the connection between the upper extremities (the arms) and the axial skeleton.

- Each **arm consists** of 1 **humerus**, 1 **radius**, 1 **ulna**, 8 **carpal bones**, 5 **metacarpal bones** and 5 **digits** (14 phalanges).
- **Phalangeal formula** is **2**, **3**, **3**, **3**, **3**.
- **Humerus** has rounded **head** at the proximal end, a middle rod like **shaft** with deltoid ridge for attachment of muscle and a pulley like **trochlea** at the distal end.
- Humerus is also called **funny bone**.

Funny bone is a highly sensitive area at the back of the elbow where the ulnar nerve passes close to the surface of the skin in a groove between end prominences of the humerus (the upper arm bone) and the ulna (the large forearm bone). A blow to the area causes the nerve to compress against bone, producing a characteristic tingling in the forearm and the last two fingers.

- Humerus is the **longest bone in the upper extremities**.
- Radius is **shorter than ulna**.
- Ulna has an **olecranon process for forming elbow**.
- Thumb of hand is called **pollex**.
- **Pelvic girdle** (also **called hip girdle**) is formed by two **innominate (= no name) bones** (**hip or coxal bones**).
- Each coxal bone consists of three separate parts – the **ilium** (short and straight bone), the **ischium** (lower elongated bone, running parallel to vertebral column), and the **pubis** (inner, smaller bone).
- The **coxal bones** are also called the **ossa coxae**.
- Pelvic girdle has deep depression called **acetabulum** in which the head of femur fits.
- **Obturator foramen** is present as a large oval gap **between the pubis and ischium**. The foramen forms passage for nerves and blood vessels.
- Pelvic girdle **articulate with the legs** and **supports the posterior region of the trunk**.
- The pelvic girdle **serves several important functions in the body**. It supports the weight of the body from the vertebral column. It also protects and supports the lower organs, including the urinary bladder, the reproductive organs, and the developing foetus in a pregnant woman.
- The pelvic girdle **differs between men and woman**. **In a man**, the pelvis is **more massive and the iliac crests are closer together**. In a **woman**, the pelvis is **more delicate and the iliac crests are farther** apart.
- These differences reflect the woman's role in pregnancy and delivery of children.
- Each **leg consists** of 1 **femur**, 1 **tibia**, 1 **fibula**, 1 **patella** (**knee cap**), 7 **tarsal bones**, 5 **metatarsal bones** and 5 **digits** (14 phalanges). **Phalangeal formula** is **2, 3, 3, 3, 3**.
- **Patella** is a sesamoid bone.
- **Femur, tibia** and **fibula** bones together support the shank of the leg. The **tarsals** form the ankle, **metatarsals** form the sole and **phalanges** form the the digits of the foot.
- The **femur** is the **longest, largest, and strongest bone** in the body whose head fits into the acetabulum of hip girdle.
- The tibia connects to the femur to form the knee joint and with the talus, a foot bone, to allow the ankle to flex and extend.
- The **tibia is larger than the fibula** because it bears most of the weight, while the **fibula serves as an area for muscle attachment**.
- **Fibula** is shorter, thinner and slender.
- **Tibio - fibula** is the **longest bone in frog**.
- **Smallest bone** in human body is **stapes** of middle ear. It is approximately .11 inches (.28 cm) long.
- The structural arrangement of tissue by which bones are joined together are called **joints**.
- **According to the mobility** joints are of **three types** – fixed or fibrous, slightly movable and synovial joint.
- In **fibrous or immovable joints** there is no movements between the bones concerned (e.g., sutures and joints between the teeth and the maxilla, etc.).
- **Cartilaginous or slightly movable joint** allows very slight movements. E.g., cartilaginous joints include the pubis and the joints between the vertebrae.
- **Synovial joints / freely movable joints (diarthrosis)** are perfect joints in which bones are not fused with each other.
- Synovial joints are **further classified according to the movements they permit**. The **main types** are – ball and socket joints, hinge joints, gliding joints, pivot joints, saddle joints and ellipsoid joint, etc.
- **Ball and socket joints** have one end like a ball and other like a cup shaped socket, e.g., shoulder joint and hip joint.
- **Saddle joint** is an imperfectly developed ball and socket joints in which one bone is movable on

another fixed bone in many direction, e.g., carpometacarpal joint of human thumb.

- **Ellipsoid or angular joint** have one movable bone on another bone in two planes. E.g., wrist or radiocarpal joint of humans, toes and sole.
- In this joint one articular end is **oval and convex** while the other end is **elliptical and concave**.
- In **pivot joint** articular end of one bone is fixed while that of the other can rotate over it. E.g., between atlas and axis in humans, upper ends of radius and ulna.
- In **hinge joint** articular end of one bone is deeper convex and that of other is deeper concave, allowing movement in one plane. E.g., elbow joint, knee joint (condylar joint), ankle joint, interphalangeal joints.
- In **gliding joint** articular ends of two bones are either flat or slightly curved to allow sliding or gliding movement. E.g, bones of palm and sole, between pre-zygapophyses and post-zygapophyses of vertebrae.
- **Osteology** is the study of bone with their structure, nature, development and functions.
- **Arthritis** is painful inflammation and stiffness of joints caused by infection, allergy, hormonal disturbances and faulty food.
- **Osteoarthritis** is a tearing of articular cartilage and development of bony lumps at places causing pain, stiffness due to inhibited secretion of synovial fluid and permanent bending.
- In **rheumatoid arthritis**, a hard tissue deposits over articular cartilage along with higher secretion of synovial fluid causing pain and stiffness.
- **Gout** is the accumulation of uric acid crystals in the region of joints which results in painful movements.
- **Dislocation** - In this case, the bone at the joints are dislodged from their positions. E.g., the ball of one bone may slip out of the socket.
- **Bursitis** is inflammation of the bursae present within synovial joint as small membrane bound pockets which stores synovial fluid. It is caused by physical injury or constant pressure on a single joint for a long time.
- **Osteomyelodysplasia** is a condition characterized by thinning of the osseous tissue of bones and increase in size of the marrow cavities, attended with leukopenia and fever.
- **Osteopetrosis** is a hereditary disease marked by abnormally dense bone, and by the common occurrence of fractures of affected bone.
- Injury to joint due to overstretching or tearing of ligament or tendon is called **sprain**.
- **Osteoporosis** is an age-dependent disorder, characterised by increased fragility of bones which become prone to fracture. Imbalance of hormones like thyrocalcitonin, parathyroid and sex hormones, deficiencies of calcium and vitamin D, are the major causative factors of the disease.
- **Fracture** is a breaking of bone accidently.
- Fracture is of **4 types - green stick fracture** (simple crack without breaking into 2 pieces, generally occurs in growing children), **simple fracture** (breaking into 2 parts which remain nearby), **compound fracture** (breaking into 2 or more parts with some protruding out), **comminuted fracture** (breaking into more than two pieces) and **evulsive fracture** (a small piece breaks but remains attached to ligament).

Phantom Limbs

Phantom Limb Pain (PLP) is a serious condition that occurs when a person who has lost a part of their body though amputation, trauma or loss of nervous connections in an appendage, perceives that the limb is still there and experiences sensations coming from this area. It was first described in 1886 by S. Weir Mitchell, an American neurologist. The phantom sensation can occur right after the amputation or many months or years later. Many phantom limb sensations ocur after some injury to the site of the amputation. Thus, a person who was born without a limb, and did not experience any type of phantom sensation could suddenly find themselves experiencing one if some type of injury occurred to the stump. Phantom limbs help with the use of prosthetics. It's easier to use some type of prosthetic device if there are phantom sensations associated with the limb.

End of the Chapter

Chapter 41

Body Fluids & Circulation

- **Body fluid** is any of the fluids found within animals, including blood, lymph, tissue fluid, urine, bile, sweat and synovial fluids.
- Body fluids are generally **involved with the processes of transport**, **excretion** or **lubrication**.
- Body fluids allow the distribution of oxygen and nutrients to the tissues and organs and the transport of waste products from the tissues, enabling their elimination from the body.
- Circulation of body fluids are of two types– **intracellular** and **extracellular**.
- **Intracellular circulation** occurs inside the cell through cyclosis.
- It occurs in unicellular organism like *Paramecium, Amoeba* etc.
- **Extracellular circulation** occurs outside the body cell, *i.e.*, extracellular fluid that circulates in the body for transport of materials.
- Extracellular circulation may be **extra organismic circulation** (outside water circulates in the body of the organism) and **intra-organismic circulation** (involves circulation of body fluids). Eg. of intra organismic circulation are - **parenchymal circulation** (flatworms), **coelomic circulation** (roundworm), **blood vascular system** (vertebrates and higher invertebrates).
- Depending upon the medium of transportation circulatory system is divided into **water** and **blood vascular system.**
- **Water circulatory system** is a system of circulation of water drawn from outside medium into body spaces for transport of respiratory gases, wastes and food articles, eg. sponges (water canal system), coelenterates (gastro-vascular system) and starfish (ambulacral system).
- **Blood vascular system** is a system containing a special body fluid or blood, blood vessels and a pumping organ or heart for moving it.
- Blood vascular system occurs in **vertebrates** and **higher invertebrates** (from annelids onwards).
- Blood vascular system may be **open** or **closed.**
- In **open circulatory system**, blood flows partly through vessels and partly through **haemocoelomic spaces.**
- The haemocoelomic spaces are called **blood sinuses**.
- The blood in open circulatory system is called **haemolymph.**
- Open circulatory system is found in some **molluscs** and in some **arthropods.**
- In a **closed circulatory system**, the blood vessels form a complete circuit in the body, carrying blood to and away from the organs.
- Closed circulatory system occurs in **annelids** (earthworm), **some molluscs** (cephalopods), **echinoderm**s and **all vertebrates**.

BLOOD

- **Blood** is a **fluid connective tissues** that circulates through the heart, arteries, capillaries and veins, carrying nutrients and oxygen to the body cells.
- **Haematology** is the study of blood forming tissues and circulating blood components.
- The **functions of blood** are – to deliver nutrients hormones, and oxygen to tissues; to collect and dispose of the waste from cellular metabolism; to deliver specialized cells to tissues for protections against the external environment; and to prevent leakage by a closing gaps in blood vessels.
- Blood measures about 5–5.5 litres in an adult man constituting 30–35% of total extracellular fluid.
- Major elements of blood consists of **cellular** (**RBC, WBC, platelets**) and **fluid (plasma) elements**.
- **Plasma** is the **relatively clear liquid protein and**

salt solution which carries the RBC, WBC and platelets.

- Plasma makes up **55 percent of the blood volume,** the **remaining components** compose **45 percent of the blood**.
- About 95% of plasma consists of water. As the heart pumps blood to cells throughout the body, plasma brings nourishment to them and removes the waste products of metabolism.
- Plasma **contains three major classes of plasma proteins** *viz*. **serum albumin**, **serum globulins** and **fibrinogen**. They serve as a source of proteins for tissue cells.
- Albumin and globulins **retain water in blood plasma by their osmotic effects**.
- **Plasma functions** in (a) transport (b) body immunity (c) prevention of blood loss (d) retention of fluid in blood (e) maintenance of blood pH (f) uniform distribution of heat all over the body, and (g) conduction of heat to skin for dissipation.
- **Red blood cells (or erythrocytes) are relatively large microscopic cells** without nuclei (in mammals **except** camel and llamas).
- The name of the **red blood cell reflects** the bright red colour **of the cell that occurs when oxygen is attached to the haemoglobin.**
- **Haemoglobin** is the **gas transporting protein molecule that makes up 95% of a red blood cell.**
- Each red blood cell has about **270,000,000 iron-rich haemoglobin molecules.**
- Optimum amount of haemoglobin in male is about **16 gm/100 ml blood** and **13–14 gm/100 ml blood** in female**.**
- Haemoglobin is a protein which is bright red in color. Individual RBCs are straw-colored, but in the aggregate they appear bright-red if the haemoglobin is bound to oxygen (*i.e.* oxygenated) and bluish-purple if not.
- Haemoglobin contains the element iron, making it an excellent vehicle for transporting oxygen and carbon dioxide. As blood passes through the lungs, oxygen molecules attach to the haemoglobin. As the blood passes through the body's tissue, the haemoglobin releases the oxygen to the cells. The empty haemoglobin molecules then bond with the tissue's carbon dioxide or other waste gases, transporting it away.
- In **each cubic millimeter of blood,** about **5 million red blood cells are present**.
- The **life span of RBC is 120** days after which they are broken down by the spleen and the Kupffer cells in the liver.
- **Average life of RBC of transfused blood (oxalated)** is 60 **days** and **fetal RBCs (with nucleus)** is **180 days.**
- **Process of RBC formation** is known as **erythropoiesis** (completed in **72 hours**).
- The ageing cells (RBC) swell up to a sphere-like shape and are engulfed by phagocytes, destroyed and their materials are released into the blood. The main sites of destruction are the liver and the spleen. The heme constituent of haemoglobin is eventually excreted as bilirubin.
- The **functions of erythrocyte** are **–**
  - Oxygen transport in the blood from the lungs to all the cells and tissues of body.
  - Assists with the transport of carbon (IV) oxide from the tissue to the lung.
  - Regulating the acid base balance of blood, thus preventing large changes in pH.
  - Also assists when a blood clot is formed.

An insect larva has red blood. The larva of genus *Chironomus* is called **'Blood worm'**. The red colour of this larva is due to haemoglobin, which has the power of attracting and storing oxygen and giving it off to the tissues as they require it.

- **Leucocytes** are **larger than red blood cells** and **have a definite nucleus**.
- Leucocytes can be **divided into two components– granulocytes (polymorphonuclear leucocytes)** and **agranulocytes (mononuclear leucocytes).**
- **Neutrophil, eosinophil** and **basophil** are categorised **as granulocytes.**
- **Neutrophils** (constitute 60 - 70%) can be recognized by their segmented nuclei and the presence of abundant, small, pale staining granules in their cytoplasm.
- Neutrophils are the **most abundant** and are **produced in red bone marrow**.
- Neutrophils are **active in phagocytosis, play a role in the healing of wounds and repairing worn out and damaged tissue; and prevent infections from spreading to other tissues of the body.**
- **Eosinophils (motile phagocytic cell)** constitutes upto 3%, are characterized by **bilobed nucleus** having clearly visible granules in the cytoplasm.

- **Basophils** are characterized by very large granules. Their nuclei often remain invisible because of the granules. They are probably like mast cells of connective tissue.
- **Nongranular leucocytes** (or mononuclear leucocytes) can be **grouped into two classes – lymphocytes** and **monocytes**.
- **Lymphocytes** are produced in the spleen, tonsils and lymph nodes and are the **smallest of the white blood cells.**
- Lymphocytes are of **two types – B and T lymphocyte.**
- Lymphocytes are **involved in the synthesis and distribution of antibodies in the blood.**
- The **B cells** are **responsible for humoral** or **antibody immunity** and **T cells** are **responsible for cellular immunity.**
- **Monocytes** are the **largest** amongst all types of leucocytes with a rounded nucleus**.**
- Monocytes are **motile** and **phagocytic in nature.**
- Individual white blood cells in man usually live about **10–13 days.**

> Some white cells (called lymphocytes) are a major part of the immune system. Other white cells (called granulocytes and macrophages) protect our bodies from surrounding and destroying bacteria, virus, fungi or other parasites. They also have the function of getting rid of old, unwanted blood cells as well as foreign matter such as dust and asbestos.

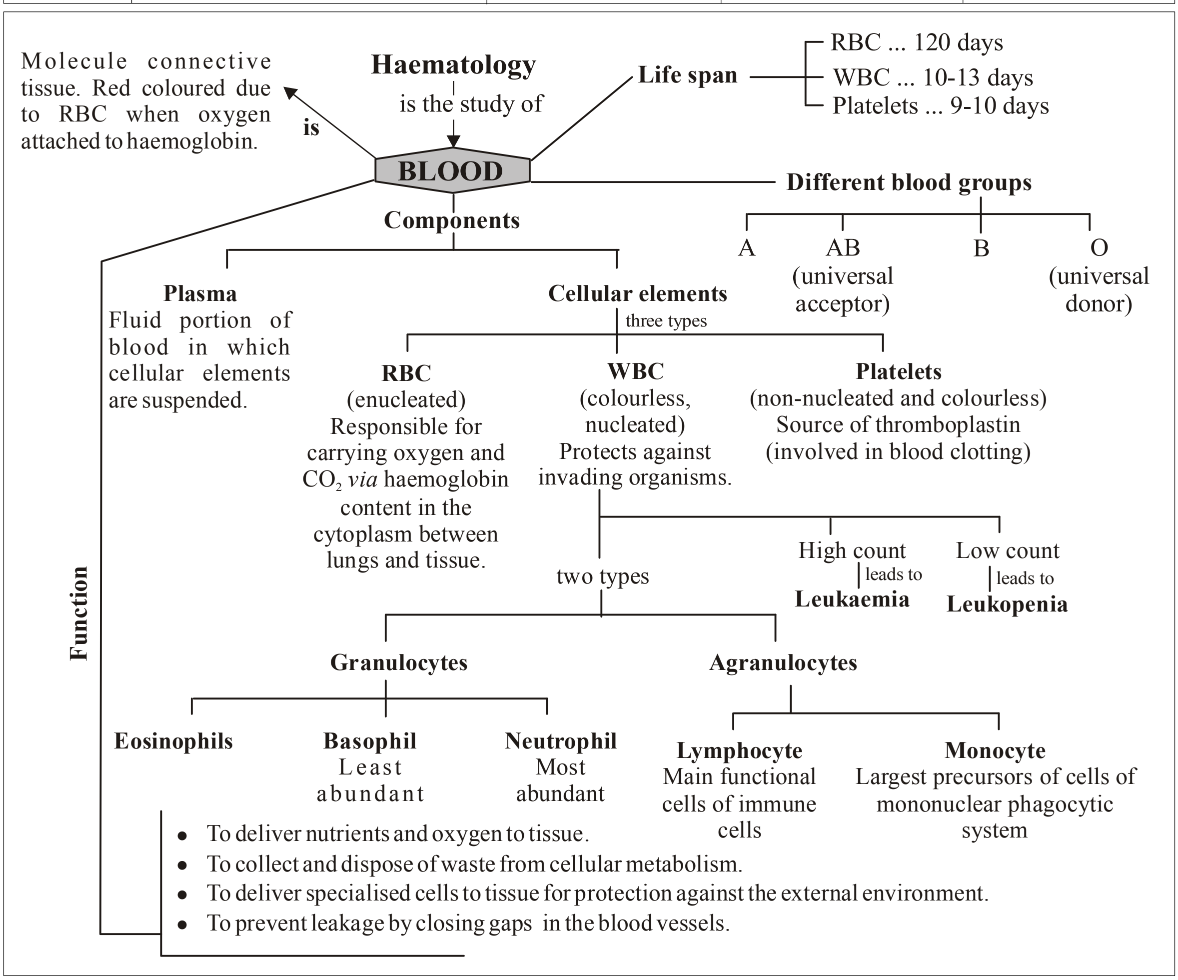
- **Leukaemia**, also called **blood cancer**, is an uncontrolled production of leucocytes.
- **Platelets or thrombocytes** are cells that **clot blood at the site of wounds** (by producing platelet factor thromboplastin).
- Platelets are **non-nucleated**, round or oval biconvex disc like bodies.
- Individual platelets measures about 1/3 the size of red cells.
- Platelet have a **life span of 9 - 10 days** (about a week).
- **Mechanism of blood clotting** at the site of injury protects the organism by stopping bleeding or haemorrhage.
- **Clotting time** is the time required for blood to coagulate. It usually varies from **2 to 8 minutes.**
- **Serum** is a pale yellow fluid that separates from the blood upon coagulation,when all cellular elements are removed.
- **Anticoagulants** like heparin, sodium or potassium oxalate are chemical substances which prevent blood clotting.
- The **cation necessary for coagulation of blood** is **calcium**.
- Platelet aggregation and fibrin formation both require the proteolytic enzyme thrombin. Platelets are the **source of thromboplastin.**
- **Lymph,** chiefly made of plasma and leucocytes is an interstitial fluid, present between the cells of a tissue.
- If the formation rate of lymph exceeds the rate of its return to blood then **oedema occurs.**
- **Blood groups** are the special characteristic of blood in human and related primates due to the presence of genetically controlled **antigens** and **antibodies.**
- **Antigens** are relatively large proteins molecules that provide the biological signative of an individuals blood type.
- Within blood there are substances called **antibodies** which distinguish particular antigen from others and causing bursting or agglutination of the red blood cells when alien antigen are found.
- More than **20 different blood group systems** are recognized in medicine. Of these, the best known are the **ABO system** and the **Rh system**.
- The antigens of ABO systems are A, B and H.
- The H antigen is the precursor to the A and B antigens.

Table : Types of blood group (ABO)

Blood Group	Antigens on RBCs	Antibodies in serum	Genotypes	Can donate to	Can recieve from
A	A	anti-B	AA or AO	A & AB	O, A
B	B	anti-A	BB or BO	B & AB	O, B
AB	A and B	Neither	AB	AB	O, A, B, AB
O	Neither	anti-A and anti-B	OO.	O, A, B, AB	O

Table : Blood group of parents on the basis of their children's blood group

S.No	Blood Group of Child	One Parent	Second Parent	Can Not Be
1.	O	O	A, B & O	AB
		A	A, B & O	AB
		B	A, B & O	AB
		O	A & AB	B & O
2.	A	A	A, B & O	AB
		B	A, B & O	AB
		A	B & AB	O & A
3.	B	B	B & AB	O & A
		O	B & AB	O & A
		A	B & AB	O & A
4.	AB	B	A & AB	O & B
		AB	A, B & AB	O
		A	B & AB	O, A



- Water **is the main component of blood**. Almost 70% of the body is water, most of which is contained in and around cells. The **blood plasma maintains the water content of cells in the tissues**.

CIRCULATORY SYSTEM

- **Sir William Harvey**, first demonstrated that the blood makes a complete circuit of the body, being pumped out of the heart through one set of vessels and returning to the heart *via* a different set.
- **Circulatory system of human beings** is of **closed type** and it **consists of blood vascular system** and **lymphatic system**.
- **Blood vascular system** consists of **blood** (*described earlier*), **blood vessels** and **heart** as their components involved in circulation.
- **Blood vessels** are intricate networks of hollow tubes that transport blood throughout the entire body.
- **Vasa vasorum** is the blood vessel which supplies blood to the blood vessel itself.
- **Three varieties of blood vessels** are – **arteries, veins** and **capillaries**.
- **Arteries** are **elastic vessels** that **transport blood (oxygenated) away from the heart** towards the other body tissue.
- **Pulmonary artery** is the **only artery which carries deoxygenated blood**.
- **Aorta** is the **largest artery** of the body which orginates from the heart and branches out into smaller arteries.
- The smallest arteries are called **arterioles** which branches into capillaries.
- Arterioles receives blood from the arteries and carries it to the capillaries.
- Walls of artery consists of **three layers–**
  - **Tunica intima** – The innermost smooth layer lining endothelium, connective tissue, elastic tissue.
  - **Tunica media** – A middle layer of smooth involuntary muscle and elastic fibres.
  - **Tunica externa** – An external layer consisting mainly of inelastic white fibres (collagen fibres).
- In artery, **tunica media** is well developed and thicker, in vein, **tunica externa** is well developed.
- **Veins** transport blood (deoxygenated) to the heart (except pulmonary vein).
- **Pulmonary vein** conveys oxygenated blood from the lungs to the left atrium of the heart.
- Veins **contain pocket valves** which prevent the back flow of blood.
- **Largest vein** in the human body is **inferior vena cava**.
- **Capillaries** are extremely **thin blood vessels** with a diameter as small as 5-9 in man. These **form capillary plexus between arterioles on one end and venules on others**.
- Capillaries, made up of **tunica interna** (single layer of endothelium), transports blood from arteries to the veins.
- Body contains **three types of capillaries - continuous capillary** (found in brain, connective tissue and skeletal muscle), **fenestrated capillary** (found in endocrine tissues, ciliary body of eye, etc), and **discontinuous capillary** (found in liver sinusoids).
- **Capillary beds** are the **sites where white blood cells are able to leave the blood** and defend the body against harmful invaders.
- **Human heart** is situated in the thorax between the lungs with its apex resting on the **diaphragm.**
- The heart measures 12 cm in length and 9 cm in breadth.
- Heart is the **busiest organ** of the body.
- The **wall of the heart consists of three layers :** the external covering layer or **epicardium**, the intermediate cardiac muscular tissue or **myocardium** and the internal layer or **endocardium** in contact with the blood.
- **Myocardium does not fatigue** due to alternate rest and activity and nonformation of lactic acid.
- Heart is enclosed in a double fibro-serous sac called **pericardium.**
- **No neurons** are present in the walls of heart.
- The mammalian heart consists of **4 chambers** - right and left atrium, right and left ventricle.
- The **walls of the atria are thinner** than those of the ventricles.
- Auricle is divided by an **interatrial or inter auricular septum**.
- On this septum, a depression, called **fossa ovalis** is present which is the remnant of embryonic **foramen ovale** (through which both the auricles communicate with each other).
- The right atrium **recieves deoxygenated blood** from superior vena cava, inferior vena cava and coronary sinus.
- The left atrium **recieves oxygenated blood** from two lungs through four pulmonary veins.

- **Right and left ventricles are separated** by an **interventricular septum**.
- **Left ventricle** is **thicker than right ventricle** because it has to push blood to all the body parts at a much greater pressure.
- Walls of the ventricles possess a network of low ridges or **columnae carnae** and a few large muscular projections or **papillary muscles/musculi papillares**.
- The **right ventricles contains** a **moderator bands** that extends between upper papillary muscle and inter-ventricular septum.
- **Bicuspid valve** or **mitral valve** is present in between the **left atrium and left ventricle**.
- **Tricuspid valves** consists of three flaps or cusps and present **between the right atrium and right ventricles**.
- **Semilunar valves** (pulmonary valve and aortic valve) are present where artery leaves the heart.
- **Valves of eustachian** (rudimentery membranous falciform fold) is present at the opening of inferior vena cava.
- **Valves of thebesius** or **coronary valve** is present at the opening of coronary sinus.
- Strong fibrous strings connecting bicuspid and tricuspid valves are known as **chordae tendinae**.
- The valves of heart **maintains unidirectional flow of blood** and **prevent its regurgitation** in the opposite direction.
- **Varicose veins** are enlarged, twisted, painful superficial veins resulting from poorly functioning valves.
- **Blue whale** has the **largest heart**.
- The **world's first heart transplant** was performed by **Prof. Christian Barnard** on December 21, 1967.

Sinus venosus is a thin walled chamber of vertebrate embryos heart. Sinus venosus receives blood from the umbilical, vitelline and common cardinal veins (*i.e.*, from the chorion or placenta, from the yolk sac, and from the embryo). The sinus venosus of the primitive heart opened into the common atrium. As development proceeds the opening of the sinus venosus moves to the right atrium. As the sinus venosus moves to the right the venous drainage from the rest of the body, the head, the vitelline and umbilical veins also move to the right. A small part of the sinus venosus still lies behind the left side of the heart to become the coronary sinus.

- **Heart beat** is the rhythmic contraction and relaxation of the heart which **include one systole** (contraction phase) and **one diastole** (relaxation phase).
- The **normal rate of heart beat is 70 - 72/min** in adult human**.**

Smaller animals have much higher heart beat rate than the larger animals because they have high metabolic rates and hence need greater action of heart to pump more oxygen and nutrients to tissue. Eg. 200/min in rabbit, 500/min in sparrow whereas elephant has 25/min.

- The heart beat is of **two types - neurogenic** & **myogenic.**
- In **neurogenic heart**, contraction is initiated by a nerve ganglion situated in the vicinity of the heart, *i.e.*, heart beat originated by nervous regulation.
- The hearts of most arthropods and some annelids like *Arenicola, Lumbricus* etc. are **neurogenic**.
- In a **myogenic heart** contraction is initiated by a special node of modified heart muscle, the **sino-atrial (SA) node**, **present in the wall of right atrium** close to the point of entry of the vena cava.
- The heart of **molluscs** and **vertebrates** are of **myogenic type**.
- **SA node** is the **first to originate** the cardiac impulse and determines the role of the heart beat, hence also known as **pace maker.**
- Origin of heart beat and its conduction is represented as **SA node → AV node → Bundle of His → the bundle branches → Purkinje fibres.**
- **AV** (auriculo-ventricular) **node** acts as **pace setter**.
- **AV (atrio-ventricular) bundle or Bundle of His** was discovered by **His (1893)**.
- A set of specialized muscle strands which originates in the AV node and pass downwards in the inter-ventricular septum is known as **purkinje fibres.**
- The bundle of his and the purkinje fibres convery impulse of contraction from the AV node to the myocardium of the ventricles.
- **Rate of heart beat is controlled** by **nerves, hormones** (epinephrine or norepinephrine, secreted by adrenal medulla), other factors [including **inorganic ions** (K, Na & Ca), **temperature, pH, CO_2** etc].
- **Nervous regulation of heart beat** includes two pairs of nerves arising from the **cardiac centre located in medulla oblongata** and **spinal cord**.
- These nerves are **acceleratory** and **inhibitory** which affect the working of heart rate by changing

the heart rate and by changing the strength of contraction of the heart.

- The acceleratory nerves **consists of sympathetic fibres** and also known as **adrenergic nerve** as they releases a substance **sympathin** (comprising hormones adrenaline and noradrenaline) which increases the fibre permeability to sodium and calcium ions.
- Inhibitory nerves **forming parasympathetic elements** are a pair of **vagus nerves** (X).
- If **sympathetic nerve and vagus nerve stimulated, the heart rate increases and decreases respectively**.
- **Foramen of panizzae** is present in between two systemic arches of the heart.
- The heart is supplied with the arterial blood by the **cornonary arteries.**
- **Cardiac output** is the amount of blood flowing from the heart over a given period of time.
- Cardiac output = **stroke volume** (the volume of blood pumped by heart/heart beat) × **heart rate** (ventricular systole/min) ⇒ 70 ml × 72/min = 5040 ml/min ⇒ about **5 litre/min**.
- Cardiac output in relation to unit surface area of body is **cardiac index.** Its normal value is 3.3 lt/min/sq.m.
- The **cardiac cycle** refers to the sequence of events which takes place during the completion of one heart beat.
- In human being, the cardiac cycle occurs about **72 times per minute**.
- These events comprises contraction (systole) and relaxation (diastole) of the chambers of heart, associated with opening and closing of the heart valves.
- Cardiac cycle is completed in **0.88 sec**.
- **Heart sounds** may be heard by **stethoscope** during each cardiac cycle.
- **First heart sound - lubb** is created by the closure of atrioventricular valves at the beginning of ventricular systole and opening of semilunar valves.
- **Second heart sound - dup** is created at the end of ventricular systole when the semilunar valve closes and the AV valves open.
- The first sound has a duration of 0.15 second and a frequency of 25-45 Hz. The second sound lasts about 0.12 seconds with a frequency of 50 Hz.
- **Murmurs** are abnormal sounds heard in various parts of the vascular system.
- The **major cause of cardiac murmurs** is a disease of the heart valves. It may **arise due to improper closing of any heart valve or in patients with inter-ventricular septal defects**.
- **ECG** is the recording of electrical changes that accompany the cardiac cycle.
- **Waller** (1887) first recorded the electrocardiogram but **Einthoven** (1908) studied ECG in detail, therefore he got Nobel prize in 1924 for the discovery of ECG
- **Einthoven** is considered to be the **father of electrocardiography.**
- Normal ECG is composed of **P wave**, **QRS wave** & **T wave**.
- **P wave**, a small upward wave, indicated the depolarisation of the atria, **caused by activation of SA node**.
- **QRS wave** begins as a small downward deflection (R) & continues as a large upright (R) & triangular wave ending as downward wave (S) at its base.
- QRS wave **represents ventricular depolarization**, & **caused by** impulse of the contraction from AV node through bundle of his & purkinje fibres and the contraction of ventricular muscles.
- **T-waves** indicates **ventricular repolarization**.
- **Enlargements in Q&R waves** indicates myocardial infarction.
- **ST segment** is **elevated in acute myocardial infarction** and **depressed** when the heart muscles recieves insufficient oxygen.
- **T-wave** is **flat** when the heart muscles recieve insufficent oxygen as in atherosclerotic heart disease. It may be **elevated** when the body's potassium level is increased.
- Blood pressure is measured by **sphygmomanometer in the brachial artery**.
- **Factors which affect blood pressure** are cardiac output, total blood volume, blood viscosity, resistance, elasticity of arteries.
- Blood pressure is measured during systole, the active pumping phase of the heart, and diastole, the resting phase between heartbeats.
- Systolic and diastolic pressures are **measured in units of millimeters of mercury** (abbreviated mm Hg) and displayed as a ratio – *Systolic pressure* (*mmHg*)/*Diastolic pressure* (*mm Hg*).
- The average blood pressure is expressed as **120/80 mm Hg**.
- The increase in the blood pressure beyond 140 mm Hg. (systolic) and 90 mm Hg. (diastolic)

is referred to as **high blood pressure**. A sustained rise in the arterial blood pressure is known as **hypertension**.

- The **reason for hypertension** are **stiffening** of arterial walls due to ageing, **thickening** of arterial walls due to cholesterol deposition, **chronic vaso-constriction** of arterial walls, **varicose veins, obesity, hormones** etc.
- High blood pressure may harm heart, brain and kidneys. In brain it may cause haemorrhage or infarction. In long run it may cause congestive heart disease and affect kidney leading to renal failure.
- **Hypotension** is a low blood pressure with systolic below 110 mm Hg and diastolic below 70 mm Hg.
- Hypotension is **caused** by low metabolic rate, anaemia, chronic vasodilation of arterioles, starvation, nervous disorder etc.
- **Marey's law of heart** is the inverse relationship between rate of heart beat and blood pressure.
- **Heart rate** is pulse per minute.
- **Pulse** is the alternate expansion and elastic of recoil (contraction) of an artery with each systole.
- Pulse can be **detected in superficial artery** like **radial artery** of wrist and temporal artery.
- The difference between systolic and diastolic pressure is called **pulse pressure**.
- **Double circulation** is the passage of blood twice in the heart through separate pathways for completing one cycle.
- Double circulation is present in lung fishes, amphibians, birds, reptiles and man where **arteriovenous heart** (means when it receives both venous or deoxygenated and arterial or oxygenated bloods) is present.
- The **advantage of double circulation** is that the blood can be sent to the lungs to pick up oxygen and then be returned to the heart to be pumped again before travelling around the body. The blood therefore is pumped through the capillary blood (which slows it down and reduces its pressures) then receives another pump before it enters another capillary bed. Double circulatory systems are therefore high pressure system. In this there is no mixing of the oxygen rich blood and oxygen poor blood in the heart.
- Double circulation **consists of pulmonary and systemic circulation**.
- In **pulmonary circulation** movement of the blood takes place from the heart to the lung and *vice versa*.
- In **systemic circulation,** the movement of blood takes place between heart and different parts of the body except lungs.
- **Systemic circulation** has **arterial** and **venous system**.
- **Arterial system** comprises all arteries coming out from the heart and supplying blood to different parts of the body. Whereas **venous system** comprises all the veins that bring blood to heart. **Two main arterial vessels are** pulmonary arch and aorta. **Two main veins are** 2 precavals and 1 post caval.
- **Single circulation** is present in fish where blood from the heart first goes to the gills to collect oxygen, but continues round the whole body before returning into heart.
- The heart of fish is called **venous heart as it receives deoxygenated blood**.
- **Microcirculation** deals with the flow of blood from arterioles to capillaries or sinusoids to venules.
- **'Blue baby'** is the name given to an abnormal human baby who has a hole in the ventricular septum so that oxygenated and less oxygenated blood mix.
- The **foetal circulation** involves the exchange of materials between the foetus and mother by means of placenta.
- The foetal circulation differs mainly from the adult one by the presence of 3 major vascular shunts.
- These shunts are – **ductus venosus** (between umbilical vein and inferior vena cava), **foramen ovale** (between the right and left atrium *i.e.,* opening in interatrial septum) and **ductus arteriosus** (between the pulmonary artery and descending aorta).
- **Coronary circulation** is the flow of oxygenated blood from the ascending aorta to the heart muscles and the return of deoxygenated blood from the heart muscle to the right atrium.
- A **portal vein** is the vein which collects blood from the organ by a set of capillaries and distributes that blood into a second organ through another set of capillaries instead of sending into heart.
- There are **three types of portal systems** - hepatic, hypophysial and renal.
- **Hepatic portal system** occurs in all vertebrates and is meant for taking blood from digestive tract, pancreas and spleen into liver.
- The system has a large hepatic portal vein that is formed by **four veins - splenic** (from spleen), **inferior mesenteric** (from rectum and distal part of colon), **superior mesenteric** (from small

intestine, caecum and proximal part of colon) and **gastroepiploic** (from stomach and pancreas).

- **Hypophysial portal system** is a minor portal system that occurs in higher vertebrates. The system consists of a single hypophysial portal vein which passes into anterior lobe of pituitary gland and breaks up into capillaries there.
- This system is meant for pouring hormones secreted by hypothalamus directly into the anterior part of pituitary.
- **Renal portal system** occurs in lower vertebrates (fishes and amphibians), **reduced in reptiles** and **aves**, and is **absent in mammals**.
- It consists of renal portal veins that bring blood from **posterior part of the body** directly into kidneys.
- **Lymphatic system** of man consists of lymphatic capillaries, lymphatic vessels, lymph nodes, lymphatic ducts, lymph and other lymph organs like spleen.
- Lymphatic system **serves as an intermediary (middle man)** between the blood and the tissues.
- **Lymph** is an interstitial fluid (tissue fluid), present between the cells of a tissue and it has the same composition like plasma except it lacks RBCs and large plasma proteins.
- All the lymph collected from the entire left side of the body, the digestive tract and the right side of the lower part of the body flows into a single major vessel, the **thoracic duct.**
- Lymphatic system **helps to maintain fluid and balance in the tissues and also have a major role in the defence against infection**.
- **Cysterna chyli** is a sac like structure situated infront of the upper lumbar vertebrae on the right of the abdominal aorta.
- **Spleen** is the **largest component of lymphatic** system.
- Spleen acts as the **reservoir for red corpuscles**, helps in formation of agranulocytes, antibodies, erythropoiesis etc.
- Spleen is termed as **'grave yard' of RBC** because fragment of red cells, old and dead cells are constantly being removed from the blood streams by it.
- **Cords of Billroth** are blood spaces **found in red pulp of spleen**.
- **Oedema** occurs when lymph capillaries fail to return lymph to the blood, fluid accumulates in the tissue resulting in a local swelling.
- **Haematoma** is localised collection of clotted blood in a tissue or organ due to injury rupturing of a blood vessel.
- **Angina pectoris** is a sudden recurring thoracic pain radiating to arms, **especially left arm**, due to ischaemia of myocardium and precipitated by effort or excitement.
- **Myocardial infarction** is the complication due to reduced blood supply to heart wall, pain, perspiration, nausea, ECG changes.
- **Rheumatic heart** is the heart with insufficient blood supply to its muscles due to rheumatic disorder or fever in childhood.
- **Cardiomegaly** is hypertrophy of heart.
- Inflammation of heart is **carditis.**
- **Atherosclerosis** is wall thickening and narrowing of lumen of medium and large arteries. In atherosclerosis, yellowish plaques **(atheromas)** of cholesterol and other lipids are deposited within intima and inner media of arteries.
- **Arteriosclerosis** is the hardening of arteries due the deposition and thickening due to precipitation of calcium salts with cholesterol.
- **Palpitations** is awareness of heart beat or a feeling of having a rapid and unusually forceful heart beat, especially if they last for several hours or recur over several days and/or cause chest pain, breathlessness or dizziness.
- **Fibrillation** is a condition in which the heart muscle is contracting very rapidly but in an uncoordinated fashion. There are atrial and ventricular fibrillation.
- **Ventricular fibrillation** is immediately life threatening unless it can be stopped by defibrillation. A machine called a **defibrillator**, which gives a DC voltage shock, is used to do this.
- **Tachycardia** is above normal heart beat/pulse.
- **Brachycardia** is below normal heart beat/pulse.
- **Phonocardiogram** is an instrument for amplifying and recording of heart sounds.
- **Lowest level of glucose** is present in hepatic vein.
- **Highest level of amino acids** is present in hepatic vein.
- **Highest level of urea** is in **hepatic vein** and **lowest** is in **renal vein**.
- **Electric shock** is given to stabilize the heart in case of arrythmia or revive the heart in case of cardiac arrest.
- **Angiology** is the study of blood vascular and lymphatic system.

End of the Chapter

Chapter 42

Excretory System

- The tissues and organs associated in the removal of waste products (called excretion) constitute the **excretory system**.
- **Excretion** is the "process of eliminating (from an organism) the waste products of metabolism of nitrogenous substances like amino acids and nucleic acids and other materials that are of no use.
- Some of these structures constitute the **urinary system** which is involved in the synthesis, separation and elimination of mainly nitrogenous waste products and other mineral salts.
- The urinary system **produces, stores and eliminates urine** after it produces and modifies a urinary filtrate **consisting of a large volume of hypotonic blood filtrate rich in serum proteins**.
- The **main aim of the excretion** is to maintain a constant body temperature by removing excess heat and maintain a constant internal environment in association with the other system of the body (called **homeostasis**).
- Excretion is an essential process in all forms of life. In **one celled organisms** wastes are discharged through the surface of the cell. The **higher plants eliminate** gases through the stomata, or pores, on the leaf surface. **Multicellular animals** have special excretory organs.
- The waste product could be nitrogenous, non – nitrogenous, chemicals, bile pigments, excess of water or CO_2.
- **Metabolism of carbohydrates and fats** produces CO_2 and H_2O which are easy to remove. Their excretion is effected through lungs (expired air), skin (sweat) or kidneys (urine).
- Carbon dioxide produced as the waste product during respiration, diffuses out of the cells into the lung tissue and leaves the body everytime we exhale.
- Other excretory products are pigments, mostly formed by the breakdown of haemoglobin; drugs etc.
- **Protein metabolism** produces nitrogenous waste material such as ammonia, which is the basic nitrogenous catabolite of protein, formed by breakdown of amino acids.
- Removal of the amino group (NH_2) is known as **deamination** and it converts the amino acid into a keto acid.
- Nitrogeneous waste **have the ability to change the pH of cells and interferes with membrane transport functions and may denature enzymes**.
- Some common nitrogenous excretory products are – **Ammonia** (very toxic and requires large amount of water, eg. aquatic invertebrate such as *Amoeba,* sponge, *Unio*, star fish etc.); **urea** (less toxic, eg. cartilaginous fishes, amphibians and mammals), **uric acid** (least toxic, eg. reptiles, birds and cockroaches), **trimethylamine oxide** (eg. marine bony fish, mollusca, crustaceae), **ornithuric acid** (birds), **guanine**, **creatinine** etc.
- The **main three nitrogenous wastes** are – **ammonia**, **urea** and **uric acid**.
- Animals excreting ammonia, urea and uric acid are respectively called as **ammonotelic, ureotelic** and **uricotelic animals.**
- Ammonia is **highly toxic** and **soluble in water** with which it forms ammonium hydroxide (NH_4OH) which injure cell directly by alkaline caustic action. Hence excretion of **ammonia requires large amounts of water to be lost from the body**.
- Ammonia is the **first metabolic waste product** of protein metabolism.
- **No energy is required** to produce ammonia.
- Ammonotelic organisms (without excretory system) **includes all aquatic invertebrates**, **bony fishes**, **aquatic amphibians**.
- The **terrestrial animals excrete urea** as nitrogenous waste product.
- Urea is **produced in liver** from some proteins

(ornithine, citrulline, arginine) and other nitrogen compound by deamination process **in presence of arginase enzyme.**

- Urea is the **end product of protein or amino acid.**
- Urea is **eliminated in the form of urine.**
- **Formation of urea cycle, also known as the urea or ornithine cycle**, is a cycle of biochemical reactions occurring in many animal organisms that produces urea from ammonia (NH_4^+) due to lack of water.
- This cycle was the **first metabolic cycle discovered** by **Krebs and Hensenleit, 1932**.
- The urea cycle consists of **five reactions - two mitochondrial** and **three cytosolic** (*Refer table given below*).
- **Earthworm excrete ammonia** when sufficient water is available **but it eliminates urea** when water is not available in good quantity.
- In anurans (amphibians) the **larval tadpole excrete ammonia, while the adults produce urea.**
- **Uric acid** is the **nitrogenous waste product of** terrestrial animals such as **birds**, **many reptiles**, **insects** and **land snails** that do not have constant access to water or rather have limited access to water.
- Conversion of ammonia to uric acid and its subsequent elimination requires lesser amount of water as it is comparatively less soluble in water and less toxic as compared to ammonia.
- Uric acid is a **more complex molecule than urea so it requires more energy to produce.**
- **Xanthine oxidase** is needed in production of uric acid.
- **Bilirubins** are the **toxic bile pigment** formed in liver during disintegration of dead RBCs.
- In some reptiles and insects the uric acid is further changed into **allantoin.**
- Marine teleost fishes excrete a large proportion of nitrogen as **trimethylamine oxide**.
- **Guanine** is a **metabolic waste of nucleotide metabolism**, found in spider and penguin.
- The regulation of water content and salt concentration in the body of an organisms is called **osmoregulation.**
- **Osmoconformers** are organisms that show changes in the body fluid concentration according to the concentration of external environment, e.g., most of marine invertebrates.
- **Osmoregulators** are organisms that maintain a fixed osmotic concentration in the body fluid despite changes in the external environment.
- **Marine invertebrates and cartilaginous fish (chondrichthyes) are isotonic** in which the concentration of solutes in isotonic animals is approximately equal to that of their environment. As a result, they do not gain or lose water.
- Birds and reptiles living near the sea consume a large amount of salt in their diet. **Nasal salt glands** remove this excess salt from their body by secreting a concentrated salt solution.
- The kidneys of sea mammals (example seal, whales, porpoise) are able to maintain a constant salt concentration in their bodies by producing urine having high concentration of salt.
- Kangaroo rats (a desert mammal) **never have to drink water**. Their water comes from metabolic

Table : Reactions in urea cycle

Step	Reactant	Product	Catalyzed by	Location
1.	2ATP + HCO_3^- + NH_4^+	Carbamoyl phosphate + 2ADP + P_i	CPSI	Mitochondrial
2.	Carbamoyl phosphate + ornithine	Citrulline + P_i	OTC	Mitochondrial
3.	Citrulline + aspartate + ATP	Argininosuccinate + AMP + PP_i	ASS	Cytosolic
4.	Argininosuccinate	Arg + fumarate	ASL	Cytosolic
5.	Arg + H_2O	Ornithine + urea	ARGI	Cytosolic
CPSI – Carbamoyl phosphate synthetase; OTC - Ornithine transcarbamoylase; ASS – Arginosuccinate synthetase; ASL – Arginosuccinate lyase.				

water released during cellular respiration and water present in their food.

- In humans the **main organs of excretion** are the **kidneys** and **accessory urinary organs**, through which urine is eliminated, and the **large intestines**, from which solid wastes are expelled.
- The **skin and lungs** also **have excretory functions**.The **skin eliminates water and salt in sweat,** and the **lungs expel water vapour and carbon dioxide.**
- The waste products are **eliminated by urination and exhalation**.
- **Urination**, also called **micturition**, is the process of disposing urine from the urinary bladder through the urethra to the outside of the body.
- The **process of urination is usually under voluntary control**. When control over urination is lost or absent, this is called **urinary incontinence**.
- **Urinary retention** refers to the **inability to urinate**.
- **Perspiration** is another excretory process which removes salts and water, although the primary purpose is cooling.

EXCRETORY SYSTEM

- The **mammalian (human) urinary system** consists of – **two kidneys** (which form the urine), two **ureters** (which conduct the urine from kidneys to the urinary bladder), a **urinary bladder** (for storage of urine) and a **urethra** (through which the urine is voided by bladder contractions).
- Human beings are **ureotelic**.
- Kidney (**mesodermal** in origin) are **excretory and homoeostatic organ**.
- An average sized kidney measures 10 to 12 cm in **length**, 5 to 6 cm in **width** and 3 to 4 cm in **thickness**, **each weighing about 150 g in adult male and about 135 g in female**.
- The human **kidneys** are **bean-shaped** excretory organs which filter wastes (especially urea) from the blood and excrete them, along with water, as urine.
- The medical field that studies the kidneys and diseases affecting the kidney is called **nephrology**.
- **Ureters** are narrow tubes started as a pelvis within kidney opening into a common urinary bladder which opens outside through urethra.
- **Urethra** is a muscular tube that connect urinary bladder and external opening of urinary tract.

Table : Organ of excretion in different animals

	Organ of excretion	Name of animals
1.	Contractile vacuoles & plasma membrane	Protozoans
2.	General body surface	*Hydra* and sponges
3.	Renette cells	Aschelminthes
4.	Flame cells (solenocytes) & protonephridia	*Planarians*
5.	Nephridia & chloragogen cells	Earthworm (annelida)
6.	Malpighian tubules	Insects (arthropoda)
7.	Coxal gland	Spider (arachnida, phylum-arthropoda)
8.	Green gland	Prawn (crustacea, phylum arthropoda)
9.	Keber's organ or organs of Bojanus	Mollusca
10.	Skin	Amphibia
11.	Kidneys	Vertebrates

- Urethra **is smaller in females and longer in males.**
- Urethra **conduct urine to the exterior**. The urethral sphincters keep the urethra closed except during voiding of urine.
- **Urinary bladder** is sac like structure which **stores urine temporarily**. Ureters and urinary bladder are **lined by flexible transitional epithelium.**
- The kidneys are **retroperitoneal**, which means they lie behind the peritoneum, the lining of the abdominal cavity (means **posterior part of the abdomen**).They are approximately at the vertebral level T_{12} to L_3.
- The **right kidney sits just below the liver**, the **left below the diaphragm and adjacent to the spleen.**
- The asymmetry within the abdominal cavity caused by the liver results in the **right kidney to be slightly lower than the left one.**
- A deep notch or concavity is present at the medial border - the **hilus (hilum),** and it is through this region the blood vessels-renal artery and vein, ureter and nerves pass.

Types of kidney

- Types of kidneys are of following types – **archinephros**, **pronephric**, **mesonephric** and **metanephric**.
- **Archinephros**, found in the larvae of some cyclostomes, is the **basic and ancestral form of kidney**.
- **Pronephric kidney** or **anterior kidney** is found only in cyclostomes and tadpole of frogs. It is **developed from anterior most part of the nephrostome and are the primitive kidney**.
- **Mesonephric kidney** or **middle kidney** is found only in fish and frog. It is **developed just after pronephros** in the nephrostome.
- Mesonephric kidney is the **second stage in the development of the kidney**.
- **Metanephric kidney** or **posterior kidney** (**most advanced type**) is found in reptiles, birds and mammals. It is formed from the **posteriormost part** of nephrostome, behind embryonic mesonephros.

- The **upper parts** of the kidneys are partially **protected by the eleventh and twelfth ribs**, and each **whole kidney is surrounded by two layers of fat (the perirenal fat and the pararenal fat) which help to cushion it**.
- The **outermost portion** of the kidney is called the **renal cortex**, which sits directly beneath the kidney's loose connective tissue capsule.
- The **renal cortex** is **granular in appearance** because the tubules here are much convoluted (proximal and distal convoluted tubules) and contain malphigian corpuscles.
- **Cortex is subdivided into** alternating radial tracts known as **rays** and **labyrinths**.
- The **rays** are radially straight since they contain the straight parts of proximal tubules and the collecting ducts. They are continuous with striated medulla, hence called **medullary rays**.
- The **labyrinths** have a granular appearance because the convoluted tubules, which compose them, are cut irregularly.
- Deep to the cortex lies the **renal medulla**, which is **divided into** 10-20 **renal pyramids** in humans. Each pyramid together with the associated overlying cortex forms a renal lobe.
- The lateral boundaries of the pyramid are formed by the projection of the darker cortex which are named as **renal columns of Bertini**.
- **Renal medulla** mainly **contains loop of Henle, collecting tubules and ducts of Bellini.**
- The tip of each pyramid (called a **papilla) empties into a calyx**, and the calyces empty into the renal pelvis.
- The pelvis **transmits urine to the urinary bladder** *via* **the ureter.**
- Each "kidney" **receives its blood supply from the renal artery,** two of which branch from the abdominal aorta.
- Due to the position of the aorta, the inferior vena cava and the kidneys in the body, the **right renal artery is normally longer than the left renal artery**. The right renal artery normally crosses posterior to the inferior vena cava.
- Upon entering the hilum of the kidney, the **renal artery divides into smaller interlobar arteries situated between the renal papillae**.
- At the outer medulla, the interlobar arteries branch into **arcuate arteries**, which course along the border between the renal medulla and cortex, giving off still smaller branches, the **cortical radial arteries** (sometimes called **interlobular arteries**).
- Branching off these cortical arteries are the **afferent arterioles supplying the glomerular capillaries**, which drain into **efferent arterioles**.
- The walls of the afferent arteriole **contain specialized smooth muscle cells** (juxtaglomerular apparatus or cells**) that synthesize renin**.
- These juxtaglomerular cells or apparatus **play a major role in the renin-angiotensin system**, which helps regulate blood volume and pressure.
- Juxtaglomerular apparatus or juxtaglomerular cells includes – granular **juxtaglomerular cells** in the afferent arteriole; **macula densa** of the proximal part of the distal collecting tubule; and agranular **Polkissen or Lacis cells.**
- **Polkissen or lacis cells** are situated in the angle created by the entrance and exit of the afferent and efferent arterioles of each glomerulus.
- Blood leaves the capillaries of the glomerulus *via* an **efferent arteriole** and enters capillaries in the medulla called **peritubular capillaries,** which collect much of the water that was lost through the glomerulus.
- Blood from these capillaries collects in renal

venules and leaves the kidney *via* the **renal vein.**

- The **renal veins connect the kidney to the inferior vena cava**. Because the inferior vena cava is on the right half of the body, the left renal vein is generally the longer of the two.
- Efferent arterioles of glomeruli closest to the medulla (those that belong to juxtamedullary nephrons) send branches into the medulla, forming the **vasa recta**.
- Along with the loop of Henle, these vasa recta **play a crucial role in the establishment of the nephron's countercurrent exchange system.**
- **Counter current mechanism** (the process due to which the urine is made hypertonic) is regular exchange of Na^+ ions between the ascending and descending limbs of kidney.
- Blood supply is **intimately linked to blood pressure**.

NEPHRON

- The **basic structural** and **functional unit of the kidney** is the **nephron**, of which there are more than a million (approximately 1.3 million) in each normal adult human kidney.
- Nephrons **regulate water and soluble matter** (especially electrolytes) in the body by first filtering the blood, then reabsorbing some necessary fluid and molecules while secreting other, unneeded molecules.
- Reabsorption and secretion are accomplished with both cotransport and countertransport mechanisms established in the nephrons and associated collecting ducts.
- Nephrons **eliminate wastes from the body, regulate blood volume and pressure, control levels of electrolytes and metabolites, and regulate blood pH**.
- **Functions of nephron are vital to life and are regulated by the endocrine system by hormones** such as antidiuretic hormone, aldosterone, and parathyroid hormone.
- **Two types of nephrons** present in kidney are: **cortical and juxtamedullary nephrons**.
- **Cortical nephrons** (70–80%) close to kidney surface, **have a shorter loop of Henle and peritubular capillary network.**
- **Juxtamedullary nephrons** (20–30%) at the junction of renal cortex and medulla, **have a longer loop of Henle and vasa recta.**
- Juxtamedullary nephrons are **important in the counter current mechanisms** in which the kidney concentrate the urine.
- Each **nephron is composed of** an initial **filtering component** (the **renal corpuscle**) and **a tubule** specialized for reabsorption and secretion (the **renal tubule**).
- The renal corpuscle **filters out large solutes from the blood, delivering water and small solutes to the renal tubule for modification.**
- The renal corpuscle (or Malpighian corpuscle) is **composed of a glomerulus and Bowman's capsule**.
- The malpighian corpuscle is named after **Marcello Malpighi** (1628 - 1694), an Italian physician and biologist.
- **Glomerulus** is a capillary (fenestrated) tuft that **receives its blood supply from an afferent arteriole of the renal circulation.**
- The remainder of the blood not filtered into the glomerulus passes into the narrower **efferent arteriole.**

NEPHRON — Types
- **Cortical nephron**
  - Present at the periphery of cortex
  - Peritubular capillary is present
  - Acts in normal condition.
- **Juxtaglomerular nephron**
  - Present towards the medulla of cortex
  - Peritubular capillary is absent
  - Acts under stress *i.e.* function most Important when water is in short supply.
  - Concentrates urine

NEPHRON — Differentiated into 5 regions
- **Renal capsule or Malpighian body** — Consists of two parts
  - Bowman's capsule
  - Glomerulus
- **Proximal convoluted tubule (PCT)**
- **Loop of Henle** — Consists of two parts
  - Ascending limb of loop of Henle
  - Descending limb of loop of Henle
- **Distal convoluted tubule (DCT)**
- **Collecting tubule**

The **glomerulus (plural glomeruli) in olfaction** is a structure in the olfactory bulb. It is made up of a globular tangle of axons from the olfactory receptor neurons in the olfactory epithelium and dendrites from the mitral cells, tufted cells and other cells types.
Glomeruli are important waystations in the pathway from the nose to the olfactory cortex. Each glomerulus receives input from olfactory receptor neurons. The glomerulus is the **basic unit in the odour map of the olfactory bulb**.

- The **diameter of the afferent arteriole is much more** than that of efferent arteriole.
- **Bowman's capsule** (also called the **glomerular capsule**) is a blind sac which surrounds the glomerulus.
- Bowman's capsule is composed of **inner visceral (simple squamous epithelial cells)** and **outer parietal (simple squamous epithelial cells) layers.**
- Bowman's capsule is named after **Sir William Bowman** (1816 - 1892), a British surgeon and anatomist.
- The **visceral layer** lies just beneath the thickened glomerular basement membrane and is **made of podocytes** which send foot processes over the length of the glomerulus.
- Foot processes interdigitate with one another forming **filtration slits** that, in contrast to those in the glomerular endothelium, are spanned by diaphragms.
- The **size of the filtration slits restricts the passage of large molecules** (eg, albumin) and **cells** (eg, red blood cells and platelets). In addition**, foot processes have a negatively-charged coat (glycocalyx)** that limits the filtration of negatively-charged molecules, such as albumin.
- Between the visceral and parietal layers is **Bowman's space**, into which the filtrate enters after passing through the podocytes' filtration slits.
- Unlike the visceral layer, the **parietal layer does not function in filtration**. Rather, the **filtration barrier is formed by three components**: the diaphragms of the filtration slits, the thick glomerular basement membrane, and the glycocalyx secreted by podocytes.
- The **process of filtration of the blood in the Bowman's capsule** is **ultrafiltration (or glomerular filtration**), and the **normal rate of filtration is 125 ml/min**.

Any protein under roughly 30 kilodaltons can pass freely through the membrane, although there is some extra hindrance for negatively charges of the basement membrane and the podocytes. Any small molecules such as water, glucose, salt (NaCl), amino acids, and urea pass freely into Bowman's space, but cells, platelets and large proteins do not. As a result, the filtrate leaving the Bowman's capsule is very **similar to blood plasma in composition** as it passes into the proximal convoluted tubule.

- The filtrate leaving the Bowmans capsule is very **similar to blood plasma in compostion** as it passes into the proximal convoluted tubule.
- **Measuring the glomerular filtration rate** (GFR) is a **diagnostic test of kidney function**. A decreased GFR may be a sign of renal failure.
- The **renal tubule functions as a dialysis unit**, in which the fluid inside the tubule is the internal solution and the blood (in capillaries surrounding the tubule) acts as the external solution.
- The **renal tube consists of three parts:** the **proximal convoluted tubule, the loop of Henle,** and **the distal convoluted tubule.**
- **Proximal convoluted tubules (PCT) or pars convoluta** is about 14 mm long and lined by a single layer of cubical cells.

'Proximal' means that it is near Bowman's capsule, and 'convoluted' describes its coiled and looped shape.

- Cells of the proximal convoluted tubule **have numerous microvilli and mitochondria which provide surface area and energy and closeness of blood capillaries**.
- **Selective reabsorption occurs** in the proximal convoluted tubule.
- The **loop of Henle** (sometimes known as the nephron loop) is a U-shaped tube that **consists of a descending limb** and **ascending limb.**
- Loop of Henle **begins in the cortex**, receiving filtrate from the proximal convoluted tubule, extends into the medulla, and then returns to the cortex to empty into the distal convoluted tubule only in juxtamedullary nephrons. In other nephrons, the loop merely extends through the kidneys cortex.
- Its **primary role is to concentrate the salt in the interstitium**, the tissue surrounding the loop.
- The **longer the nephron**, the better **it performs its**

countercurrent exchange mechanism.

- **Loop of Henle** is **short or absent** in other vertebrates like reptiles which cannot secrete hyperosmotic urine.
- **Descending limb** are **thin walled, lined by squamous epithelium.**
- Descending limb is **permeable to water but completely impermeable to salt**, and thus only indirectly contributes to the concentration of the interstitium.
- Longer descending limbs allow more time for water to flow out of the filtrate, so **longer limbs make the filtrate more hypertonic than shorter limbs.**
- **Ascending limb** are **thick walled formed by cuboidal epithelium** and **impermeable to water**. It **actively reabsorbs** the remaining 25% of the filtered K^+ and some amounts of Cl^-, some Na^+ is also reabsorbed by diffusion due to electrostatic attraction of reabsorbed Cl^-.
- The ascending limb actively **pumps sodium out of the filtrate, generating the hypertonic interstitium** that drives countercurrent exchange. In passing through the ascending limb, the filtrate grows hypotonic since it has lost much of its sodium content. This hypotonic filtrate is passed to the distal convoluted tubule in the renal cortex.
- The **distal convoluted tubule (DCT)**, a portion between the loop of Henle and the collecting duct system, is **partly responsible for the regulation of potassium, sodium, calcium,** and **pH.**
- The DCT **regulates pH** by absorbing bicarbonate and secreting protons (H^+) into the filtrate. **Sodium and potassium levels are controlled by secreting K^+ and absorbing Na^+**.
- Sodium absorption by the distal tubule is **mediated by the hormone aldosterone**.
- The DCT **also participates in calcium regulation by absorbing Ca^{2+} in response to parathyroid hormone.**

Histologically, cells of the DCT can be differentiated from cells of the proximal convoluted tubule :
- DCT cells do not have an apical brush border
- DCT cells are less eosinophilic than proximal cells
- DCT cells have less cytoplasm
- DCT cells are more likely to have visible nuclei

- **Thiazide diuretics inhibit** Na+/Cl- reabsorption from the DCT.
- DCT is **lined by cuboidal epithelium without brush border**.
- The **reabsorptive activity of the distal convoluted tubule** is **under the influence of ADH (vasopressin)**, which is one **determinant of the volume of urinary output**.
- The **collecting duct** system **begins in the renal cortex** and **extends deep into the medulla.**
- As the urine travels down the collecting duct system, it passes by the medullary interstitium which has a high sodium concentration as a result of the loop of Henle's countercurrent multiplier system.
- Though the collecting duct is normally impermeable to water, it **becomes permeable in the presence of antidiuretic hormone (ADH)**.
- The collecting ducts unite with each other in the medulla to form still **larger ducts of Bellini** which open into renal pelvis.
- The **epithelium of the collecting ducts is made up** of **principle cells (P cells)** and **intercalated cells (I cells)**.
- The **P cells**, which predominate are relatively tall and have few organelles. They are **involved in Na^+ reabsorption**.
- The **I cells**, which are present in smaller numbers and also found in the distal tubules, have more microvilli, cytoplasmic vesicles, and mitochondria. They are **concerned with acid secretion and HCO_3^- transport**.
- Lower portions of the collecting duct are also permeable to urea, allowing some of it to enter the medulla of the kidney, thus maintaining its high ion concentration (which is very important for the nephron).

URINE FORMATION

- The **formation of urine** is the result of the following process – **ultra filtration or glomerular filtration** of the blood plasma by the glomeruli; **selective reabsorption** by the tubules, and **secretion** by the tubules.
- **Glomerular filtration** is the **first of the three processes that form urine.**
- The molecules that leave the blood and enter the glomerular capsule are called the **glomerular filtrate.**
- If the glomerular filtrate were excreted from the body unchanged, persons would be in **constant**

danger of both dehydration and starvation.

- Glomerular filtration occurs because **the pressure of the blood flowing in the glomerular capillaries is higher than the pressure of the filtrate in Bowman's capsule**.
- **Effective filtration pressure** may be expressed as – EFP = GCP – (GOP + CHP)
  where, EFP = effective or net filtration pressure; GCP = glomerular capillary pressure; GOP = glomerular osmotic pressure; CHP = capsular hydrostatic pressure.
- **Tubular reabsorption** is the **second process in the formation of urine from filtrate**. As a result of tubular reabsorption, much of the filtrate passes out of the nephron tubule and returns to the blood through the peritubular capillaries.
- **Reabsorption occurs** within cell, three regions of the nephron and in the collecting duct, **but most of it takes place within the proximal convoluted tubule.**
- Depending on the type of molecule being reabsorbed, movement into and out of epithelial cells occurs by **passive transport or active transport.**
- **Water and urea**, for example, are **reabsorbed by passive transport**, by which they move from regions of higher concentration to regions of lower concentration.
- Water is reabsorbed by **osmosis** and urea by **simple diffusion. Water is reabsorbed** in all parts of the tubule **except the ascending loop of Henle.**
- Glucose and amino acids are reabsorbed by **active transport.**
- The **reabsorption of Na^+** occurs by **both passive and active transport**. Na^+ moves passively by diffusion from the filtrate into tubule cells but is actively transported out of the tubule cells on its way to the peritubular capillaries.
- **Renal threshold** of a substance is its highest concentration in the blood upto which it is totally reabsorbed from the glomerular filtrate.
- **High threshold substances** are almost completely absorbed from nephric filtrate, e.g., glucose, amino acids, vitamin C, Na^+, water. **Glucose** has a **threshold value of 180 mg/100 ml**.
- **Low threshold substances** (in which only very small reabsorption occurs) are urea, uric acid, xanthin, phosphate and **non-threshold substances** are not at all reabsorbed, e.g., creatinine, hippuric acid.
- Certain chemicals in the blood that are not removed by filtration from the glomerular capillaries are removed by a third process of urine formation called **tubular secretion.**
- Ions removed from the blood by tubular secretion include potassium (K^+), hydrogen (H^+) and ammonium (NH_4^+) and foreign substances like drugs, penicillin, uric acid, creatine etc.
- The **secretion of H^+** is an **important way in which kidneys help control blood pH**.
- **Water reabsorption** is **controlled by antidiuretic hormone (ADH)**, secreted by posterior pituitary gland, in negative feedback and **aldosterone hormone** (secreted by adrenal cortex) regulates the transfer of sodium from the nephron to the blood.
- ADH increases the reabsorption of water by the distal tubule and collecting duct.
- **Dehydration results in an increase in ADH**, while **water sufficiency results in low ADH** allowing for diluted urine.
- The **more ADH**, the more permeable the ducts, the more water reabsorbed; the **less ADH**, the less permeable the ducts, the less water reabsorbed. This is **related to the high osmolarity of the interstitium due to the countercurrent multiplier system of the loops of Henle**.
- Drugs called **diuretics** increase the production of dilute urine and prevent the excessive water retention and tissue swelling (oedema) that may accompany congestive heart failure, high blood pressure and other conditions.
- **Alcohol inhibits the secretion of ADH**, thus increases water loss.
- Under the **deficiency of ADH**, a disease called **diabetes insipidus** is caused in which the output of urine may reach 3-40 litre/day in place of normal 1.2–1.8 litre/day. Frequent urination and thirst is the symptoms of the disease.
- **Renin** (secreted by the cells of afferent arteriole) initiates a series of chemical reactions that ultimately result in **aldosterone** secretion from the adrenal cortex, which **acts primarily on the distal convoluted tubule to promote absorption of sodium and excretion of potassium.**
- Renin acts in the following way : renin ⇒ adrenal cortex ⇒ aldosterone ⇒ distal convoluted tubule ⇒ reabsorption of sodium and excretion of potassium.
- The presence of too much blood in the circulatory system stimulates the heart to produce **atrial natriuretic hormone (ANH)**.
- This hormone **inhibits the release of aldosterone**

by the adrenal cortex and **ADH** by the posterior pituitary causing the kidneys to excrete excess water.

- The hormone, **erythropoietin,** a circulating glycoprotein is produced by interstitial cells in the peritubular capillary bed of the kidney.
- Erythropoietin is **concerned with the regulation of normal erythropoiesis.**
- In the kidneys primary prostaglandins causes an increase in renal blood flow and vasodilation.
- **Kininogen** produced by the kidneys **has an anti-hypertensive effect and regulates blood pressure**.
- Kidneys play an important role in **vitamin D metabolism**.
- **Micturition** is the act of emptying the bladder or passing urine. The total volume of urine (approx. 1.5 lt) in 24 hours is much less than the amount of glomerular filtration (approx. 170 lt).
- Urine is **transparent, amber coloured, hypertonic fluid** with a **slightly acidic pH (average - 6.0).**
- The **yellow colour** of the urine is **caused by the pigment urochrome**.
- **Least concentration of urea** is found **in renal vein.**
- **Highest concentration of urea** is found **in hepatic vein.**
- **Kidney transplantation** or renal transplantation is the organ transplant of a kidney in a patient with chronic renal failure or some renal tumors.
- **Renal failure or kidney failure** is the loss of the kidneys' ability to excrete wastes, concentrate urine, and conserve electrolytes, *means* a condition where the kidneys fail to function properly.
- The **first successful kidney transplantations** were done in 1954 in Boston and Paris. The transplantation was done between identical twins, to eliminate any problems of an immune reaction. It was actually the **first successful human organ transplant in history.**
- The **artificial kidney** uses the principle of dialysis to purify the blood of patients whose own kidneys have failed.
- **Dialysis** is a method of removing toxic substances (impurities or wastes) from the blood when the kidneys are unable to do so.
- In haemodialysis (also known as artificial kidney) the patient's blood is passed through a tube to a semipermeable membrane **(dialyzer)** that filters out waste products. The cleaned blood is then returned back to the body. The procedure is monitored by a machine, which also provides the dialysis fluid, mixing it from a concentrate and water.

DISORDERS

- **Albuminuria** is presence of albumin in urine and it occurs when the filtering pores enlarge in size (it is the indication of increase in glomerular permeability).
- **Nephritis or Brights disease** infection is caused by bacteria (Streptococci) which results in inflammation of kidney that involves glomerulus.
- **Pyelonephritis** is inflammation of the tissue of kidneys and the ureters in the pelvic region.
- **Renal stone** is formation of calculi (large stones) in the kidney due to dehydration, excess uric acid formation, excess calcium intake etc.
- **Polyuria** occurs when excess amount of dilute urine is passed out as in diabetes insipidus.
- **Uraemia** is the increased concentration of urea in blood.
- **Alkaptonuria** is a genetic disease in which homogentisic acid is excreted out with urine.
- **Pyuria** is presence of pus in the urine.
- **Glycosuria** is presence of glucose in urine due to diabetes.
- **Haematuri**a is presence of blood in the urine. **Anuria** is the failure of kidney to form urine.
- **Ketosis** is the presence of ketones or acetone bodies in urine due to metabolism of fatty acids instead of glucose during diabetes, starvation and pregnancy.
- Acetone bodies are acetoacetic acid, beta-hydroxybutyric acid and acetone.
- **Cystitis** is the inflammation of urinary bladder, caused by bacteria. It is **more common in female due to short urethra**.
- **Gout** is high level of uric acid in blood.
- **Dysuria** is painful urination. **Diuresis** is a condition in which the excretion volume of urine is increased.

End of the Chapter

Chapter 43

Nervous System

- **Nervous system** is a system of neurons, nerves and nervous organs that coordinate and control the activities of different parts of animal body by sending and receiving nerve impulses.
- Study of morphology, physiology and pathology of nervous system is called **neurology**.
- The **nervous system** is the **body's information, gatherer, storage centre** and **control system**.
- The nervous system –
  - **Gathers information** both from the outside the body (called **sensory function**)
  - **Transmits the information** to the processing area of the brain and spinal cord
  - **Processes the information** to determine the best response (called **integrative function**)
  - **Sends information to muscles glands and organs** (effectors) so they can respond correctly (called **motor function**).
- In humans the cells called **neurons** make up the nervous system.
- Neurons allow messages to be carried from one cell to another so that communication among all body parts is smooth and efficient.
- Neuron is the **basic functional and structural unit of the nervous system.**
- A neuron **carries impulse in only one direction.**
- A neuron has **three parts** : **cell body/cyton, dendron** and **axon**.
- Extending from the nerve cell body several fine cytoplasmic threads called **dendrites** are present.
- One of these very long dendrites is called **axon**.
- Axon is **covered by a myelin sheath**, which again is covered by a membrane called **neurolemma** or **Schwann sheath**.
  [*For more on neurons refer chapter Animal tissue*]
- **Minimum power of regeneration** is found in nervous system.
- The nervous system is divided into **two major division :** the **central nervous system** and the **peripheral nervous system**.
- **Central nervous system** consists of **brain** and **spinal cord** whereas the **peripheral nervous system** consists of neurons not included in the brain and spinal cord.
- Some peripheral neurons collect information from the body and transmit towards the CNS (called **afferent neurons**) and other peripheral neurons transmit information away from the CNS (called **efferent neurons**).
- The **motor or efferent neurons** is further **divided into somatic** and **autonomic nervous system.**
- The **somatic nervous system** is the **voluntary part** of nervous system that coordinates a body's movement such as maintaining a particular posture and walking.
- The **autonomic nervous system** is the **involuntary part** which seems to be concerned with striking a balance or maintanining homeostasis in the functioning of many organs of the body.
- The central nervous system serves as the **control centre of the body.**
- The central nervous system **relays messages, processes information** and **compares** and **analyzes information**.
- CNS is dorsal, hollow and non ganglionated in all the **vertebrates** including man.
- Central nervous system is composed of two main organs *i.e.,* **brain** and **spinal cord**.
- Two types of matter is present in central nervous system, these are **grey matter** and **white matter**.
- **Grey matter** is **formed of cell bodies and non medullated nerve fibres** and can be found on the surface of cortex as well as in clusters called nuclei deep within the brain.

- **White matter** refers to axons and their surrounding myelin insulation which gives this its white colour. White matter is found in bundles of fibres known as tracts which connects the different parts of the brain.

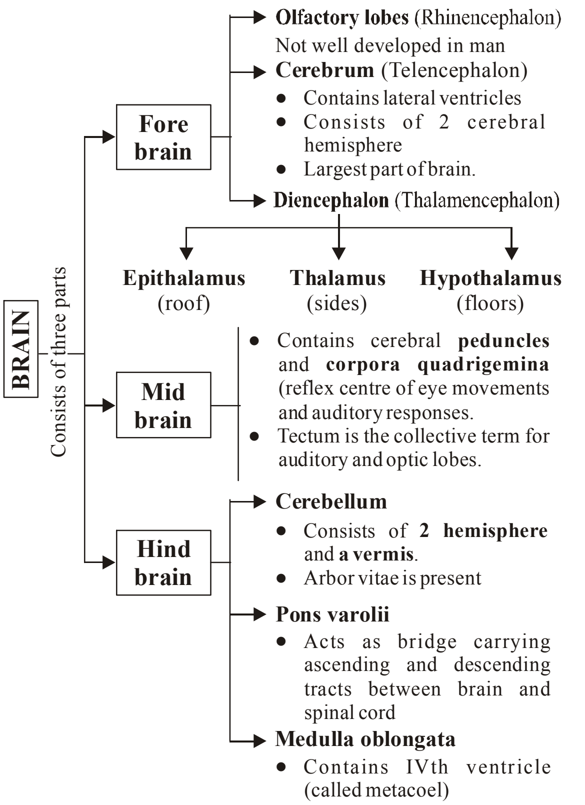
Brain

- **Brain** (also called **encephalon**) is the widest and uppermost part of CNS which **lies protected** (against mechanical injury and shock) **inside the cranial cavity of skull** and **controls all activities** of **nervous system**.
- Brain is **surrounded by 3 meninges** (dura, pia and arachnoid) in rabbit, man and other mammals, which separates the skull from the brain; while 2 meninges in frog (dura and piamater).
- **Meninges** are connective tissue membranes which protect the CNS and projection of its structure and separate the brain and spinal cord from the skull and vertebrae.
- **Piamater** is the **innermost** and **duramater** is the **outermost** meninges. **Arachnoid** is **present in between piamater and duramater**.
- The **dura and arachnoid are separated by a subdural space**; **the arachnoid and pia mater are separated by the subarachnoid space**.
- Between the meninges arachnoid and piamater **cerebrospinal fluid is present**.
- Piamater is **highly vascularised** and **nutritive.**
- Arachnoid is **porous** and **serous** membrane and is made up of **reticular connective tissue**.
- **Duramater** is double layered, thick and tough non-vascular meninx.
- The dura mater, consists of an outer periosteal layer and an inner meningeal layer.
- Within the vertebral canal, the periosteal layer of the dura is absent. The meningeal layer forms a dural sheath around the spinal cord; between the sheath and surrounding bone lies the **epidural space**.

Table : Ventricle system of the brain.

Structure	Description	Significance
Ventricle, **lateral**	paired spaces within cerebral hemispheres	they drain cerebrospinal fluid to the third ventricle *via* the interventricular foramina (of Monro)
Ventricle, **third**	midline space within the diencephalon between the paired dorsal thalami and the hypothalamus	communicates posterolaterally with paired lateral ventricles *via* interventricular foramina, communicates posteroinferiorly with fourth ventricle *via* cerebral aqueduct
Ventricle, **fourth**	midline space between cerebellum posteriorly and pons and upper medulla anteriorly	communicates anterosuperiorly with third ventricle *via* cerebral aqueduct; drains CSF *via* median aperture and lateral apertures
Choroid plexus	vascular membranes that occur within the ventricles	production of cerebrospinal fluid
Interventricular foramen	communication between the lateral ventricle and the third ventricle; paired, one on each side	also known as *foramina of Monro*
Cerebral aqueduct	canal connecting third and fourth ventricles, passing through midbrain	also known as *aqueduct of Sylvius* (iter)
Median aperture	midline, irregular foramen draining fourth ventricle posteroinferiorly into cerebellomedullary cisternae	also known as *foramen of Magendie*
Lateral aperture	paired foramina draining fourth ventricle laterally into cerebello-medullary cisternae	also known as *foramina of Luschka*
Central canal of spinal cord	small opening in the centre of the spinal cord	continuous with the central canal of the medulla and, through it, with the fourth ventricle of the brain

- Duramater is **protective in function**.
- The brain has four internal chambers called **ventricles** *(Refer table on page no.412)*. Each **cerebral hemisphere houses a large lateral ventricle that communicates with a third ventricle through an interventricular foramen**. The **cerebral aqueduct connects the third with the fourth ventricle**.
- A **choroid plexus** within each ventricle **produces cerebrospinal fluid** (CSF).
- **Cerebrospinal fluid**, secreted by anterior choroid plexus and posterior choroid plexus, fills four interconnected **ventricles**, or cavities in the brain. Within the ventricles, cerebrospinal fluid **acts as a transport medium for substances that are important to brain function**.
- The cerebrospinal fluid, is a **blood filtrate** which is **colourless**, **clear and slightly alkaline** (7.33 pH) fluid that **protects the brain from mechanical injury by acting as a shock absorber**.
- CSF **also maintains a constant pressure inside the cranium** inspite of variation in the pressure of blood in the cranial vessels.
- CSF **lends buoyancy**, **protects**, **removes wastes**, **and provides a stable chemical environment**.
- CSF circulates throughout the ventricles, and makes its way into the central canal of the spinal cord. **It exists the fourth ventricle through two apertures and enters the subarachnoid space**.
- Increase in cerebrospinal fluid may results in **meningitis**.
- The **CNS is protected by a blood-brain barrier that regulates substances entering the brain**. Tight junctions within capillaries and astrocytes comprise this barrier.
- The blood-brain barrier is **absent in areas of the brain (called circumventricular organs) that monitor blood glucose, pH, salinity, and so forth**.
- Brain is the **main switching unit of the central nervous system**. It is the place to which impulses flows and from which impulse originate.
- The brain is primarily made up of two types of **cells: glia** and **neurons**.
- **Glia** function primarily to support and protect the neurons. The **neurons** carry information in the form of electrical impulses known as **action potentials.**
- They communicate with other neurons in the brain and throughout the body by sending various chemicals called **neurotransmitters** across gaps known as **synapses.**
- The brain is protected by a bony covering called the **skull.**
- If the oxygen supply to the brain is cut off even for a few minutes, the brain will usually suffer enormous damage. Such damage may result in death.
- Brain is made of **three main parts : fore brain** (also called prosencephalon); **mid brain** (also called mesencephalon); **hind brain** (also called rhombencephalon) which continues into spinal cord.
- **Fore brain** occupies **anterior two third** of brain and is formed of the following three parts : **olfactory lobes** (rhinencephalon), **cerebral hemisphere** (telencephalon) and **diencephalon**.
- Olfactory lobes **control the smell**. These are **small sized** in man.
- **80%** of the weight of brain is formed of **cerebral hemisphere**.
- Two cerebral hemisphere are collectively called **cerebrum** but are demarcated by **cerebral**



Flow chart : Brain and its parts

fissure.

- Thick dorsal wall of cerebrum is called **pallium** and the ventrolateral walls is called **corpora striata**.
- The ridges and depressions in the roof of cerebral hemisphere is called **gyri** and **sulci** respectively.
- The gyri **increases the surface area of the cortex**.
- The increased surface area permits the large numbers of neurons to fit easily within the confines of the skull.
- The whitish nervous band by which two cerebral hemispheres are interconnected is called **corpus callosum**.
- Corpus callosum **participates in the formation of 5th ventricle or pseudocoel.**
- The grey matter of cerebral hemisphere is called **cerebral cortex** and deeper white matter is called **cerebral medulla**.
- **Centre of highest sensation and activities** is **cerebral cortex**.
- **Cerebrum** is the **most prominent and the largest part** of the human brain.
- Each cerebral hemisphere is divided into four regions called **lobes.** These are **frontal** at the front, **parietal** towards the top of the head, **temporal** on the side and **occipital** at the rear (*Refer table given below*).
- **Diencephalon** contains **epithalamus, thalamus** and **hypothalamus**.

Table : Functional areas of cerebrum.

	Area	Location	Function
1.	Premotor area	Frontal lobe	The highest centre for involuntary movements of muscles and ANS
2.	Motor area	Frontal lobe	Controls voluntary movements of the muscle
3.	Broca's area	Frontal lobe	Motor speech area
4.	Somesthetic area	Parietal lobe	Perception of general sensation like pain, touch and temperature
5.	Gustatory area	Parietal lobe	Sense of taste
6.	Auditory area	Temporal lobe	Hearing
7.	Olfactory area	Temporal lobe	Sense of smell
8.	Wernicke's area	Temporal lobe	Understanding speech
9.	Visual area	Occipital lobe	Sensation of light

- Diencephalon lies between cerebrum and mesencephalon. Its cavity is called **third ventricle or diocoel**.
- **Epithalamus** is **non-nervous part** which is fused with piamater to form anterior choroid plexus.
- The **thalamus and hypothalamus** are found in the part of the brain between the brain stem and cerebrum.
- The **thalamus**, which is composed of grey matter, serves as a **switching station for sensory input** including sound and balance. **With the exception of smell**, each sense channels its sensory nerves through the thalamus.
- Thalamus **forms the roof of third ventricle**.
- Immediately below the thalamus is the **hypothalamus**, which is the **control centre for hunger, thirst, fatigue, anger and body temperature.**
- The hypothalamus **forms the floor and the part of the lateral walls of the third ventricle**.
- The hypothalamus **acts like a 'thermostat'** by sensing changes in body temperature and then sending signals to adjust the temperature. For e.g. if one is feeling hot, the hypothalamus detects this and then sends a signal to expand the capillaries in skin. This causes heat loss.
- Hypothalamus **links nervous system to endocrine system** (*via* hypothalamus - hypophyseal axis) and exercises a regulatory control on the functioning of endocrine glands by secreting neurohormones. It synthesises the posterior pituitary hormones and control their release into the blood.
- Hypothalamus is **partially protected by the sella turcica of the sphenoid bone**.
- Parts of the diencephalon and the cerebrum are included in an important group of connected brain centres called the **limbic system**.
- The limbic system includes the thalamus, the hypothalamus, some deeper parts of the cerebral cortex, and centres in the temporal lobes.
- The limbic system plays an **important role in emotions, memory, and motivation, among other things**.
- Midbrain is formed of **optic lobes** and **cerebral peduncles**.
- In rabbit, man and mammals 4 solid optic

lobes are present. These are known as **quadrigemina**.

- Midbrain **controls muscle tone and some motor activities**.
- **Cerebellum, medulla oblongata** and **pons varolli** are the three parts of **hind brain**.
- **Cerebellum** is also called **little brain**.
- The **cerebellum** is similar to the cerebrum in that it has two hemispheres and has a highly folded surface or cortex. Cerebellum is **associated with regulation and coordination of movement, posture, and balance**.
- Sections of cerebellum shows branching radiation of white matter into grey matter, called as **arbor vitae**.
- The cerebellum is the **second largest part of the brain**, and is located at the back of the skull.
- The cerebellum receives sensory impulses from muscles, tendons, joints, eyes and ears as well as input from other brain centres.
- The left side of the brain controls the right side of the body and *vice versa*.
- **Medulla oblongata** (myelencephalon) is the **posterior most** part of the brain.
- The cavity of medulla oblongata is known as **IVth ventricle** or **metacoel**.
- Medulla oblongata controls **involuntary functions** like, heart beat, rate of respiration, secretion of glands, vomiting, coughing etc.
- Another important part of the medulla is group of cells known as the **reticular activating system** or **reticular formation (RAS).**
- The reticular activation system (RAS) actually **helps to alert, or awaken, the upper parts of the brain, including the cerebral cortex**.
- The RAS also **helps to control respiration and circulation** and **serves as a filtering system** for incoming sensory signals.
- In medulla oblongata and pons varolli, **grey matter** is **internal** and **white matter** is **external** while the arrangement is reverse in other parts of brain.
- **Pons varolli** is situated in front of the cerebellum below the mid brain and above the medulla oblongata.
- It **carries impulse from one hemisphere of the cerebellum to another**.
- Functionally, the pons is **concerned with maintenance of normal rhythm of respiration**. It **has got two respiratory centres** - the **pneumotaxic centre** and **apneustic centre**. It is also related with the control of facial expression, movement of the eye-ball, micturation etc.
- The **brain stem** connects the brain to the spinal cord.
- The brain stem, which **maintains life support system**, consist of the diencephalon, medulla oblongata, pons varolii and the midbrain.
- The brain stem not only coordinates and integrates all incoming information; it also serves as the **place of entry or exit for ten of the twelve cranial nerves**.

Spinal cord

- Spinal cord **provides the link between the brain and rest of the body.**
- Spinal cord is about **45 cm long** and about **35 gm in weight**.
- Spinal cord is divided into two by **dorsal septum** and **ventral fissure**.
- The arrangement of white matter and grey matter in spinal cord is **same as in medulla oblongata.**
- In spinal cord, **white matter** is found outside the **grey matter** (reverse in brain).
- Spinal cord **coordinate and control those reflex responses which occur without brain**.
- Spinal cord is **present in neural canal of vertebrates**.
- Spinal cord in rabbit **extends upto 4th lumbar vertebra.**
- **Filum terminale** is the terminal non-nervous part (made of only piamater) of spinal cord.
- **Cauda equina** (horse-tail) is the tail-like collection of roots of spinal nerves at the posterior end of spinal cord.
- The cavity of spinal cord is known as **central canal** or **neurocoel** which is **lined with ciliated ependymal epithelium.**
- Grey matter surrounding central canal is **H-shaped** or **butterfly-shaped.**
- Spinal cord **conduct impulses** to and from the brain and **controls most of the reflex activities and provides a means of communication between spinal nerves and the brain**.

Peripheral nervous system

- All nerves connecting the central nervous system with receptors and effectors (muscles and glands) constitute the **peripheral nervous system** (PNS).

- **Cranial nerves** and **spinal nerves** are the **main constituents of PNS**.
- **12 pairs** of cranial nerves are present in amniotes and **10 pairs** in anamniotes.
- Twelve pair of cranial nerves are – (I) **olfactory**, (II) **optic**, (III) **oculomotor**, (IV) **trochlear**, (V) **trigeminal**, (VI) **abducens**, (VII) **facial**, (VIII) **auditory**, (IX) **glossopharyngeal**, (X) **vagus**, (XI) **spinal accessory** and (XII) **hypoglossal**.
- There are **3 pair** of sensory, **5 pair** of motor and **4 pair** of mixed cranial nerves.
- **Spinal accessory** and **hypoglossal** are the two nerves **present in man but absent in frog**.
- **Trochlear** is the **smallest cranial nerve** and the **only nerve that exists the posterior side of the brain stem**.
- The **largest cranial nerve** is **trigeminal** (mandibular branch).
- **Vagus** is the **longest cranial nerve**. It has maximum branches and also called **wandering nerve**.
- Vagus **supplies the regions other than head.**
- **Spinal nerve** is a **mixed nerve**.
- When the motor and sensory fibres exit the spinal column through the intervertebral foramina and pass through the meninges, they join together to form the spinal nerves.
- **31 pair of spinal** nerves are present in human.
- There are **8 cervical** (C1-C8), **12 thoracics** (T1-T12), **5 lumbar** (L1-L5), **5 sacral** (S1-S5), and **1 coccygeal nerve**.
- The spinal nerves provide innervation to body areas below the neck while cranial nerves (also second order neurons) carry impulses only to the head and neck, except for the vagus.
- The **spinal formula** of spinal nerve in man is $\mathbf{C_8Th_{12}L_5S_5Co_1}$.

Autonomic nervous system

- **Autonomic nervous system (ANS)** is a system of peripheral nerves and ganglion which innervates various organs & glands to stimulate, accelerate, slow down or inhibit their function without directly consulting the will.
- The ANS has **three main components** –
  – **Pre-ganglionic nerve fibres**. These are motor nerve fibres, which emerge from CNS and pass to autonomic ganglia.
  – **Autonomic ganglia**. These are swollen bulbous structures containing the cell bodies of many neurons.
  – **Post-ganglionic nerve fibres**. These are axons of neurons emerging from the autonomic ganglia and supply smooth muscles and glands.
- Autonomous nervous system is **regulated by centres in brain like - cerebral cortex**, **hypothalamus** and **medulla oblongata**.
- ANS is concerned with **heart rate, breathing rate, blood pressure, body temperature** and other visceral activities that work together to maintain homeostasis.
- Autonomic nervous system was explained and coined by **Langley (1921)**.
- ANS, also called **visceral efferent nervous system**, is made of two opposing divisions– **sympathetic** and **parasympathetic**.
- **Sympathetic nervous system** is also called **thoracico-lumbar outflow**.
- Sympathetic nervous system is represented by a chain of 21 sympathetic ganglia on either side of spinal cord. It receives preganglionic sympathetic fibres from the spinal cord which make their exit alongwith thoracic and lumbar nerves.
- It is **active** in stress condition, pain, fear and anger.
- The post-ganglionic sympathetic fibres are **mostly adrenergic** *i.e.*, they release neurotransmitter **noradrenaline** at their terminations. However, pre-ganglionic sympathetic fibres are **cholinergic** *i.e.,* liberate **acetylcholine** at their endings.
- Action of sympathetic system results in **accelerated heart rate, increased blood pressure** and blood flow away from the periphery and digestive system toward the brain, heart and skeletal muscles. It also causes adrenaline to be released, temporarily increasing physical strength.
- The sympathetic nervous system is an **involuntary system** often associated with the flight or fight response.
- **Parasympathetic nervous system** consists of preganglionic para-sympathetic fibres, para-sympathetic ganglia and postganglionic parasympathetic fibres.
- Preganglionic parasympathetic fibres make their exit along with the 3rd, 7th, 9th and 10th cranial nerves, and 2nd, 3rd, 4th sacral nerves.
- Parasympathetic ANS is also called **cranio- sacral**

outflow.

- The parasympathetic system brings the body **back to a state of equilibrium**. It slows heart rate and decreases the release of hormones into the blood stream.
- Parasympathetic provides **relaxation, comfort, pleasure at the time of rest**. It helps in the **restoration and conservation of energy**.
- Preganglionic nerve fibre of sympathetic ANS is **small sized** whereas that of parasympathetic ANS is **larger**.
- Postganglionic nerve fibres of sympathetic ANS involve **expenditure of energy** but postganglionic never fibre of parasympathetic ANS involve **conservation of energy**.
- Action of sympathetic and para sympathetic ANS is **antagonistic** to each other but **neither exclusively excitatory nor inhibitory**.
- Sympathetic nerves stimulate the adrenal glands to secrete **adrenaline**.
- Both of the pre and post-ganglionic parasympathetic fibres are cholinergic *i.e.*, they release **acetylcholine** at their endings for the transmission of nerve impulses.

Nerve impulse

- **Nerve impulse** is a wave of bioelectric disturbance that passes along a neuron during conduction of an excitation.
- The **mineral necessary for nervous conduction is sodium** and **potassium**.
- **Nature of nerve impulse** or conduction of nerve impulse is an **electro-chemical process**.
- Impulse conduction **depends upon permeability of axon membrane (axolemma)** and **osmotic equilibrium** and **electrical equivalence between the axoplasm and extracellular fluid (ECF)** present outside the axon.
- Nerve impulse is **marked by the flow of ions across the membrane of the axon** caused by changes in the permeability of the membrane, **producing a reduction in potential difference that can be directed as the action potential**.
- The electrochemical potential developed during depolarisation is called **action potential/reverse potential/reverse polarisation**. Its value is **20 – 30mV(+)**, occasionally **+ 60mV**.
- During the conduction of nerve impulse along the nerve fibres (called transmission of impulse), the action potential is the result of **movement of Na^+ from extracellular fluid to intracellular fluid**.
- Change in potential due to stimulation of nerve fibre is called **nerve potential**.
- The **strength of the impulse** produced in any nerve fibre is **constant**.
- In **resting state** the **neuron membrane is polarised with outer surface + vely charged and inner surface – vely charged**.
- The **resting membrane potential** is about **–40 mV to –90 mV** with an **average of –70 mV** (1 mV or milli volt = 1/1000 volt).
- The **threshold stimulus** for opening of Na^+ channels is generally **–55 to –60 mV** (about 10 mV less than resting potential).
- **Threshold** or **firing level** is the minimum strength to initiate action potential.
- The time for restoration of nerve fibres is called **refractory period**. It is about **0.001 sec**.
- **Transmission of nerve impulse occurs in three** stages – **polarised state**, **depolarised stage** and **repolarised stage**.
- Resting condition of the nerve is called **polarized nerve**.
- At **polarized nerve** Na^+ is 10-12 times more outside than inside of a nerve.
- In **depolarized** nerve Na^+ enters inside and thus +ve charge is formed inside and -ve outside.
- After conduction of impulse resetting of membrane potential takes place and charges arrange as in polarised nerve. It is called **repolarised nerve**.
- Movement of Na^+ from inner side to outer side is called **sodium pump** and that of potassium from outer to inner side is called **potassium pump**.
- Speed of nerve impulse in **more** (about 20 times faster) **in myelinated nerve than in unmyelinated fibre**.
- In myelinated nerve fibres the exchange of ions take place only at the **node of Ranvier**. This jumping conduction of action potential from node to node is called **saltatory conduction**.

  Saltatory conduction occurs because the voltage gated sodium ion channels are found only at the nodes of Ranvier and between the nodes the myelin sheath acts as a good electrical insulation. It leads to conduction speed upto 120 m/s and is responsible for the high speed impulse transmission.

- **Saltatory propagation** increases the speed of nerve impulse.
- **Velocity of nerve impulse** depends on myelination as well as diameter of the fibre. It is **slower in thinner fibre than in thicker fibre**.
- Nerve terminates in **3 different ways** – on the receptor; on the next neuron and make synapse and on the surface of muscles and make motor end plate.
- A **synapse** is in the close proximity of end knob of one neuron and dendron or cell body of next neuron.
- Term synapse was coined by **Sir Charles Sherrington**.
- Nerve impulse through synapse is **unidirectional**.
- The process of chemical transmission across synapse was discovered by **Henry Dale (1963)**.
- The chemical causing the transmission of the nerve impulse across synapse/ end plate is **acetylcholine**.
- Synapse comprises of a **synaptic cleft** between the end of one nerve fibre and the beginning of the next. The presynaptic neuron forms terminal swellings called **synaptic knobs**, on the post synaptic neuron.
- The synaptic knob **contains numerous synaptic vesicles**, which contain the neurotransmitter acetylcholine.
- Acetylcholine is **formed in the cell body** with the help of a special enzyme, choline acetylase and then transported down the axon to the pre-synaptic terminals.
- The **arrival of an impulse at the synaptic knob causes acetylcholine to be discharged** into the synaptic cleft.
- **Accumulation of acetylcholine** in the synaptic cleft **reduces the polarization of dendrites, or cell body of the next neuron**. If depolarization is sufficient the threshold of the next neurons will be reached and a nerve impulse generated in it.
- With each passing nerve impulse, the concentration of acetylcholine becomes highly concentrated in the synaptic cleft and diffuses in all directions.
- An enzyme, acetylcholinesterase is present to break down the acetylcholine (to choline and acetate), preventing continued depolarization of the next fibre or the inordinate (exceeding normal limits) spreading of the nerve impulse to other nerve fibres.
- In a synapse **the propagation is strictly one way proceeding from axon of one neuron to the soma, or dendron of another neuron**.

  Since dendrites do not release any chemical neurotansmitter so, any nerve impulse passing along a single neuron from axon to dendrites would fade out as the synapse. Hence the **synapse acts as a valve permitting only one way traffic of nerve impulse**.
- **Neuromuscular junction** is a **specialised form of synapse** which is **found between a motor neuron and skeletal muscle fibre**. Each muscle fibre has a specialised region called **motor end plate** which contains vesicles and mitochondria. When the motor impulse from the nerve is received on the motor end plates, a local depolarization occurs thereby resulting in the excitation of the muscle fibre. They **always use the neurotransmitter acetylcholine and are always excitatory**.
- Neurotransmitter may be **excitatory** (depolarizing post-synaptic membrane) or **inhibitory** (hyperpolarizing post-synaptic membrane).
- **Examples of excitatory neurotransmitter** are - acetylcholine, norepinephrine, serotonin, dopamine, histamine, glutamate and 5 hydroxytryptamine etc.
- **Examples of inhibitory neurotransmitter** are glycine and GABA (Gamma amino butyric acid).
- **Neuromodulators** are additional neurotransmitters, that are released and **modify the transmission of an impulse at a synapse, either prolonging or inhibiting it and are responsible for mood and emotion in the brain**.

  Addictive drugs, such as cocaine, often act as neuromodulators. The brain adjusts its synapses to accommodate such drugs, and the result is physiological dependence, or addiction.
- Neurotransmitter is a chemical that transmits information across the junction (synapse) that separates one nerve cell (neuron) from another nerve cell or a muscle.
- Neurotransmitters are **stored in the nerve cell's bulbous end (axon)**.
- Neurotransmitters transmit information within the brain and from the brain to all the parts of the body. **Acetylcholine**, for example, sends messages to the skeletal muscles, sweat glands, and heart; serotonin

release underlies the process of learning and consciousness.

- Abnormalities in the production or functioning of certain neurotransmitters have been implicated in a number of diseases including **Parkinson's disease, amyotrophic lateral sclerosis, and clinical depression**.
- **Synaptic fatigue** is due to exhaustion of neurotransmitter.
- **Cybernetics** deals with neural and chemical integration of the body.

Reflex action

- **Reflex action** (**Marshal Hall**, 1833) is the spontaneous, automatic mechanical response produced by stimulating specific receptors.
- A reflex action or reflex is a biological control system linking stimulus to response and mediated by a reflex arc. Reflexes can be built-in or learned.
- **Reflex arc** is the arrangement of neurons in the pathway that always pass through central nervous system.
- Reflex arc is formed by **receptor - spinal cord-effector** (muscle or gland).
- Reflex arc may be **monosynaptic** (sensory and motor neurons) or **polysynaptic** (sensory, association or internuncial or interneurons and motor neurons).
- **Reflex action** is of **two types**: **conditioned (acquired)** and **unconditioned (simple)** reflex action.
- **Unconditioned or inborn reflexes** can be evoked even immediately after birth and do not need previous experience, e.g breast feeding, constriction of eye pupil of a new born in bright light.
- **Conditioned/acquired reflexes** are those reflex actions that are **not present at birth but develop later in life through learning, habit, experience or regular association of an indifferent stimulus (without any effect) with unconditioned stimulus**.
- Conditioned reflexes are **liable to change, disappear or reappear**. They reduce burden on brain, e.g., pedalling, driving a vehicle, playing musical instrument, writing, reading, daily chores, knitting without looking, salivation at sight or smell of food.
- **Conditioned reflex** was **first demonstrated by I.P. Pavlov**.
- Pavlov (1906) found that a dog salivated at the sight of food. He would sound a gong every time the dog was given food. After some days, the dog would salivate on hearing the bell even without food.
- **Examples of simple reflex** are –
  - **Knee jerk** (stress reflex) – tendon of patella tapped.
  - **Corneal reflex** (Blinking reflex) – closing of eyelids.
  - Rapid withdrawal of hand while burned or pricked.
  - Quick recovery of balance while falling.
  - **Scratch reflex** of frog – in pithed frog with acetic acid.
  - Coughing, sneezing and yawning –

Disorders of nervous system

- **Stroke** is a condition due to the lack of oxygen to the brain which may lead to reversible or irreversible damage. The damage to a group of nerve cells in the brain is often due to interrupted blood flow, caused by a blood clots or blood vessel bursting. Depending on the area of the brain that is damaged, a stroke can cause coma, paralysis, speech problems and dementia.
- **Hydrocephaly** is an increased quantity of cerebrospinal fluid (CSF) inside the brain that can result in increased pressure. Often the result of a disturbance (obstruction) in the normal CSF circulation or the over-production of CSF.
- **Meningitis** refers to infection or inflammation of meninges resulting in severe headache, vomiting and pain, and stiffness of the neck. Cause of meningitis is the infection of bacteria *viz. Streptococcus pneumoniae, Neisseria meningitidis* and *Haemophilus influenzae*.
- **Encephalitis** is the inflammation of the brain. Its symptoms include lethargy (fatigue), and drowsiness.
- **Epilepsy** happens when electrical activity in the brain is not normal.

End of the Chapter

Chapter 44

Sense Organs

- **Sense organs** is a part of the body of an animal that contains or consists of a concentration of receptors that are sensitive to specific stimuli.
- Stimuli include **pressure**, **temperature**, **chemical substances**, **vibrations**, **mechanical deformation** and **radiant energy**.
- Receptors **may act directly by opening ion channels in the cell membrane** that are part of the same receptor molecule **or indirectly by inactivating second messenger system** that go on to affect various processes in the cell.
- Stimulation of these receptors initiates the transmission of nervous impulses to the brain, where sensory information is analysed and interpreted.
- The sense of touch/pressure/pain is called **general sense** as its receptor cells lie scattered in the skin & various body parts.
- **On the basis of their location** receptors may be **interoceptors, proprioceptors, extero-receptors**.
- **Interoceptors** or **visceroceptors** receive internal stimuli like hunger, thirst etc.
- The interoceptors are simple and **mostly consists of free nerve endings**.
- **Proprioceptors** are **sensitive to changes** in tendons, muscles & joint movements. They **provide the information about the orientation of the body in space and the position of the limbs**.
- **Exteroreceptors** are somatic receptors located at or close to the body surface to receive external stimuli. Eg. cutaneous receptors & special sense organ.
- **According to type of stimuli** receptors may be **mechanoreceptors** (mechanical stimuli) **chemoreceptors** (sensitive to chemicals or their concentration); **photoreceptors** (sensitive to intensity & wavelength of light, image formation, *eg*., rods, cones & ommatidia); and **thermoreceptors** (sensitive to temperature).
- Thermoreceptors are of two types – **caloreceptors** (sensitive to heat, eg. Ruffini's organs) and **frigidoreceptors** (sensitive to cold, eg. end bulbs of krause).
- **Ampulla of Lorenzini** is a type of thermoreceptors **in scoliodon**.
- Chemoreceptors includes **taste** and **smell**.
- Skin receptors are broadly divisible into two types : free nerve endings & encapsulated nerve endings.
- **Functionally skin receptor** are of the following types– **algesireceptor** (pain); **tactile or tangoreceptors** (touch); **thermoreceptors** (temperature changes) and **vibroreceptors** (vibrations).
- **According** to their **shape & distribution**, types of tangoreceptors are –
  - **Merkels disc** [epidermis of hairless skin (glabrous)].
  - **Meissner's corpuscles** (dermis of skin of finger tip; lips & nipples, sensitive to touch & gentle pressure).
  - **Pacinian corpuscles** (present in subcutaneous tissue of palm, soles of fingers, etc. stimulated by pressure contact).
  - **Corpuscles of Mazzoni** (subcutaneous tissue of fingers, sensitive to heavy touch, pressure, joint, rotation).
  - **Free nerve endings** (present on skin, perceive the sensation of touch, pressure and pain).
  - **Hair and organ** (sensitive to touch & movement of objects).
- Tactile receptors in mammals are **maximum on the face**.
- **Rheoreceptors** detect water current like lateral line sense organ in fishes & amphibian tadpoles.
- **Nociceptors** are **sensitive to deep pain & damage to tissue**.

- **Phonoreceptors** are sensitive to sound, eg. organ of Corti.
- **Statoreceptors** are equilibrium receptors, eg. cristae & maculae.
- The **main human sense organs** are –
  – The **eye** which detects light and colour (different wavelengths of light)
  – The **ear** which detects sound (vibrations of the air) and gravity
  – The **nose** which detects some of the chemical molecules in the air
  – The **tongue** which detects some of the chemicals in food, giving a sense of taste.

ORGAN OF SIGHT - EYE

- Eyes are sense organ for **sight (vision)**.
- It is **spherical** in shape and is **located in the orbit-oblong socket of the skull**.
- Movement of eyeball in the eye orbit occurs with the help of **six eye muscles** (also called **extraocular muscles**) namely – superior oblique, inferior oblique, superior rectus, inferior rectus, external rectus and internal rectus.
- These 6 extraocular muscles are **governed by the cranial nerves III** (oculomotor), **IV** (trochlear) and **VI** (abducens).
- Eye movement disturbances can cause images to fail to focus on corresponding portions of the retina, thus resulting in double vision **(diplopia)**.
- **General structure of eye** are the **outer fibrous tunic**, the **middle vascular tunic** and the **inner nervous tunic**.
- **Fibrous coat** consists of sclera and cornea.
- Sclera and uvea are **mesodermal** and rest of the eye is **ectodermal**.
- The white of the eye is called **sclera** which **helps maintain the shape of the eye ball** and **also provides a means of attachment for the muscles that move the eye**.
- Sclera consists of tough white connective tissue.
- In the front of the eye the sclera becomes transparent forming the **cornea**.
- **Cornea** is **transparent because** the collagen fibres in this region are more regularly arranged and do not reflect light.
- Cornea is **non-vascular** (due to which its transplantation is successful) and **convex anteriorly**.
- The cornea admits light to the interior of the eye and bend the light rays and contributes to the formation of a clear image.
- Cornea **receives its nutrients from the tears and aqueous humour that fills the chamber behind it**. The cornea **admits light to the interior of the eye and bends the light rays so that they can be brought to a focus**.
- Cornea and rest of the sclerotic layer is covered by another very thin, vascularized (containing blood vessels) and transparent membrane called **conjunctiva**.
- Conjunctiva is composed of stratified epithelium and is **kept clean by the reflex blink mechanisms**.
- **Vascular coat** (commonly referred as **uveal tract**) is **deeply pigmented with melanin and reduces reflection of stray light within the eye**.
- The vascular tunic is **made up of the choroid** (the thin, dark, blood-vessel containing layer behind the retina), the **ciliary body** (that makes the fluid in the front chamber of the eye and helps to support the lens) and the **iris** (the tissue that makes up the pupil).
- Choroid layer **prevents reflection of light inside the eye**.
- The **choroid coat forms the iris** (a diaphragm) in the front of the eye. This, too, is **pigmented** and **is responsible for eye "colour"**.
- The **pupil** is the **opening (or black dot) in the centre of the iris that regulates the amount of light received by the retina**.
- The iris has **radial and circular muscles** which allow it to vary the opening to it called the **pupil**.
- Pupil becomes **smallest in bright light** and in **dim lighter it becomes larger**.
- The size of its (**iris**) opening, the **pupil**, is variable and under the control of the autonomic nervous system. **In dim light (or when danger threatens), the pupil opens wider** letting more light into the eye. **In bright light the pupil closes down**. **This not only reduces the amount of light entering the eye but also improves its image-forming ability.**
- **Atropin** is a chemical **used** by doctors **to dilate the pupil**.
- **Ciliary body** immediately behind the peripheral margin of the iris is **thicker and less vascular** than choroid. **Its inner surface is folded to form ciliary processes**.
- Present within the ciliary body are **ciliary muscles**

HUMAN EYE

Composed of three coats (walls)

- **Fibrous coat** (Tunica fibrosa)
  - Outer coat
  - Thick and tough layer made of dense **avascular connective tissue**
  - comprises of
    - **Sclera** – Posterior and opaque (5/6th part)
    - **Cornea** – Anterior and transparent (1/6th part)
- **Vascular coat** (Tunica vasculosa or **Uvea**)
  - Middle coat
  - **Highly vascularized and pigmented layer**
  - differentiated into three layers
    - **Choroid** (Uvea) – Lies in contact with sclera and remains just behind the retina forming the posterior 5/6th of the middle coat
    - **Ciliary body** – Immediately behind the peripheral margin of iris
    - **Iris** – Anterior part, lies behind the cornea.
- **Nervous coat** (Tunica interna) Innermost coat
  - consists of delicate, **non vascular light sensitive coat** called **retina**
  - Formed of 3 parts
    - **Optic** – Lines choroid, sensory and differentiated into two parts
      - **Pigmented part**
      - **Nervous part** – Transparent, made of 3 layers
        - Photosensitising layer of visual cells (Receptor cells)
          - **Rods** – Contain *rhodopsin* pigment, vision in dim light
          - **Cones** – Contain *iodopsin* pigment, responsible for colour vision hence colour appreciation comes only when the light is bright
        - Layer of bipolar nerve cells
        - Ganglion cells that form nerve fibres (called **optic nerves**)
    - **Ciliary** – Nonsensory, formed by simple layer of pigmented cells that lines ciliary body and iris respectively
    - **Irridial**

as circular sheet of smooth muscle fibres that **form bundles of circular and radial muscles which alter the shape of the lens during accomodation**.

- **Accomodation** is an **adjustment for distant and close vision** during which contraction of ciliary muscles releases tension in the suspensory ligaments and allows the lens to elastically recoil and bulge out on both of its sides. This **increases the convexity of the lens and increases the level of refraction of light passing through it**.
- The **lens** is a **soft**, **transparent**, **elastic** & **biconcave structure**, **attached by suspensory ligaments** to the ciliary body.
- The lens is **responsible for focussing light coming in through the pupil onto the retina in the back of the eye**.
- The cells that forms the lens contain a protein called **crystalin** which is almost transparent and allows light to pass through.
- The **ciliary muscles of the ciliary body** contract or relax which varies the shape of the lens so that light can be focused on the inner layer – the retina.
- The **lens and the sensory ligament divide** the interior of the **eyeball into two chambers** – **aqueous** and **vitreous chamber**.
- The aqueous chamber itself consists of two chamber– **anterior** and **posterior**.
- **Anterior chamber** is the **space between the iris and cornea**.
- **Posterior chamber** is the **space between lens and iris**.
- Both anterior chamber and posterior chamber are filled with a fluid called **aqueous humour**.
- **Aqueous humour** fills space **between the cornea and the lens**.
- In addition to supplying the cornea and lens with nutrients, the aqueous humour **helps to maintain the shape of the eye**.
- Aqueous humour is **produced and renewed every four hours by the ciliary body**.
- The large space between the lens and the retina is filled with a viscous matrix called **vitreous humor**.
- Aqueous humour a clear fluid produced by the ciliary body **maintains the shape of the cornea and supply nutrition to** both lens and cornea while vitreous humour (a gel-like substance that helps to maintain the round shape of the eye **maintains the shape of the eyeball and contribute to intraocular pressure and also to the focussing of light on the retina**.
- Aqueous and vitreous humors are **rich in vitamin C**.
- A narrow **hyaloid canal** passes through vitreous humor from centre of lens to blindspot (found in rabbit not in man).
- **Canal of Schlemm** drains aqueous humor and passes to blood.
- **Nervous coat** is the innermost ocular coat that **lines the eyeball ending at the margin of the pupil**.
- **Retina** is delicate, inner, non-vascular light sensitive coat of the eyeball.
- It is differentiated into **three parts** – **optic**, **ciliary** and **iridial**.
- Ciliary and iridial parts are **nonsensory** and formed of a single layer of pigmented cells that lines the ciliary body and iris respectively.
- The irregular margin of the pars optica lying internal to the junction of choroid and ciliary body is called **ora serrata retinae**.
- The retina **acts like the film in a camera and transmits electrical images through the optic nerves to the brain**.
- The **retina may be divided into ten layers**, from the outside they are - 1. pigment layer, 2. the photoreceptor layer of rods and cones, 3. external limiting membrane, 4. external nuclear layer (cell bodies of rods and cones), 5. external plexiform layer (synapses of the rods and cones), 6. internal nuclear layer (bipolar cells), 7. internal plexiform layer (synapses of the bipolar cells with the ganglion cells), 8. ganglion cell layer, 9. nerve fibre layer, 10. internal limiting membrane.
- The **retina contains the light receptors** - the **rods** and **cones** (and thus serves as the "film" of the eye).
- The retina also has many interneurons that process the signals arising in the rods and cones before passing them back to the brain.
- The **rods** contain a purple coloured photosensitive pigment **rhodopsin** (formed from vitamin A) and are sensitive even in dim light and dark. The **cones** have a violet coloured photosensitive pigment **iodopsin** and are sensitive to bright light and colour perception.
- The **three types of cones** are– red absorbing cones **(erythrolabe)** which absorb best at the relatively long wavelengths peaking at 565 nm; green absorbing cones **(chlorabe)** with a peak absorption at 535 nm and blue absorbing cones **(cyanolabe)** with a peak absorption at 440 nm.

- The nerve fibres in the retina converge and leave the eye ball to form the **optic nerve** to conduct nerve impulses from the eye ball to the brain.
- The spot at the back of the eye, from where optic nerve fibres leave is free from rods and cones. This **spot is devoid of the ability for vision** and is called the **blind spot**.
- **Macula lutea** or **yellow spot** or **area centralis** is in the exact **centre of the retina**.
- Cones are most densely concentrated in the central **fovea**, a small depression in the centre of macula lutea.
- The **fovea centralis** is the area of **sharpest vision** (or more distinct vision) because of high concentration of cones and they are smaller and more closely packed than elsewhere on the retina. **Ability for vision is highest in the fovea**.
- **Peripheral portion** of retina is **most suitable for detecting motion** *i.e* moving objects.
- Rods are absent in **fovea & macula**.
- **Photopic vision** is associated with cones.
- Light splits rhodopsin (visual purple) into a pigment **retinene (= retinol)**, an aldehyde derivative of vitamin A and a protein **scotopsin (opsin)**. The process of splitting is called **bleaching**. This depolarizes the rod cells to release a neurotransmitter, transmitting the nerve impulse to the bipolar cells, ganglion cells and then to the optic nerves.
- **Vitamin A** is an **important constituent of retinene** so **its deficiency causes deficiency of rhodopsin** inducing **night blindness**. Red green colour blindness is hereditary.
- **Path taken in the eye ball by light rays are** – conjunctiva → cornea → aqueous humour → lens (through pupil) → vitreous humour → retina.
- The retina **converts light energy into electrical signals and sends them to the brain** *via* **the optic nerve**. In the brain the electrical signals are translated into an image that is perceived in an upright position.
- The **eyelids** are extensions of the skin of the face, and they are designed to protect the eye. The outer surface of the eyelid is covered with skin and sometimes contains the cilia (eyelashes). The inside is lined with a pink-white coloured conjunctival membrane.
- The nictitans or **third eyelid** arises from the inside corner of the eye and contains a strong cartilage support and a tear gland. It is also designed as an extra protective mechanism for the eye.
- The **lacrimal system**, which includes the lacrimal (major tear) gland and the gland of the third eyelid, is **responsible for tear production and drainage of tears away from the eye**.
- **Harderian glands**, found in whale, mice, shrew etc., are located close to the inner angle of eye & secrete a lubricant for nictitating membrane.
- **Rabbit and man** do not possess harderian gland.
- **Pecten**, a comblike structure is found in eye of birds.
- **Grandy's corpuscles** is a special type of merkel's corpuscles present in skin of beak & tongue in birds.
- Binocular vision is found in **mammals & birds** (owl).
- Retina of **owl contains only rods** and **fowl contains only cones**.
- **Tapetum lucidum**, made up of crystalline layer with zinc, cystein & guanin, increases sensitivity of vision.

Disorders of eye

- **Myopia**, also called **short sightedness** is characterized by longer eye ball & focal point in front of retina.
- **Hypermetropia**, also called **long sightedness**, is characterized by short eye ball in anterior-posterior direction and focal point behind the retina.
- **Presbyopia** is inability to focus on nearby objects due to loss of elasticity of crystalline lens.
- **Cataract** is loss of transparency of the lens.
- **Trachoma** is a chronic contagious conjunctivitis caused by infection of a bacterium *Chlamydia trachomatis*.
- **Astigmatism** is a condition in which irregular lens or cornea produce a blurred image.
- Deficiency of any cone pigment result in **colourblindness**.
- **Protanopia** is red colour blindness.
- **Deuteronopia** is green colour blindness.
- **Tritanopia** is blue colour blindness.
- **Glaucoma** is a condition in which loss of vision occurs because of an abnormally high intraocular pressure in the eye may be due to blockage of canal Schlemm [a venous channel at the junction between the iris and the cornea (anterior chamber angle)]. It may cause blindness.
- Squint results in **diplopia or two images**. It occurs

due to **weakness in ocular muscle** or due to **defect in position of the two eyes**.

ORGAN OF HEARING - EARS

- Ears are **statoacoustic organs** meant for both balancing & hearing.
- Ear **contains** both **receptors that respond to movements of the head** and **receptors that convert sound waves into nerve impulses**. Impulses from both types of receptors are transmitted *via* the vestibulocochlear (VIII) cranial nerve to the brain for interpretation.
- The ear of a human adult consists of **three structural and functional divisions** : the **external ear, the middle ear**, and **the inner ear**.
- External ear consists of **pinna (auricle)**, **auditory canal** & **tympanic membrane**.
- **Pinna** is **non-functional (vestigial)** in human.
- It is an **immovable cartilaginous** structure that lead into the auditory canal.
- In case of mammals like cats, dogs & elephant, **pinna is movable**.
- Pinna, the outer visible part of the outer ear, is meant for **collecting sound waves**.
- The pinna consists of a cartilaginous framework of elastic connective tissue covered with skin. The **lower flexible lobe** (called **lobule**) **is the only part of the pinna which is not supported by cartilage**.
- The **external auditory meatus** is a S-shaped, short canal extending from the pinna to the ear drum (tympanic membrane or tympanum).
- Deeper within the meatus are **ceruminous glands** (wax-secreting glands), which keeps the tympanum soft and waterproof and together with the hairs prevent foreign objects from reaching the ear drum.
- **Tympanic membrane** (also **called ear drum**) is a thin, delicate membranous structure that **vibrates in response to the sound waves tapping on its outer surface**.
- Tympanum is composed of an outer concave layer of stratified squamous epithelium and an inner, convex layer of low columnar epithelium.
- It is **innervated by the auriculotemporal nerve** [a branch of the mandibular portion of the trigeminal (V) cranial nerve] and the auricular nerve (a branch of the vagus (X) cranial nerve].
- The **middle ear** is a narrow air filled cavity **(tympanic cavity)** located in the temporal bones of the skull. It is separated from the external auditory meatus of the outer ear by the tympanic membrane.
- Middle ear is connected to pharynx by an air filled tube called **eustachian canal**.
- The eustachian canal **maintains the balance in air pressure between two sides of the eardrum** thus allows it to vibrate freely when sound wave strike it.
- The pharyngeal opening of eustachian tube is closed by **tensor palati**.
- Middle ear consists of **three tiny bones** (called **ear ossicles**) that vibrate in response to the vibrations of the ear drum.
- **Three ear ossicles** are : hammer shaped **malleus**, anvil shaped **incus** and stirrup shaped **stapes**.
- **Stapes** bone and its muscle **'stapedius'** are the **smallest in the human body**.
- There are **two small skeletal muscles** - the **tensor tympani** which attaches to the malleus; and the **stapedius** which attaches to the stapes. They contract reflexly and very quickly to protect the ear against loud noises.
- The tensor tympani **pulls the malleus away from the tympanic membrane** while the stapedius **pulls the stapes away from the oval window** and changes its orientation 90 degrees.
- The auditory ossicles **transmit sound induced vibrations of the ear drum to the fluid called endolymph**, **filling the internal ear**.
- Tympanic cavity is connected with auditory capsule by **two apertures** – **oval window** (fenestra ovalis) and **round window** (fenestra rotundus).
- The **internal ear or inner ear** is called labyrinth consisting of two parts – **bony labyrinth**, **membranous labyrinth**.
- Bony labyrinth is filled with a fluid called **perilymph**.
- Membranous labyrinth contains a fluid called **endolymph**.
- Membranous labyrinth is divided into **three parts** – **vestibule, semicircular canal** & **cochlear duct**.
- **Vestibule** is a central sac having larger upper **utriculus** & a smaller lower **sacculus** sac containing granules of calcium carbonate called **otolith** (ear stones).
- Both utricle and saccule **contain receptors which are sensitive to gravity and linear movements of the head**.
- Utriculus and sacculus, connected by a small narrow **sacculo-utricular duct**, are often called **otolith organ**.

EAR — Consists of 3 major parts

- **Outer Ear** (external ear) — Consists of 3 parts
  - **Pinna**
    - Collect sound waves and funnels it through the ear canal to the ear drum
  - **Auditory canal**
    - (also called auditory meatus)
    - Between pinna and tympanic membrane.
  - **Tympanum**
    - (Ear drum)
    - Separates external auditory canal from middle ear.
    - Sound in the form of air waves causes the membrane to vibrate and these vibrations are transmitted to the attached auditory ossicles.
- **Middle ear** — Consists of 2 parts
  - **Tympanic cavity**
    - Consists ear drum and two openings called **fenestra ovalis** and **fenestra rotunda.**
  - **Auditory ossicles**
    - [*i.e.* three inter-connected bones called - hammer (*malleus*), anvil (*incus*) and stirrup (*stapes*)]
    - Cross the space of middle ear in series and connect the tympanic membrane to the oval window.
    - Help to convert sound waves to mechanical vibrations in tissue and fluid filled chambers.
- **Inner ear** (also called membranous labyrinth) — Consists of 3 parts
  - **Vestibule**
    - Composed of 2 chambers of utricle and saccule.
    - Contains **macula**, a special group of sensory cells.
    - Macula **functions as sensors of gravity** and **linear movement**.
  - **Semicircular canals**
    - Consist of cristae ampullaris as sensory regions in their dilated portion called ampulla.
    - These **function as sensors of angular movement**.
  - **Cochlea**
    - Consists of cochlear duct arising from sacculus.
    - Cochlear duct is middle compartment of cochlear canal.
    - Have three chambers - **scala vestibuli, scala media** (containing organ of corti for sound perception) and **scala tympani.**

- **Macula**, a group of sensory cells are found in both sacs.
- Macula **takes part in maintaining static equilibrium**.
- The **sense organ of the utricle** is called the **macula triculi** which is an oval thickened area in which fibres of the vestibular branch of the acoustic nerve terminate. It is covered with hair cells which respond to movement of the endolymph.
- The saccule has openings into the endolymphatic duct and the cochlear duct.
- The sense organ of saccule is the **macula sacculi**.
- **Crus commune** is the **dorsal part of utriculus**. Anterior and posterior semicircular canals arise from crus commune.
- **Semicircular canals** are three semicircular ducts borne over the utriculus at right angles to one another.
- Three semicircular canals are – **anterior vertical**, **posterior vertical** and **lateral horizontal**.
- The lower end of each semicircular canal has a swelling called **ampulla** containing a group of sensory hair cells called **cristae**.
- **Cristae**, covered by a mass of gelatinous material (**cupula**) **has longer sensory hairs** & **lacks otolith** (particle of calcium carbonate).
- Cristae **maintains dynamic equilibrium of the body**.
- There are two types of equilibria – **static equilibrium** and **dynamic equilibrium**.
- **Static equilibrium** refers to orientation of the body (mainly head) relative to gravity.
- **Dynamic equilibrium** is the maintenance of the body position in response to sudden movements.
- The **receptor organs for equilibrium** are the **sacculus**, **utriculus** and **semicircular canals**. All of these are known as **vestibular apparatus**.
- Vestibular apparatus is a type of **proprioceptor**.
- Utriculus and sacculus are considered to be sense organs of **static equilibrium**. The three semicircular canals maintain **dynamic equilibrium**.
- Semicircular canals **responds to rotatory movement of head**. The crista is stimulated by movement of endolymph. This movement causes distortion of hair cells and effect neural impulse from ampulla. The direction and rate of displacement of the cupula (which is bent in the opposite direction to head movement) are both detected by the receptor cells. Linear acceleration is detected by both the maculae and cupulae.
- The **utricle responds to vertical movements of the head and the otoconia** (regions of the walls of utricle and saccule, called maculae, contain receptor cells which have their hair like process embedded in a gelatinous mass that contain $CaCO_3$ granules, this mass is called an otoconium) **produce maximum stimulation when pulling the receptor hairs downwards when the body is upside down**.
- The saccule **responds to sideways movement of the head**.
- **Cochlea** (auditory region of internal ear) is a long coiled tubular and blind outgrowth of sacculus.
- Cochlea is **divided into 3 chambers** – **scala vestibuli**, **scala media** & **scala tympani**.
- **Scala media** is also known as **cochlear duct**.
- Scala media **contains endolymph** while the other two chambers contain **perilymph**.
- Two partitions in cochlea are dorsal vestibular membrane, also called **Reissner's membrane**, between scala media and scala vestibuli & ventral **basilar membrane** between scala media and scala vestibuli.
- **Helicotrema**, a small whole or narrow passage permits continuity between scala vestibuli & scala tympani.
- Scala media **has receptor organ for hearing** called **organ of corti** containing **receptor hair cells**, **Deiter's cell** & **cells of Hensen** etc.
- **Organ of Corti** (also called **spiral organ**) rests on the basilar membrane.
- **Tectorial membrane** is a thin, gelatinous ribbon-like sheet of connective tissue.
- Tectorial membrane overhangs the hair cells in close contact with tissue.
- The organ of Corti is stimulated by sound waves or nerve impulse of hearing starts from organ of Corti.
- Organ of Corti is **associated with hearing**.
- The perception of sound by a mammal involves the stimulation of mechanoreceptors located on organ of corti.
- The **measuring unit of sound** is **decibel**.
- Ear is most sensitive to frequency **1000-3000 cycles/sec**.

Disorders of ear

- **Labyrinth** is an infection or inflammation of the inner ear causing dizziness and loss of balance.

- **Meniere's disease** is an inner ear fluid balance disorder that causes episodes of vertigo, fluctuating hearing loss, tinnitus (a raging or roaring in the ears), and sensation of fullness in the ear.
- **Otitis media** is an infection or inflammation of the middle ear. This inflammation often begins when infections that cause sore throats, colds, or other respiratory or breathing problems spread to the middle ear.
- **Presbyacusis** is a hearing loss occurring with age. It occurs due to decreased blood supply to the inner ear possibly due to heart disease, high blood pressure or arteriosclerosis or hereditary factors.
- **Tinnitus** is a ringing sensation in the ears caused by irritative stimulation of either the inner ear or the vestibulocochlear nerve. In this the person hears when there is no real sound. It is usually accompanied by hearing loss.
- Ear is most sensitive to frequency **1000-3000 cycles/sec**.
- Inflammation of ear drum is called **myringitis**.
- **Deafness** means impairment of hearing. It can occur at any age.
- Deafness is **classified principally as being of two types** : conductive loss of hearing and sensorineural deafness.
- **Conductive loss** occurs when the ossicular chain (the bones in the middle ear – the hammer, anvil and stirrup) do not function properly. This type of loss can be surgically treated.
- **Sensorineural deafness** (or **nerve deafness**) occurs from damaged nerves in the inner ear and can generally be treated only by the use of a hearing aid (if there is residual hearing). Sensorineural deafness can result from long exposure to excessive noise levels, diseases such as whooping cough or measles, or the ageing process.

ORGAN OF SMELL–NOSE

- The nose may be called the sense organ for olfaction (smell).
- Receptors for smell occur in a modified form of pseudostratified epithelium covering a part of the nasal mucosa. It is called **olfactory epithelium**.
- The olfactory receptor cells function as **chemoreceptors**. They are **stimulated by specific chemical substances and produce impulse of smell**.
- Olfactory receptor cells are **bipolar neurons**.
- **Jacobson organ** is concerned with smell, present in the anterior part of nasal cavity. This organ is **well developed** in dogs and snakes & **less developed** in birds and mammals.
- Continuous smelling of an odour make the receptor cells immune to the odour and the receptor cells fail to respond to the sensation. It is called **olfactory adaptation**. This is the reason that a person cease to smell the perfume on his dress after sometime.

ORGAN OF TASTE–TONGUE

- **Taste buds** are the **organs for taste sensation** (gustatory receptors).
- They are present on the papillae of mucous membrane on the surface of tongue. The human tongue bears about 10,000 taste buds. Some taste buds occur in hard palate, pharynx and epiglottis also.
- Papillae containing taste buds are of **four types** - foliate, fungiform, filiform & circumvallate.
- **Foliate** is **absent in man**.
- **Filiform** does not contain taste buds and are located near centre & most of them on the upper surface of tongue. Hence nongustatory in function.
- **Foliate** is present on the posterior part of tongue, anterior to circumvallate papillae and found in rabbit & other mammals.
- **Circumvallate** (largest type) form an inverted V shaped row at the posterior **part of the tongue**.
- Types of taste buds corresponding to the taste are – **sweet**, **sour**, **bitter** & **salt**.
- **Sweet taste** are produced by various class of organic molecules including sugar, glycols & aldehydes.
- **Salt taste** is associated with anions of ionizable salt.
- **Sour taste** is produced by weak acid like the one present in unripened fruits etc.
- **Bitter taste** refers to the taste of alkaloids (little quinine, caffeine).
- Moth & butterflies have their chemoreceptors on **antennae**.
- A taste bud has **taste receptor cells** or **gustatory cells** which act as **chemoreceptors**.
- These cells bear sensory hair at free ends, which are connected to nerve fibres at other end. The taste bud communicates to the surface of the tongue by a narrow taste pore.
- The anterior part of the tongue is most sensitive to **sweet taste**, back to the bitter and sides to **salty** and **sour**. The taste of chillies is a sensation of burning pain of the pain receptors of the tongue.

End of the Chapter

Chapter 45

Endocrine System

- **Endocrine system** are those systems which generally control long term activities of target organs as well as physiological process such as digestion, metabolism, growth, development and reproduction in contrast to more rapid activities under the control of nervous system either directly or indirectly.
- The endocrine system carries out a wide variety of physiological processes through chemical messengers called "**hormones**."
- Endocrine system **comprise endocrine glands and their hormones**.
- **Gland** is an organ, tissue or cell that secretes a chemical for performing a particular function.
- **Types of glands** are - exocrine, endocrine and heterocrine.
- **Exocrine gland** is a gland whose secretions perform metabolic activity on the surface or into a particular region by means of ducts. Eg. sebaceous gland, salivary gland, liver etc.
- **Endocrine gland** is an isolated gland that pour their secretion directly into venous blood or lymph for passage to different organs in order to control their growth, function, metabolism etc.
- Endocrine gland is also called as **ductless gland**.
- **Heterocrine gland** (mixed gland) consists of both exocrine and endocrine region.
- **Endocrinology** is the study of endocrine glands, hormones and their effect.
- Father of endocrinology was **Thomas Addison**.
- The major glands that make up the human endocrine system are the pineal body, hypothalamus, pituitary, thyroid, parathyroids, adrenals and the reproductive glands (the ovaries and testes).
- The pancreas is also part of this hormone secreting system, even though it is also associated with the digestive system because the exocrine part of the pancreas also produces and secretes digestive enzymes into the intestine.
- Although the endocrine glands are the body's main hormone producers, some non-endocrine organs - such as the brain, heart, lungs, kidneys, liver, thymus, skin, and placenta - also produce and release hormone.
- **Hormones** are chemical regulators or chemical messenger of the body which are secreted in response to changes in the environment inside or outside the body.
- **Lag period** is a period between the secretion of hormone from endocrine gland and biological response from target organ.
- **First hormone** discovered in 1902 **by Bayliss and Starling** was **secretin**.
- Hormones may be **excitatory** or **inhibitory** in their effects.
- **On the basis of their chemical composition**, hormones may be **divided into three categories** – amine hormones, steroids and proteinaceous and peptide hormones.
- **Amine hormones** are derived from tyrosine amino acids and have amino group, eg. thyroxine, epinephrine and nor-epinephrine.
- **Steroids** are fat soluble and have sterol group. They are derived from cholesterol, eg. hormones of adrenal cortex, testis and ovaries.
- **Proteinaceous and peptide hormone** are water soluble and includes hormones of hypothalamus, pancreas and pituitary.
- Hormones can be divided into **lipophilic** (lipid soluble) and **hydrophilic** (water soluble).
- The **lipophilic hormones**, all of the steroid hormones and thyroxine as well as other lipophilic regulatory molecules (including the retinoids, or vitamin A) can easily enter cells. This is because

the lipid portion of the cell membranes does not present a barrier to the entry of lipophilic regulators.

- **Water soluble hormones** in contrast can not pass through cell membranes. They must regulate their target cells through different mechanisms.
- **Hormone action at the cellular level** begins with the association of the hormone and its specific receptor.
- Hormones can be **classified by the location of the receptor** and **by the nature of the signal or second messenger** used to mediate hormone action within the cell.
- **Hormone receptors are found** either exposed **on the surface of the cell** or **within the cell (cytoplasm)**, depending on the type of hormone.
- **Peptide hormones** usually **act at a specific receptor on the plasma membrane**. The signal is then communicated to the cytoplasm by one of the signal transduction pathways (e.g., *via* a receptor, G proteins, adenylyl cyclase, AMP, and kinase).
- **Steroids**, produced by endocrine glands of mesodermal origin, easily **pass through both the plasma and nuclear membranes**.
- Steroid bind with a specific Hormone Response Element (HRE) in the nucleus to activate DNA transcription.
- The thyroid hormone's mechanism of action resembles that of the steroid hormones.
- Hormone action is **usually short-lasting** because hormones are **catabolised by the liver**.
- Hormones which control activity of other endocrine glands and/or growth are called **trophic hormones**.
- When two hormones work together it is called **synergistic hormone**. Eg. FSH & LH.
- **Moulting hormone** (ecdysone) and **juvenile hormone** (corpora allata) are important in insect development.
- **Local hormones** (also called **tissue hormone**, **para hormone** or **paracrine**) are those hormone which do not pass into blood but diffuses to the target and work upon adjacent tissue.
- **Types of local hormones** are neurohormones, prostaglandin and pheromones.
- **Neurohormones** are secreted by nerve cells and released into tissue fluid at synapses by the synaptic vesicles of axon, eg. - acetylcholine and nor-epinephrine.
- **Prostaglandin** are fatty acid derivatives and secreted by many organs (kidney, gonads, seminal vesicle, thymus etc.) into their tissue fluid.
- Prostaglandin **controls either contraction/ relaxation of smooth muscles** or **dilation/ contraction of blood capillaries**.
- Prostaglandin were **first reported** in semen of man and produced by prostate gland.
- **Kinin or bradykinins** are polypeptides that causes contraction of smooth muscles and dilation of blood vessels.
- The gaseous hormone, **nitric oxide** (also an air pollutant) is also a local hormone.
- New researches demonstrated that the NO linked to haemoglobin allow **blood vessels to expand or contract**, depending on how much of the molecule is present. This principle is used in **'viagra' medicine**.
- **Pheromones** are the chemicals used for communication amongst individuals of the same species.
- Pheromones are also known as **ectohormones** or **sex attractants** or **sanio-chemicals**.
- Pheromones are **volatile** in nature and travel with air.
- It invoke a specific response in other members like **recognition**, **warning** and **attraction**.
- **Bombykol** is a sex attractant pheromone produced by female silkworm moth.
- A deer produces **seven different types of pheromones**, all from different sites and with different functions.

PINEAL GLAND

- The **pineal gland** (or **epiphysis**) is a stalked, small rounded organ. It is located on the midline, attached to the posterior end of the roof of the third ventricle in the brain.
- The pineal body is located above the superior colliculus and behind and beneath the stria medullaris, between the laterally positioned thalamic bodies.
- The pineal body is **part of the epithalamus**.
- The pineal gland consists mainly of **pinealocytes**, but four other cell types have been identified: interstitial cells, perivascular phagocyte, pineal neurons and peptidergic neuron-like cells.
- It **secretes two biogenic hormones** – **melatonin** and **serotonin**.

- The **pineal gland calcifies with age** and melatonin production correspondingly decreases. This decline in melatonin has been suggested to be a trigger for the ageing process.
- **Also called epiphysis cerebri**, the pineal gland is important because it is the centre for the production of the hormone melatonin and it contains magnetic material in birds and other animals. It is a **centre for navigation**.
- **Melatonin**, or 5-methoxy-N-acetyltryptamine, is a hormone produced by pinealocytes in the pineal gland, and a derivative of the amino acid tryptophan.
- The **production of melatonin** by the pineal gland is **stimulated by darkness** and **inhibited by light**.

There is a pathway from the retinas to the hypothalamus called the retinohypothalamic tract. It brings information about light and dark cycles to a region of the hypothalamus called the suprachiasmatic nucleus (SCN). From the SCN, nerve impulses travel *via* the pineal nerve (sympathetic nervous system) to the pineal gland. These impulses inhibit the production of melatonin. When these impulses stop (at night, when light no longer stimulates the hypothalamus), pineal inhibition ceases and melatonin is released. The **pineal gland is therefore a photosensitive organ and an important timekeeper for the human body**.

- To synthesize melatonin, serotonin is converted to N-acetylserotonin by the enzyme 5-HT N-acetyltransferase. N-acetylserotonin is then converted to melatonin by the enzyme 5-hydroxyindole-O-methyltransferase.
- **Melatonin has important effects** in integrating photoperiod and affecting circadian rhythms. Consequently, it has been reported to **have significant effects on reproduction, sleep-wake cycles and other phenomena showing circadian rhythm**.
- Melatonin **delays sexual development** and **inhibit ovarian functions,** hence referred as **antigonadotrophic hormone**.
- **Brain sands** (also called acervuli), found in pineal body, are particles of calcium salts ($CaCO_3$ & Ca_3PO_4).

Nobel Prize Laurate **Julius Axelrod** performed many of the seminal experiments elucidating the role of melatonin and the pineal gland in circadian rhythms.

HYPOTHALAMUS

- The **hypothalamus**, a region of the brain that controls an immense number of bodily functions, is located in the middle of the base of the brain, and encapsulates the ventral portion of the third ventricle.
- The hypothalamus is the **main link between the endocrine and nervous systems**.
- Nerve cells in the hypothalamus control the pituitary gland by producing chemicals that either stimulate or suppress hormone secretions from the pituitary.
- **Herring bodies** formed in hypothalamus store neurosecretory substance.
- The hypothalamus **regulates homeostasis**. It **has regulatory areas** for thirst, hunger, body temperature, water balance, and blood pressure.
- In addition to secreting neuromodulators, the hypothalamus synthesizes and secretes a number of neurohormones.
- These neurohormones are known as **releasing hormones** because the major function generally is to stimulate the secretion of hormones originating in the anterior pituitary gland.
- The **hypothalamo-pitiutary axis** is the unit formed by the hypothalamus and pituitary gland, which exerts control over many parts of the endocrine system.
- This unit functions by means of interaction of the nervous and endocrine system whereby the nervous regulates the endocrine system and endocrine activity modulates the activity of the CNS.
- Neurohormones were first discovered by **Guillemin** and **Schally** (Nobel Prize 1977).
- **Types of neurohormones** are – TRH or TSH-RH; GnRH; ACTH-RH or CRH; SRH or GH-RH; GIH; PRH or LTH-RH; PIH or LTH-RH; MSH-RH or MRH and MSH-IH or MIH.
- **Thyrotropin releasing horomone (TRH)** is the simplest of the hypothalamic neuropeptides.
- It is also called thyrotropin releasing factor (TRF), thyroliberin or protirelin.

The **sequence of TRH was first determined** and the hormone synthesized by **Roger Guillemin** and **Andrew V. Schally** in 1969.

- TRH is involved in the **control of body temperature** and that it has psychological and behavioural effects.
- The TRH-secreting cells are subject to stimulatory and inhibitory influences from higher centres in the brain and they also are inhibited by circulating thyroid hormone. In this way TRH **forms the topmost segment of the hypothalamic-pituitary-thyroid axis**.
- **GnRH (gonadotrophins releasing hormone)** stimulates the synthesis and release of the two pituitary gonadotrophins – **luteinizing hormone (LH)** and **follicle-stimulating hormone (FSH)**.
- There may be two distinct releasing hormones – **FSH-RH** and **LH-RH in female** and one **ICSH-RH in male**.
- Neurons that secrete GnRH have connections to an area of the brain known as the limbic system, which is heavily involved in the control of emotions and sexual activity.
- Some individuals have **hypogonadism** (in which the functional activity of the gonads is decreased and sexual development is inhibited) due to a **congenital deficiency of GnRH**.
- **Abnormalities in the GnRH secretion** result in subnormal fertility, abnormal or absent menstruation, and possibly cystic disease of the ovary or even ovarian cancer.
- **Adrenocorticotropin-releasing hormone (CRH) stimulates** not only **secretion of corticotropin or adrenocorticotropin (ACTH) hormone in the pituitary gland** but also the synthesis of corticotropin in the corticotropin-producing cells (corticotrophs) of the anterior lobe of the pituitary gland.
- CRH, also called **corticoliberin,** is a polypeptide hormone and neurotransmitter involved in the stress response.
- **Excessive secretion of CRH** leads to an increase in the size and number of corticotrophs in the pituitary gland, often **resulting in a pituitary tumor**. This, in turn, leads to excessive stimulation of the adrenal cortex, resulting in high circulating levels of adrenocortical hormones.
- Like CRH, **growth hormone-releasing hormone (GH-RH)** is a large peptide and stimulate anterior pituitary to produce and secrete growth hormone.
- GH-RH secretion is **stimulated by stresses**, including physical exercise, and **secretion is blocked by a powerful inhibitor** called **somatostatin**.
- GH releasing hormone (GH-RH) is also known as **somatotropin releasing hormone (SRH) or somatocrinin**.
- Negative feedback control of GH-RH secretion is mediated largely through compounds called **somatomedins**. Somatomedins is a growth-promoting hormone that are generated when tissues are exposed to growth hormone itself.
- **Growth inhibiting hormone (GIH) or somatostatin** inhibits adenohypophysis to secrete growth hormone.

Somatostatin is also secreted by delta cells of stomach, intestine, and pancreas. It binds to somatostatin receptors.

- Somatostatin is **also a powerful inhibitor of pituitary TSH secretion**.
- Somatostatin, like TRH, is **widely distributed** in **the central nervous system** and in other tissues. It **serves an important paracrine function** in the islets of Langerhans, by blocking the secretion of both insulin and glucagon from adjacent cells.
- Somatostatin has emerged **not only as a powerful blocker of the secretion of GH, insulin, glucagon**, and other hormones **but also as a potent inhibitor of many functions of the gastrointestinal tract**, including the secretion of stomach acid, the secretion of pancreatic enzymes, and the process of intestinal absorption.
- **Prolactin releasing hormone (PRL-RH)** stimulate anterior pituitary to secrete prolactin (PRL or LTH).
- **Prolactin inhibiting hormone (PRL-IH)**, also called **dopamine,** stops synthesis of LTH by anterior pituitary.
- **In brain**, dopamine **functions as a neurotransmitter,** activating dopamine receptors. Its (dopamine) chemical name is 4-(2-aminoethyl) benzene-1, 2-diol and it is abbreviated as DA.
- Dopamine can be supplied as a medication that acts on the sympathetic nervous system, producing effects such as increased heart rate and blood pressure.

- Deficits in dopamine levels are implicated as one of several possible causes for Adult attention-deficit disorder (AADD), and some types of medications used to treat Attention-deficit hperactivity disorder (ADHD/ADD) will help to stimulate dopaminergic systems, leading to potentially heightened sensation, for those afflicted by it and receiving treatment for it.
- **Melanocyte stimulating hormone (MSH-RH)** induces intermediate lobe of pituitary to secrete MSH.
- **Melanocyte stimulating hormone inhibiting hormone (MSH-IH)** stops synthesis of MSH.

PITUITARY GLAND

- **Pituitary** is the **smallest, pea shaped endocrine gland** which is connected to hypothalamus by an infundibular stalk formed of connective tissue with blood capillaries and nerves.
- It lies in the cavity called **sella turcica** of sphenoid bone of skull.
- It is also called as **hypophysis** or **hypothalamus cerebri**.
- Pituitary gland is **cranio-epithelial in origin**.
- Removal of pituitary is known as **hypophysectomy**.
- The pituitary gland is sometimes called the "**master" gland of the endocrine system**, because it controls the functions of the other endocrine glands.
- The pituitary gland itself consists of **three lobes**: the **anterior lobe**, the **intermediate lobe** and the **posterior lobe**.
- Each lobe of the pituitary gland produces certain hormones.
- Pituitary is a **composite gland** comprising anterior lobe (adenohypophysis) and posterior lobe (neurohypophysis) on the basis of anatomy and embryology.
- **Adenohypophysis** (makes 75% of total weight) develops as an outgrowth of pharynx called **Rathke's pouch**.
- The adenohypophysis **consists of three principal types of hormones secreting parenchymal cells** according to the pattern of staining : **acidophils** (which stains with acidic dyes), **basophils** (which stain with basic dyes), and **chromophobes** (which have only pale staining).
- **Acidophils** are subdivided into two classes – **lactotropes** (mammotropes) and **somatotropes**. Lactotropes produce prolactin and somatotropes produce GH.
- **Basophils** are subdivided into three classes – **corticotropes, thyrotropes,** and **gonadotropes**. Corticotropes produce ACTH and lipotropic hormones (LPH); thyrotropes produce TSH; and gonadotropes produce LH and FSH.
- **Chromophobes** probably are acidophile or basophile that have lost their specific staining properties after releasing their hormone-containing granules.
- Adenohypophysis is formed of three parts - **pars distalis** (largest), **pars tuberalis** (highly vascular region) and **pars intermedia** (also called intermediate lobe of pituitary gland).
- Pars distalis and pars tuberalis are collectively known as **anterior lobe of pituitary or adenohypophysis**.
- Hormones of anterior pituitary are called **trophic hormones or tropins**.
- Secretion of the trophic hormones is **controlled by neurohormones of hypothalamus** through a feedback mechanism which operates either at gene level or at enzyme level.
- **Hormones of adenohypophysis** are :
  - **GH** (growth hormone, somatotropin or somatotrophic hormone, STH)
  - **TSH** (thyroid stimulating hormone)
  - **ACTH** (adrenocorticotrophic hormone)
  - **GnTH** (gonadotrophic hormones)
  - **PRL or LTH** (prolactin or lactogenic or luteotrophic hormone).
- **GH** (or **STH**) is a proteinaceous hormone whose effects on the tissues of the body can generally be described as anabolic (building up).
- Growth hormone is **also called somatropin and somatotropin**. The **genes for human growth hormone are localized in the q22-24 region of chromosome 17** and are closely related to human chorionic somatomammotropin (hCS, also known as placental lactogen) genes.

GH, hCS, and PRL are a group of homologous hormones with growth-promoting and lactogenic activity.

- GH **stimulates** growth of body by synthesis and deposition of protein in tissue, increased glucose level in blood by decreased secretion of insulin, increased cell division and increased growth of bones by increased absorption of calcium from intestine.

- GH **promotes body growth** by:
  - binding to receptors on the surface of liver cells
  - this stimulates them to release insulin-like growth factor-1 (IGF-1; also known as somatomedin-C)
  - IGF-1 acts directly on the ends of the long bones promoting their growth
- In childhood, **hyposecretion of GH** produces the stunted growth of a **dwarf**. Dwarfism is characterised by retarded physical growth but normal alertness and intelligence.
- The dwarf are called **midgets**.
- **Simmond's disease** in a adult is a rare condition in which patient becomes thin and show sign of premature ageing. It is caused due to **hyposecretion of growth hormone**.
- **Hypersecretion of GH leads to gigantism** in **childhood** before the closure of epiphyseal plates at the end of bones and **in adults it leads to acromegaly**.
- **Gigantism** is characterised by extra ordinary growth in height (7-8 feet) caused by abnormal elongation of long bones. And **acromegaly** is characterised by abnormal growth of hand, feet, face, especially lower jaw. Appearence may be ape like.
- Gigantism is also called **pituitary giant**.
- Secretion of **thyroid stimulating hormone (TSH)** is **controlled by feedback mechanism from thyroid hormone**.
- TSH **consists of two subunits** – the **alpha** and the **beta subunit**. The α (alpha) subunit is identical to that of human chorionic gonadotrophin (hCG), luteinising hormone (LH), follicle-stimulating hormone (FSH). The β (beta) subunit is unique to TSH, and therefore determines its function.
- TSH **control structure and functioning of thyroid gland to synthesize** and **release of its hormones** thyroxine and triiodothyronine.
- TSH is a proteinaceous hormone, secreted by pars distalis.
- **Hyposecretion of TSH** leads to thyroid atrophy while **hyperactivity** produces symptoms similar to Grave's disease.

Table : Effects of TSH deficiency

Metabolic	Body weight increases Oxygen consumption decreases Heat production decreases Basal metabolic rate decreases
CNS	Impaired mentally Poor memory and concentration Drowsiness
Motor nervous system	Activity decreases
Sympathetic nervous system	Activity decreases
Cardiovascular	Bradycardia Reduced output and blood pressure
Gl tract	Activity decreased Constipation

- **ACTH** is a peptide hormone which **controls the structure and functioning of adrenal cortex especially secretion of glucocorticoids and sex corticoids**.
- **Hypersecretion of ACTH** leads to **rheumatoid arthritis** while **hyposecretion** leads to **excessive growth of adrenal cortex**.
- **Gonadotrophins** or **gonadotrophic hormone (GTH)** regulates the growth and function of gonads.
- The two main gonadotrophins are – **FSH** and **LH/ICSH**.
- **FSH** or follicle stimulating hormone are also called **gametokinetic factor**.
- FSH is a **proteinaceous hormone** which **stimulates spermatogenesis and growth of seminiferous tubules in testes**; **maturation of Graafian follicle** and **secretion of estrogen** (by the cells of ovarian follicle) and **progesterone** (from the corpus luteum).
- **LH (luteinizing hormone)** is known as **gamete releasing factor**.
- In **sexually-matured females**, LH
  - **Stimulates the follicle to secrete estrogen** in the first half of the menstrual cycle
  - Surge **triggers the completion of meiosis I** of the egg and its release (process called ovulation) in the middle of the cycle

- Stimulates the now-empty follicle to develop into the **corpus luteum**,which secretes progesterone during the latter half of the menstrual cycle.

- **In males** LH **acts on the interstitial cells of the testes** stimulating them to synthesize and secrete the male sex hormone, testosterone and other androgens for the development of secondary sex organs and secondary sexual characters.
- LH in males is also known as **interstitial cell stimulating hormone (ICSH).**
- **Hyposecretion of ICSH** results in impaired development of external genitalia and **LH** results in sterility in females.
- **PRL (prolactin)** acts to **initiate and maintain milk secretion by the mammary glands**, hence it is also known as **hormone of maternity**.
- PRL **works with other hormones such as oxytocin**, which actually causes milk ejection, and **oestradiol, progesterone, glucocorticoids, GH, thyroxine and insulin**, which prepare the mammary gland for milk production.
- The hormone prolactin is **downregulated by dopamine** and is **upregulated by estrogen**.
- PRL **secretion is under inhibitory control of dopamine**. This means that if the link between the hypothalamus and pituitary is severed PRL secretion increases, unlike all other pituitary hormones, where production would decrease without stimulatory control of the hypothalamus.
- TSH has a **stimulatory affect on PRL secretion**. Oestradiol **increases** PRL production and **levels of PRL rise during pregnancy** and **remain high during lactation**.

During pregnancy, prolactin levels rise as rising estrogen promotes prolactin release, causing further maturing of mammary glands, preparing them for lactation. After childbirth, prolactin levels fall as the internal stimulus for them is removed. Sucking by the baby on the nipple promotes further prolactin release, maintaining the ability to lactate.

- **Hyperprolactinaemia** is a **common cause of menstrual problems** in women, and high levels of prolactin can cause gynaecomastia (breast enlargement) in men. It can also cause inappropriate galactorrhoea (milk production) in males and females.
- Usually, in the absence of galactorrhea, lactation will cease within one or two weeks of the end of demand breastfeeding.
- **High prolactin levels** also tend to **suppress the ovulatory cycle by inhibiting both FSH and GnRH**.
- Prolactin is **also called luteotrophic hormone** (LTH) because it also stimulates the corpus luteum of the ovary to secrete progesterone hormone.

Sometimes, newborn babies (males as well as females) secrete a milky substance from their nipples. This substance is commonly known as **Witch's milk**. This is caused by the foetus being affected by prolactin circulating in the mother just before birth, and usually stops soon after birth.

- **MSH** (also called **intermedin**), a polypeptide hormone is produced by pars intermedia so called intermediate lobe of pituitary.
- It stimulates **synthesis and dispersal of melanin** pigment present in skin of fish, amphibia and some reptiles.
- It is **non-functional in man**.
- **Neurohypophysis** develops as a downgrowth of hypothalamus.
- The neurohypophysis has three main components – **pars nervosa** (infundibular process), **media eminence** and **infundibular stalk**.
- **Pars nervosa,** also called the posterior lobe, does not actually produce hormones, but stores and secretes hormones made by the hypothalamus. Therefore posterior lobe is also called **storage organ**.
- **Pituicyte cells** formed in neurohypophysis, secrete two octapeptide hormones – **vasopressin** and **oxytocin** from supraoptic and paraventricular nuclei respectively.
- Vasopressin is also called **antidiuretic hormone (ADH) or pitressin** or **arginine vasopressin (AVP)**.
- **Antidiuretic hormone (ADH)** is a peptide hormone and **acts on the kidneys**, concentrating the urine by promoting the reabsorption of water and salt into the cortical collecting duct.
- ADH is **activated by "water receptors"** in both the extracellular fluid volume and the intracellular fluid volume.
- In the extracellular fluid the activators are mainly

baroreceptors in the veins, atria, and arterioles. In the intracellular fluid the activators are mainly osmoreceptors in the hypothalamus.

- **Ethanol and caffeine block the release of ADH** from the posterior pituitary gland. This decrease in water reabsorption **leads to a higher volume of urine output**.
- **ADH is under negative feedback control**. A fall in blood volume stimulates release of ADH. Also, a fall in the arterial partial pressure of oxygen and a rise in partial pressure of carbon dioxide stimulate ADH release.
- Secretion of ADH is **also affected by the angiotensin II, adrenaline, cortisol and sex steroids**. At the level of the hypothalamus, pain, trauma, nausea and vomiting, and a rise in external temperature increase AVP secretion, and psychological and emotional stimuli also affect its release.
- **Overproduction of ADH** can occur due to brain trauma. It leads to water retention, serum hypo-osmolality, hyponatraemia and high urine osmolality.These effects cause symptoms of headache, apathy, nausea and vomiting, impaired conciousness and can be fatal in extreme cases.
- **Underproduction of ADH** results in the condition of **diabetes insipidus**. Clinical signs are excretion of large volumes of urine (diuresis, 10 litre urine/day) leading to dehydration and thirst (polydipsia), as well as increased plasma osmolality.
- **Oxytocin** secretion occurs in response to nervous stimulation of the hypothalamus.
- Oxytocin **causes** contraction of the smooth muscle of the uterus (hence called **birth hormone**) and also of the myoepithelial cells lining the duct of the mammary gland (hence called **milk ejection hormone**).

Synthetic oxytocin is also called as **pitocin and syntocinon**. Oxytocin is destroyed in the gastrointestinal tract, and therefore must be administered by injection or as nasal spray. Oxytocin has a half-life of typically about three minutes in the blood. Oxytocin given intravenously does not enter the brain in significant quantities - it is excluded from the brain by the blood-brain barrier. Drugs administered by nasal spray are thought to have better access to the CNS. An oxytocin nasal spray has been used to stimulate breastfeeding.

- **Release of oxytocin is under positive feedback control**. Stimulation of mechanoreceptors in the uterus and vagina during parturition cause a rise in oxytocin levels up to a maximum until the stimulus is no longer present and the action of the hormone is no longer needed.
- **Negative feedback** is an important factor in controlling the hypothalamic pituitary-target organ axis function. Once hypothalamic hormones stimulates the release or inhibition of the pituitary hormone, this may then act as a target gland, such as the thyroid, causing release of further hormones of causing metabolic effects.
- The action of hypothalamic hormones may be inhibited by **long feedback loops** from the target gland hormone or **by short feedback loops** from the pituitary hormone. There may also be direct feedback from the target gland hormone to the pituitary gland.
- Positive feedback also plays a part in certain systems. For example, in the situation where high levels of oestradiol in the blood cause a surge in LH levels during the menstrual cycle.

THYROID GLAND

- The **thyroid gland** is located in the front of the neck, below the larynx (voice box).
- The small, two-inch thyroid gland **consists of two lobes**, one on each side of the windpipe, **connected by tissue** called the **isthmus**.
- The thyroid tissue is made up of two types of cells: **follicular cells** and **parafollicular cells (G-cells).**
- **G-cells or parafollicular cells** are group of endocrine cells scattered in connective tissue and between the thyroid follicles.
- Thyroid follicles contains **thyroglobulin.**
- **Thyroglobulin**, a glycoprotein in colloidal suspension, is a stored formed of thyroxine and an exocrine secretion product of follicular epithelial cells.
- **Follicular cells**, secrete iodine-containing hormones called **thyroxine or tetraiodothyronin (T_4)** and **triiodothyronine (T_3)**.
- Thyroglobulin contains multiple copies of one amino acid **tyrosine**.
- The level of thyroglobulin present in the body can be measured with blood tests.

Table : Physiological effects of thyroid hormones.

Target tissue	Effect	Mechanism
Heart	Chronotropic	Increase number and affinity of β-adrenergic receptors.
	Inotropic	Enhance responses to circulating catecholamines. Increase proportion of α myosin heavy chain (with higher ATPase activity).
Adipose tissue	Catabolic	Stimulate lipolysis
Muscle	Catabolic	Increase protein breakdown.
Bone	Developmental	Promote normal growth and skeletal development.
Nervous system	Developmental	Promote normal brain development.
Gut	Metabolic	Increase rate of carbohydrate absorption.
Lipoprotein	Metabolic	Stimulate formation of LDL receptors.
Other	Calorigenic	Stimulate oxygen consumption by metabolically active tissues (exceptions : testes, uterus, lymph nodes, spleen, anterior pituitary). Increase metabolic rate.

- Thyroglobulin **serves a useful readout for the presence or absence of thyroid cells**, particularly in patients with thyroid cancer where it serves as a "tumor marker".
- The thyroid **needs iodine** to produce the hormones.
- The thyroid plays an **important role in regulating the body's metabolism and calcium balance**.
- The **T_4 and T_3 hormones** stimulate every tissue in the body to produce proteins and increase the amount of oxygen used by cells.
- **T_3 is 3 - 4 times more potent** than T_4.
- T_4 and T_3 are **deiodinated** in the liver, kidneys and many other tissue.
- The level of T_4 circulating in the blood controls its release from the thyroid gland **by negative feedback mechanism involving the hypothalamus and anterior pituitary.**
- **If excess T_4 is present in the blood** it switches off its own production by **switching off production of TRH** (thyrotropin releasing hormone) by the hypothalamus and **TSH** (thyroid stimulating hormone) by the anterior pituitary.
- Thyroxine **control BMR** (basal metabolic rate) of the body.
- The BMR of a normal adult man is **40 cal/m^2** and **37.5 cal/m^2** in woman.
- Apart from carrying out metabolic and regulatory function, thyroxine **also controls some developmental process** like metamorphosis. Eg. amphibia & teleost fish.
- It **controls urine output**, **maintains nervous and muscular tonus**, **increase the oxidation of glucose** in tissue and **also acts on SA node & maintains the normal heart beat** and also **reduce the formation of ketone bodies** etc.
- In its (thyroxine) absence or presence of thiourea (antithyroid substance), **tadpoles remains in larva stage indefinitely**. They stimulate tissue differentiation, therefore they affect metamorphosis of a tadpole into an adult frog.
- **Hypothyroidism** results in **cretinism**, **myxoedema**, **endemic or simple goitre or colloid goitre** and **Hashimoto's disease**.
- **Hypothyroidism** is the condition in which the thyroid is underactive (*i.e.*, it is producing an insufficient amount of thyroid hormones).
- Hypothyroidism is the **most common thyroid disorder.**
- The **most common cause of hypothyroidism** is an autoimmune reaction, where the body produces antibodies against the thyroid gland.
- Severe hypothyroidism can lead to a condition called **myxoedema.**
- Myxoedema is also called **Gull's disease** developing in adult life, **most commonly in middle-aged women**.
- Myxoedema is **characterized** by **puffy appearance**

due to subcutaneous accumulation of fat, low BMR, low heart rate and body temperature, retarded sexuality.

- **Cretinism** is a **condition produced in infants and children** due to lack of thyroid hormone.
- Children who are hypothyroid from birth or before are called **cretins.**
- Cretinism **usually results** from a congenital defect. However, it can develop later if there is a lack of iodine in the diet, or if the thyroid is diseased or surgically removed.
- The **main cause of congenital hypothyroidism** are - maternal iodine deficiency, inborn errors of thyroid hormone synthesis, maternal antithyroid antibodies that cross the placenta etc.
- Cretinism **causes** very serious retardation of physical and mental development; if the condition is left untreated, growth is stunted and the physical stature attained is that of a dwarf. In addition, the skin is thick, flabby, and waxy in colour, the nose is flattened, the abdomen protrudes, and there is a general slowness of movement and speech.
- If the condition commences after adulthood is reached it is called myxoedema (*described earlier*).
- **Goitre** is a non-specific term describing enlargement of the thyroid gland.
- **Symptoms of goitre** are feeling of pressure; increased neck size; a feeling of narrowness, as if there's a lump in the neck region; difficulty in swallowing and hoarseness.
- When the dietary iodine intake falls below 50μg/dL, thyroid hormone synthesis is inadequate and secretion declines.
- **Endemic goitres** are those which occur at high incidence in certain geographic regions. They are **associated with iodine deficiency** but other factors must be involved as the prevalence varies in areas with similar low levels of iodine. Factors such as the intake of goitrogens or metabolic defects in thyroxine synthesis may be important.
- **Simple goitres** arise from compensatory hyperplasia in an attempt to maintain thyroid hormone levels. Once a state of euthyroidism is reached, colloid accumulates - hence, the term **colloid goitre**.
- **Hashimoto's thyroiditis** is a type of autoimmune thyroid disease in which the immune system attacks and destroys the thyroid gland. Hashimoto's prevents the gland from producing enough thyroid hormones for the body to work correctly. It is the **most common form of hypothyroidism**.
- Hashimoto's disease is **also known as suicide of thyroid gland.**
- **Hyperthyroidism** means **overactivity of the thyroid gland**, resulting in too much thyroid hormone in the bloodstream which **leads to overactivity of the body's metabolism**.
- **Symptoms** may include: nervousness, irritability increased perspiration, thinning of the skin; fine, brittle hair; weak muscles, especially in the upper arms and thighs; shaky hands; fast heartbeat; high blood pressure; increased bowel movements; weight loss; sleeping difficulty; eye sensitivity to light; staring; confusion, irregular menstrual cycle.
- **Grave's disease** is most often **associated with hyperthyroidism**.
- Grave's disease is **categorized as an autoimmune disorder** (in which circulating antibodies formed against the TSH receptor activate the receptor, making the gland hyperactive). The disease is **most common in young to middle-aged women** and tends to run in families.
- **Symptoms of Graves' disease** are identical to hyperthyroidism, with the addition of three other symptoms – **goitre** (enlarged thyroid which may cause a bulge in the neck), **bulging eyes** (**exophthalmos** due to swelling of extraocular muscle), **thickened skin over the shin area.**
- **Thyroiditis** (the inflammation of the thyroid gland) causes temporary hyperthyroidism, usually followed with hypothyroidism.
- **Calcitonin** (non–iodinated polypeptide hormone) **is secreted from the parafollicular or C cells** in the thyroid gland, but it is also synthesized in a wide variety of other tissues, including the lung and intestinal tract.
- Calcitonin is **also called thyrocalcitonin** (TCT).
- Calcitonin plays a **role in calcium and phosphorous metabolism**. In particular, calcitonin has the ability to decrease blood calcium levels at least in part by effects on two well-studied target organs : bone and kidney.

Bone : Calcitonin suppresses resorption of bone by inhibiting the activity of osteoclasts, a cell type that "digests" bone matrix, releasing calcium and phosphorous into blood.

Kidney : Calcium and phosphorous are prevented from being lost in urine by reabsorption in the kidney tubules. Calcitonin inhibits tubular reabsorption of these two ions, leading to increased rates of their loss in urine.

- The most prominent factor controlling calcitonin secretion is the **extracellular concentration of ionized calcium.**
- **Elevated blood calcium levels** strongly stimulate calcitonin secretion, and secretion is suppressed when **calcium concentration falls below normal.**
- When serum calcium levels rise, calcitonin secretion occurs, bone resorption decreases and serum calcium level falls again.
- The calcitonin hormone **works together with the parathyroid hormone** to regulate calcium levels in the body.
- Calcitonin is **used to treat hypercalcemia** resulting from a number of causes, and **has been a valuable therapy for Paget disease**, which is a disorder in bone remodeling.
- Calcitonin **also appears to be a valuable aid in the management of certain types of osteoporosis and loss of bone density** (due to dissolution of PTH).
- In birds, fish and amphibians, calcitonin is secreted from the **ultimobrachial glands.**

PARATHYROID GLANDS

- **Parathyroid glands** are small glands which are located in the neck behind the thyroid.
- There are usually **4 parathyroid glands** which are normally a little smaller than a pea, 2 in the left lobe of the thyroid and 2 in the right lobe.
- The **normal role of the parathyroid glands** is to control the blood calcium **by secreting parathyroid hormone (PTH).**
- The levels of blood calcium are constantly monitored by a protein expressed by parathyroid cells, designated the calcium sensing receptor.
- **Parathyroid hormone** (secreted by **chief cells**) is also called **parathormone** (PTH) or **Collip's hormone**.
- The **parathyroid hormone stimulates the following functions** –
  - Release of calcium by bones into the bloodstream
  - Absorption of food by the intestines
  - Conservation of calcium by the kidneys.
- PTH has an effect that **opposes the effect of calcitonin.**
- PTH affects the synthesis of 1, 25 dihydroxy-cholecalciferol (a metabolite of vitamin D), which indirectly affects serum calcium by increasing the efficiency with which dietary calcium is absorbed in the gastrointestinal tract.
- Persistent excess production of PTH may lead to the development of a high level of blood calcium, referred to as **hyperparathyroidism**.
- **Hyperparathyroidism may be associated with** the development of **osteoporosis** (destruction of bone with increased incidence of fractures), **kidney stones**, **impaired kidney function**, **increased thirst** or increased frequency of urination, **osteitis fibrosa cystica** (means normal bone is replaced by cysts and fibrous tissue) and sometimes, stomach upset and ulcers.
- **Hyposecretion of PTH** leads to **tetany** characterised by decreased serum Ca^{2+} and increased serum phosphate, and decreased urinary phosphate, muscle spasm, twitching, increasing neuroexcitation etc.

THYMUS

- The **thymus** (throne of immunity) is a **ductless gland** which lies in the upper part of the mediastinum behind the sternum and extends upwards into the root of the neck.
- The **thymus reaches its greatest size at puberty**, after which it undergoes slow involution and both cortical and T lymphocytes are reduced in peripheral blood.
- The thymus is the **first developing lymphoid organ.**
- The main function of the thymus is to **develop immature T-cells into immunocompetent T-cells**.
- The thymus is divided into two distinct compartments– the **outer cortex** and the **inner medulla.**
- Both regions are **densely populated with lymphocytes** (or thymocytes while in the thymus).

- The **maturation of the thymus and other lymphoid tissue** is stimulated by **thymosine**.
- **Thymosine**, a polypeptide hormone secreted by reticular epithelial cells, increases the rate of growth, accelerates cell division, helps in maturation of genital organs and produces lymphocytes and antibodies.
- **Thymic or Hassal's corpuscles** made of concentrically arranged epithelioreticular cells become more common into adulthood. They **act as phagocytes**.
- The thymus **plays an important role in the development of the immune system in early life**, and its cells form a part of the body's normal immune system.
- **Thymopoietin**, also called **thymin**, depresses neuromuscular transmission, induces T-cell markers, and has a role in the generation of cytotoxic T cells and prevention of autoimmunity.
- The human thymus, especially in the foetus, **supports erythropoiesis** and **granulopoiesis**.
- The thymus is also present in many other animals. When animal thymus tissue is sold in a butcher shop or at a meat counter, thymus is known as **sweetbread.**
- **Hypersecretion of thymosine hormone** may lead to **Myasthenia gravis**, characterised by abnormal muscular excitation.

ADRENAL GLAND

- The adrenal gland is called **supra renal gland** because it is situated on the anteriosuperior aspect of the kidney and receives its blood supply from the adrenal arteries.
- Adrenal gland is separated into two distinct structures – the **adrenal medulla** (10–20% and **ectodermal in origin**) and the **adrenal cortex** (80–90% and **mesodermal in origin**), both of which receive regulatory input from the nervous system.
- The **adrenal medulla** is the body's **main source of the catecholamine hormones like epinephrine (adrenaline) and norepinephrine (nor-adrenaline)**.
- Adrenal medulla is composed of masses of catecholamines secreting cells surrounded by complex network of blood vessels.
- Catecholamines secreting cells are sometimes called **chromaffin cells** because their granules stain a brownish colour when exposed to solutions containing dichromate ions.
- The **release of epinephrine and nor-epinephrine is controlled by the central nervous system through the preganglionic sympathetic fibres in the medulla**.
- These hormones are **derived from aminoacid tyrosine**.
- **Dopamine** is an intermediate in the biosynthesis of adrenaline and nor-adrenaline from the tyrosine and phenylalanine.
- A deficiency of dopamine results in **Parkinson's disease**.
- **Secretion of adrenaline** is **5-10 times higher** than nor-adrenaline.
- These hormones are secreted for **meeting an emergency** as in cold, emotional stress, pain, anger, fear etc.
- Adrenaline is also known as **emergency hormone**.
- It **increases** blood pressure, basal metabolic rate, lipolysis in adipose tissue to increase level of fatty acids in blood, acts as vasodilator, increase respiration rate as it dilates trachea, increases sugar level in blood by stimulating glycogenolysis in liver and skeletal muscle and slows down peristalsis.
- **Nor-adrenaline** more or less resembles adrenaline in its biological effects except that **it operates during normal state, exercises, lesser effect on cardiac activity and produces greater constriction of blood vessels in muscles**.
- **Hypersecretion of adrenaline** causes hypertension, high level of sugar in blood and urine, high metabolic rate, nervousness and sweating etc.
- **Adrenal cortex,** composed of cortical cells, secretes 40 different steroid hormones which are collectively called as **corticoids**.
- Corticoids are divided into **mineralocorticoids, glucocorticoids** and **sexcorticoids**.
- The adrenal cortex can be divided into **three distinct layers of tissue based on cell type and function –**
  - **Zona glomerulosa** (outer) - mineralocorticoid production, primarily aldosterone
  - **Zona fasciculata** (middle) - glucocorticoid production, mainly cortisol (roughly 95%)
  - **Zona reticularis** (inner) - sex corticoids, androgen production, including testosterone

- Two common mineralocorticoids (secreted by zona glomerulosa) are **aldosterone** and **deoxycorticosterone**.
- Aldosterone is also called as **salt-retaining hormone**.
- **In response to increased potassium levels or decreased blood flow and sodium to the kidneys**, cells of the **zona glomerulosa secrete the aldosterone** into the blood as part of the renin-angiotensin system.
- **Aldosterone** regulates the body's concentration of electrolytes, primarily sodium and potassium, by acting on the distal convoluted tubule of kidney nephrons to increase potassium excretion; increase sodium reabsorption; and increase water reabsorption through osmosis.
- **Zona fasciculata responsible for the production of glucocorticoids** are the **primary effectors of adrenocorticotropic hormone (ACTH)**.
- **ACTH** stimulates cortical cells to secrete glucocorticoids.
- **Important glucocorticoids** are **cortisol and corticosterone**.
- The **primary glucocorticoid** released by the adrenal gland is **cortisol.**
- Cortisol **enhances metabolism in several ways:**
  - Stimulating the release of amino acids from the body
  - Stimulating lipolysis, the breakdown of fat
  - Stimulating gluconeogenesis, the production of glucose from newly-released amino acids and lipids conserving glucose by inhibiting uptake into muscle and fat cells.
- Glucocorticoids are **used maximum in medicine for allergic condition, rheumatoid arthritis, skin disease and asthma** etc.
- Cells of the zona reticularis **provide a secondary source of androgens** such as testosterone, dihydrotestosterone (DHT), androstenedione, and dehydroepiandrosterone (DHEA). These enhance muscle mass, stimulate cell growth, and aid in the development of the secondary sexual characteristics.
- **Addison's disease** usually results due to **deficient secretion of aldosterone and cortisol**.
- During **addison's disease**, excessive loss of Na^+, Cl^- and HCO_3^- takes place and level of K^+ ion increases in blood. Imbalance in sodium potassium ratio's alter muscle and nerve functions.
- **Hypersecretion of aldosterone** due to adrenal cortical tumor causes **aldosteronism** or **Conn's syndrome**.
- **Conn's syndrome** is characterised by rise in blood volume & blood pressure, muscular weakness, high plasma Na^+ (due to decreased renal excretion) resulting in kidney damage and polyuria, tetany, hypokalemic alkalosis.
- **Excessive loss of sodium ion** is known as **acidosis**.
- Acidosis **means decrease in pH of blood from 7.4 to 6.8**.
- **Over secretion of cortisol** causes **cushing syndrome**, characterised by high sugar level in blood, loss of sugar in urine, loss of weight, high Na^+ & low K^+ concentration in plasma, rise in blood volume and blood pressure etc.
- Cushing syndrome is also produced by **tumors of non–endocrine** tissues that secretes substances with CRH activity or more commonly ACTH.
- **Cushing disease**, same as cushing syndrome is **caused by oversecretion of cortisol due to excessive hormone stimulation by adrenal cortex by tumor/hyperplasia** (due to increased cell mass) of **anterior pituitary**.
- Cushing disease mainly **occurs in females** and causes obesity, hypertension, glycosuria (sugar in urine), virilism.
- **Excessive secretion of sex corticoids** results in **virilism** or appearance of male secondary characters like male voice, beard, moustaches in females.
- **Hirsutism** is the **presence of facial and excess body hair in females** due to adrenal virilism, while it causes **gynaecomastia** in males characterised by enlarged breast.
- Secretion of glucocorticoids and sexcorticoids are **regulated by ACTH of pituitary**.
- Mineralocorticoid release is stimulated by the **activity of renin and angiotensin**.
- Adrenal gland is also called **4 S gland** (= sugar metabolism, salt retaining, sex hormones, source of energy) and **3 F gland** (fright, fight and flight.)

PANCREAS

- The **pancreas** is a **retroperitoneal organ**.
- Pancreas is the **second largest gland** located in the loop of duodenum.
- It is an **heterocrine gland** in which exocrine part occurs as **acini** while the endocrine part (2-3%) is represented by **islets of Langerhans** or **pancreatic islets**.

- **Control of the exocrine function of the pancreas** occurs by the enzymes gastrin, cholecystokinin and secretin, which are secreted by cells in the stomach and duodenum, in response to distension and/or food and which cause secretion of pancreatic juices.
- The acinar cells are **specialized to secrete the proteins in the digestive process.**
- Hormones of pancreas, secreted by different types of endocrine cells present in islet of Langerhans, are - α **cell** (secretes glucagon); β **cell** (secretes insulin); γ **cell** (secretes gastrin); δ **cell** (secretes somatostatin); and **F cell** (secretes pancreatic polypeptides).
- Islets **have fenestrated capillaries** (typical of all endocrine tissues) **which facilitate hormone transport.**
- **Insulin** and the **glucagon** are the **chief hormones** produced in the islet tissue.
- **Glucagon** (secreted by α cells of pancreas), is a proteinaceous hormone whose **secretion is stimulated by low blood sugar level**.
- Glucagon **stimulates glycogen breakdown and glucose synthesis** in the liver thereby increasing the blood glucose concentration.
- **Excess of glucagon** may cause **glycosuria** due to presence of sugar in urine.
- Glucagon is **antagonistic to insulin**.
- **Insulin** (secreted by β-cells of pancreas), is **also called hypoglycaemic or antidiabetic factor**.
- **Rising blood glucose levels** stimulates insulin secretion and **falling blood glucose levels** stimulate glucagon synthesis.
- Insulin is **anabolic hormone** whereas glucagon is **catabolic hormone**.
- **Normal range of blood sugar is 80-120 mg/100 ml** of blood (80 mg/100 ml before fasting & 120 mg/100 ml after meal).
- **Deficiency of insulin** causes **diabetes mellitus**.
- **Diabetes** is **characterised** by **polyuria**, **polydipsia**, weight loss inspite of **polyphagia** (increased appetite), **hyperglycemia**, **glycosuria**, **ketosis** (increased ketone bodies in blood), **acidosis** (increased H^+ ions in blood) & **coma**.
- **Polyuria** or excessive urination is due to increase in water content of urine.
- **Polydipsia** means excessive thirst inspite of drinking more and more water.
- Indication of diabetes start when blood sugar level increases about **3 times** and is **more than 150 mg/100 ml of blood** due to regular supply from alimentary canal and failure of cells to absorb glucose.
- Diabetes mellitus are of **two types** – **type I diabetes** and **type II diabetes**.
- **Type I diabetes** usually **develops before age 40** and it is **characterised** by loss of β-cells with eventual absence of insulin in the circulation.
- Type I diabetes is also called **juvenile diabetes and insulin-dependent diabetes mellitus** (IDDM). It is **ketosis prone diabetes** means that fatal high level of ketone bodies increase in the blood due to severe non-availability of insulin. Insulin is a metabolic hormone which prevents ketone body formation.
- **Type II diabetes** usually **develops after age 40** and is **not** associated with total loss of the ability to secrete insulin.
- Type II diabetes is also called **maturity-onset diabetes** and **non-insulin dependent diabetes mellitus**. It is **ketosis-resistant diabetes**.
- **Somatostatin** (secreted by δ cell) is a local hormone which controls functioning of α and β cells.
- Somatostatin **inhibits the secretion of insulin and glucagon**.
- **Pancreatic polypeptide** (secreted by F-cells) check secretory activity of digestive glands.
- **Gastrin** (secreted by γ cells) is similar to the one produced by pyloric stomach.
- **Hypokalaemia** means low level of potassium in blood and **ketonaemia** refers to presence of ketone bodies in blood due to increased oxidation of fats.

GONADAL HORMONES

- **Gonads** (testes in male and ovary in female) are both exocrine and endocrine in function.
- Secretion of gonadal hormones are **stimulated** by **GnTH of pituitary**.
- Endocrine part of testes is formed of group of cells called **interstitial cells** or **leydig cells.**
- Leydig cells are the most important functional cells in the interstitium (the space between the seminiferous tubules of testis).
- Leyding cells synthesize and secrete male sex steroids called **androgens.**
- **Testosterone (**steroid hormone) is the **most abundant androgen** released by leydig cells.
- Testosterone is responsible for the growth and

development of male secondary sex organs (like epididymis, seminal vesicle etc.) and male secondary characteristics (like beard, moustaches etc.)

- It **stimulates** spermatogenesis & erythropoiesis.
- The surgical removal of testes is called **castration or orchidectomy**. **Cryptorchidism** is non descent of testis from its abdominal origin to testicular sac.
- Castrated human male are called **eunuch or neuter** and **oxen** (instead of bulls) in case of cattle.
- **Eunochoidism** is a hormonal disorder due to non secretion of testosterone in a genetically male individual.
- Just like testes, the ovaries are **cytogenic** as well as **endocrine in function**.
- Ovaries secrete **3 types of female hormones – estrogen**, **progesterone** and **relaxin**.
- **Estrogen**, group of steroid hormone is mainly **secreted by follicular epithelial cells of membrana granulosa of Graafian follicles**.
- **Secretion of estrogen** is **stimulated by LH** of anterior lobe of pituitary gland.
- Estrogen includes **estradiol**, **estriol** and **estrone**.
- **Principle estrogen** is **estradiol**.
- Estrogen stimulates the growth and development of female secondary sex organs and female secondary sexual characteristics.
- Estrogen **decreases** the secretion of FSH while **increases** the secretion of LH during menstrual cycle.
- During pregnancy, estradiol is secreted by **placenta**.
- **Progesterone** is a steroid hormone secreted by corpus luteum.
- Small amount of progesterone is also secreted by **adrenal cortex** and **placenta**.
- Progesterone is **responsible for the maintenance of pregnancy,** hence called as **pregnancy hormone**.
- During pregnancy **progesterone** helps in attaching embryo to uterine wall, development of placenta & growth of secretory alveoli in mammary glands.
- Progesterone is **thermogenic** and is probably responsible for the rise in basal body temperature at the time of ovulation.
- **Hyposecretion of progesterone** results in **abortion** and **misconception**.
- Progesterone is also called as **antiabortion hormone**.
- **Relaxin** is a proteinaceous hormone, **secreted by corpus albicans** which is formed from the corpus luteum at the end of gestation period.
- Relaxin **softens the pubic symphysis so helps in parturition (child birth) in rats and guinea pig**. In women, this role is played by **estrogens & progesterone**.

PLACENTAL HORMONES

- **Placenta** is the connection between foetus and uterine wall for physiological exchange like respiration, excretion, nutrition etc.
- During **pregnancy**, placenta also **acts as an endocrine gland**.
- The **chorionic villi of placenta** secretes **two steroids** (estradiol & progesterone) and **two proteins** (human chorionic gonadotrophin, HCG and placental lactogen, PL) hormones.
- **HCG** is a glycoproteinaceous hormone that maintains the corpus luteum for continued secretion of progesterone so as to maintain the pregnancy.
- Pregnancy test is confirmed by the **presence of HCG in urine**.
- **HPL** (human placental lactogenic hormone) prepares the mammary glands to secrete milk.
- **Inhibin** hormone is **produced by corpus luteum, placenta & testes**.
- It supplements the effect of excess sex hormones for depressing gonadotrophic activity (FSH, CH, ICSH) of pituitary.

OTHER HORMONES

- **Juxta glomerular region of kidney** produces two hormones – **erythropoietin** (regulates erythrocyte production) and **renin** (changes angiotensinogen of liver into angiotensin.)
- **Heart** produces a peptide hormone, **atrial natriuretic factor** (ANF) in case of hypertension.
- This hormone inhibits **renin** (in kidney) and **ADH secretion** (in pituitary).
- **Salivary gland** produces a proteinaceous hormone, **parotin** for calcification of teeth.
- **Gastrointestinal hormones** are proteinaceous in nature. These are of following types – gastrin, secretin, enterogastrone cholecystokinin, pancreozymin, enterocrinin, duocrinin and villikinin.
  [*For the functions of these hormones refer chapter Nutrition and Digestive System*].

HORMONES AND GLANDS AT A GLANCE

Hormone of maternity	–	Prolactin
Birth hormone and milk ejecting hormone	–	Oxytocin
Milk production hormone	–	Prolactin
Emergency hormone	–	Adrenaline
Antiabortion hormone	–	Progesterone
Hormones of metabolism	–	Insulin, glucagon, calcitonin, corticoids.
Hormones of reproduction	–	FSH, LH (ICSH in male), oxytocin, sex hormones
Hormones of growth and development	–	GH (somatotropin), thyroxine.
Salt-retaining hormone	–	Aldosterone
Antidiuretic hormone	–	Vasopressin
Prolactin inhibiting hormone.	–	Dopamine
Anti-gonadotrophic hormone	–	Melatonin
Hormones helps in parturition	–	Relaxin and oxytocin
Hormone responsible for maintaining pregnancy	–	Progesterone
Sex hormones	–	Steroid hormones except hCG and relaxin
Hormone associated with immune system	–	Thymus
Pregnancy test hormone	–	HCG (Human chorionic gonadotropin)
Anti-ageing hormone	–	Thymus, melatonin
Largest endocrine gland.	–	Thyroid.
Largest endocrine organ.	–	Gut.
Temporary endocrine gland.	–	Corpus luteum, placenta.
Receding endocrine gland.	–	Thymus, shrinks after puberty.
Smallest endocrine gland.	–	Pituitary (0.5-1.0 gm).
Triple 'F' & Four 'S' gland	–	Adrenal gland

End of the Chapter

Chapter 46

Reproduction in Flowering Plants

- **Reproduction** is the process of formation of new individuals of a species from the pre-existing ones.
- In **lower organism**, reproduction occurs commonly by **fission** and **budding**.
- In **higher organisms** reproduction occurs with the help of well developed **sex organs**.
- Plants show **two types of reproduction - asexual** and **sexual**.

ASEXUAL REPRODUCTION

- **Asexual reproduction** is the mode of formation of new individuals from parts of parents without meiosis and formation of gametes.
- **Basic characteristies of asexual reproduction** are–
  - Involvement of single organism without the production of gametes.
  - Cell division are only mitotic in nature.
  - Individuals formed are generally identical to the parent.
  - It is a rapid way of reproduction under favourable conditions.
- Asexual reproduction is of **3 types - agamospermy, spore formation** and **vegetative reproduction**.
- **Agamospermy** is asexual formation of seed, but embryo inside the seed is produced by abnormal method **omitting** meiosis and fertilization. (*described later*).
- **Spore formation** is seen in algae, fungi, bacteria, and protistans, where different spore types as zoospores, aplanospores hypnospores, sporangiospores, etc. help in reproduction.
- Spores taking part in asexual reproduction are called **accessory spores** or **mitospores**.
- **Vegetative reproduction** is the process of multiplications from a part of plant body that function as propagule and develops into new individual. It could be **natural** or **artificial**.
- The technique of propagation in which a portion gets detached from the plant body and functions as propagule naturally is called **natural vegetative propagation**.
- **Roots** of plants like *Dalbergia sisso*, *Murrya sp* etc. **develop adventitious buds** to grow into new plant.
- **Root tubers** of sweet potato, *Asparagus* etc. have adventitious buds that give rise to new plants.
- **Underground stem modification** show various modes of vegetative reproduction as –
  - **Suckers** in *Chrysanthemum* produce new plants.
  - **Rhizome** possess buds to give rise to new plants.
  - **Corms** of *Colocasia* possess buds.
  - **Bulbs** of garlic
  - **Stem tubes** have buds in nodes and internodes.
- **Creeping stems** like runner (grass), stolons (*Vallisneria*) and offsets (*Pistia*) **gives rise to new plants from the base of old shoot**.
- A stem segment of *Opuntia* and other cacti develops into a new plant after falling on the soil.
- Leaves of many plants possess adventitious buds Eg. *Bryophyllum*.
- **Bulbils** develops into new plants after falling on the ground, eg. *Agave*.
- **Turions** are fleshy buds that develop in aquatic plants for perennation and propagation, eg. *Utricularia*.
- **Artificial methods of vegetative reproduction** are the technique developed by man to propagate desired varieties.
- The **various modes of artificial vegetative reproduction** are – **cutting**, **layering**, **grafting**, **micropropagation** etc.

- A cutting is **separated portion of root, stem or leaf**. It is very common method employed for artificial vegetative propagations, *eg.* sugarcane, roses, *Citrus, Duranta,* grapes, cocoa, *Bougainvillea*.
- Cut parts must have **one node**.
- Auxin like **IBA, NAA, IAA** are used for stem cutting because they lead to the **quick formation of adventitious roots**.
- The rooting success varies with **species, age** (the younger the better), the **position** on the donor tree where the cutting originated (lower is more juvenile and therefore more successful) and **time of year**.
- When the roots appear, the stem is cut below the level of roots and planted. This method is also popularly called **gootee.**
- Favourable time for **planting of cuttings** is the **spring**.
- **Layering** (**or soil layering**) occurs in nature when a drooping lower branch contacts the soil and adventitious roots form at point of soil contact, eg. grapevine, jasmine, strawberry gooseberry etc.
- **Air layering** can be done artificially by wounding a shoot (away from ground) and wrapping the wound in a moist medium (e.g., *Sphagnum*) surrounded by a waterproof covering.
- **Air layering** is done in plants –
  - Which do not produce adventitious roots easily
  - Whose branches fail to bent due to larger diameter
  - Whose stems are so mature that latent buds near the base do not sprout by other methods of layering.
- This method of artificial vegetative propagation is widely used in plants like litchi, *Citrus*, pomegranate, guava, *Croton* etc.

Methods of soil layering
- **Tip layering** – Eg blackberry, raspberry.
- **Serpentine layering** – Eg *Clematis*.
- **Mound layering** – Eg currant, gooseberry.
- **Trench layering** – Eg walnut

- **Grafting** is the process of attaching a shoot (or less frequently a bud) from the individual you want to clone to the root of another tree.
- The plant of which the root system is to be taken is called **stock** and the other of which shoot system is to be used is known as **scion.**
- The **success of the grafting mostly depends upon** the union of the cambium of scion and stock which results in **organic connection** (connection among organs so that transport of solute, minerals and water occurs in continuous manner) between them.
- All shoots sprouting from the stock should be removed otherwise they will not **permit the scion to grow.**
- Grafting is of three types - **tongue grafting, wedge grafting** and **crown grafting**.
- In **tongue or whip grafting** stock and scion are almost of the **same diameters**. The stock and scion are given oblique cuts followed by a notch in the tongue or whip grafting. Then the scion closely fits over the stock.
- In **wedge grafting** a V-shaped notch is given in the stock, while scion is cut like a **wedge**. Here also the stock and scion are almost of the same diameters.
- In **crown grafting**, diameter of the stock is many times than that of scion. So many scions are grafted on single stock.
- Grafting is commonly used to establish genetically superior trees in seed orchards and to propagate unique trees for **horticultural purposes** (*e.g.,* weeping varieties, infertile flowering cherries).
- Grafting is **used for quick multiplication and proper growth of better varieties with weak roots**, eg mango, apple, pear, rubber etc.
- **Bud grafting** is another method of artificial vegetative reproduction. Here a bud with small portion of surrounding bark is taken from the stem of a desired plant and inserted into the small slit made in the bark of stock.
- Bud grafting is **widely practised in roses**, **plums**, **apple etc**.
- **Micropropagation** is the raising of new plants from a small plant tissue with the help of tissue culture technique.
- **Tissue culture** is the technique of maintaining and growing cells, tissues etc and their differentiation on artificial medium under aseptic conditions inside suitable containers.
- Tissue culture is **based on totipotent nature of plant cells or concept of totipotency** *i.e.*, each and every plant cell has the inherent capacity to develop into a complete plant.
- **Haberlandt** first proposed the **concept of totipotency**.
- **Steward** first **developed a full plant from a single cell of wild carrot root**.

- **Explant** is group of cells **used in tissue culture**.
- When grown an artificial medium under aseptic conditions in a suitable condition, the explant forms an irregular unorganized mass of actively dividing cells called **callus**.
- Process of haploid production from pollen grains is called **androgenesis**.
- **Embryoids** are non-zygotic or somatic embryo like structures produced through tissue culture.
- **Embryo culture technique** was **first started by E. Hanning** (1904) and further improved by **Laibach (1925)**.
- Embryo culture is **used in the following** –
  - Shortening of breeding cycle
  - To obtain rare hybrids
  - To propagate some rare plants
  - Used as rapid seed viability test.
- **Endosperm culture** is used for **triploid plant production**.
- **Triploidy** is commercially used in many varieties of apple, banana, sugar beet, tea, watermelon etc.
- **Protoplast culture** is mostly **used in production of somatic hybrids.**
- **Genetic manipulations** can be **carried out more rapidly when plants cells are in protoplast state**. New genes can be introduced.
  Chloroplast + 'nif' genes → Nitroplast.
- Genetically uniform and disease free clones have been produced by **nucellus culture**, eg. *Citrus*, mango.
- **Meristem tip culture is used** in – **clonal propagation** and **in obtaining virus free plants**.
- Dry freezed storage of germplasm is called **cryobiology**.
- **Importance of vegetative propagation** are –
  - Growing of some seedless fruits plants like banana, grapes, oranges, rose, jasmine etc.
  - Vegetative propagation is the only mean to produce genetically identical offsprings & preserve a stock of desired variety.
  - It is an easier less expensive & a rapid method of propagation.
  - Superior quality of flowers and fruits can be produced by the method of grafting.
  - A large number of disease free identical plants can be grown in a very short time by tissue culture technique.

SEXUAL REPRODUCTION

- **Sexual reproduction** is the formation of new individuals through the meiotic gamete formation and their subsequent fusion during fertilization.
- Sexual reproduction is also called **amphimixis**.
- The study of sexual reproduction in plant includes **microsporogenesis**, **megasporogenesis**, **pollination**, **fertilization**.

Microsporogenesis

- The formation of microspores or pollens is called **microsporogenesis**.
- Pollen grains are formed inside the **anther** which is the **fertile part of the stamen** or **microsporophyll**.
- The anther consists of two lobes which are separated in the anterior region by a deep groove and attached to each other on the back side by sterile tissue called **connective**.
- Each anther lobe consists of two long and cylindrical **pollen sacs or microsporangia**.
- Parietal layer or wall layers of anther contains the following –
  - **Epidermis** of single layer **for protection**
  - **Endothecium** of single layer **for dehiscence of anther**
  - 1-4 number of **middle layers**
  - **Tapetum**, the **innermost parietal layer** with cells having dense cytoplasm and large nuclei.
- Tapetum **provides nourishment to developing microspores**.
- Tapetum **also secretes callase enzyme** which dissolves callose substances by which 4 pollens of a pollen tetrad are united, hence separating microspores or pollens of a tetrad.
- Tapetum **secretes ubisch bodies** which **gets covered with sporopollenin** and so **increase thickness of exine**.
- **Tapetum** is of **two types** – **amoeboid** and **secretory**.
- In **amoeboid or plasmodial tapetum**, the inner and radial walls breakdown at an early stage and these cells are free in microsporangia.
- In **secretory or glandular tapetum**, the tapetum remain as such throughout.
- **Pollen kit** is the outermost oily, thick, sticky, coating of pollen grains, mainly **composed of**

lipids and carotenoids. It is **secreted in case of entomophilous pollen grains**.

- **Main functions of pollen kit** are –
  - Due to sticky nature, the pollen get attached to bodies of insects
  - Acts as insect attractant
  - Protects pollens against harmful UV rays.
- **Sporogenous tissue** (or **archesporial tissue**) is **present in the pollen chambers**.
- Sporogenous tissues **gives rise to microspores by microsporogenesis**.
- Primary sporogenous cell given rise to **microspore mother cell** (MMC).
- Each microspore mother cell **gives rise to 4 haploid microspores or pollen grains**.
- **Isobilateral tetrads** are **formed in monocot**.
- **Tetrahedral tetrads** are **formed in dicots**.
- One microspore is formed from one pollen mother cell, eg. cypraceae.
- In member of asclepiadaceae and orchidaceae all the pollens of an anther lobe are packed in a bag like structure called **pollinium**.
- Pollinia of two adjacent anthers together form a **translator**.
- **Polyspory** is the **occurrence of more than 4 spores in a pollen tetrad**, eg. *Cuscuta reflexa.*
- When 4 pollens do not separate and remain in tetrads it is known as **compound pollen**.
- **Dehiscence of anthers** are of **different types** –
  - (i) **Longitudinal dehiscence**, eg. *Datura.*
  - (ii) **Transverse dehiscence**, eg. *Ocimum.*
  - (iii) **Porous dehiscence**, eg. *Solanum*
  - (iv) **Valvular dehiscence**, eg. *Beberis.*
- Each **microspore** is a **unicellular haploid, oval or rounded structure**.
- **Smallest pollens** are present in *Myosotis* (10 m) and largest pollens are present in some members of cucurbitaceae and nyctaginaceae (*Mirabilis*-250 m).
- Pollen grains are classified according to number (N), position (P) and character (C) of apertures and this type of classification is called **NPC system**.
- Pollens of *Ambrosia* of family compositae cause **hay fever**.
- Each pollen grain have **two layered** walls : **exine** and **intine.**
- Terms **intine** and **exine** were given by **Fristsche** (1837).

> - Study of pollen grains or microspores is called **palynology**.
> - **Geopalynology** is the study of fossil pollen grains.
> - **Aeropalynology** is the study of pollens found in air or atmosphere.
> - **Iatropalynology** is the study of pollens in criminology and medical aspects.
> - **Melittopalynology** is the study of pollen grains in honey.

- Pollen grain of monocots contains **single germpore** and that of a dicot contains **three germpores**.
- The **outer layer** called **exine** is thick, tough, cuticularized and is **composed of sporopollenin**.
- Sporopollenin is absent in the pollen grains of *Zostera*.
- The thin areas of the exine are called **germ pores** or **germ slits**.
- **Inner layer** called **intine** is thin, smooth and is composed of **pectocellulose**.
- **Exine** is **differentiated** into **extexine** and **endexine**.
- Extexine is further **differentiated into foot layer, baculate layer** and **tectum**.
- **Tectum** provides a characteristic sculpturing or designs over the surface of pollen grains.
- Microspore or pollen is the **beginning of male gametophytic generation**.
- **Development of the male gametophyte** (uniform in all angiosperms) is called **microgametogenesis**.
- **Male gametophyte** when fully developed is a **3 nucleate structure**.
- The pollen grain nucleus grows in size and shifts to one side near the wall.
- The protoplast then **divides to form small generative cell** and **large vegetative or tube cell**.
- Initially, the position of vegetative nucleus is the terminal portion of pollen tube and generative cells behind it.
- Their position will be reversed during the movement of pollen tube in the **stylar canal**.
- On the stigma the pollen grains absorb water and nutrients from the stigmatic secretion through its germ pores.
- The **tube or vegetative cell** enlarges and comes out of the pollen grain to form **pollen tube**.
- The tube nucleus descends to the tip of the pollen tube and finally gets degenerated.

- The **generative cell** passes into the pollen tube and divides into **2 male gametes**.
- **Nemec** (1898) reported pollen grain embryo sac (or male gametophyte like female gametophyte or embryo sac) in *Hyacinthus* (fam. *Liliaceae*), which is called '**Nemec phenomenon**'.

Megasporogenesis

- **Gynoecium** or pistil is the **female reproductive part** and **carpel** is the **unit of gynoecium**.
- Carpel is considered to be **modified leaf bearing ovules or megasporophyll.**
- The folded carpel bears one or more ovules along the ventral suture.
- Carpel is distinguished into three parts as **stigma, style** and **ovary.**
- The **integumented nucellus** or **megasporangium** is called **ovule**.
- The main body of the ovule is called **nucellus or megasporangium**.
- Ovary at maturity forms **fruit** and ovule forms **seed**.
- Inside the ovary, there is present either a **single ovule at its base** or **many ovules on its sides**.
- Arrangement of ovules inside the ovary is called **placentation**.
- The ovule is attached to placenta by means of a stalk called **funiculus**.
- **Hilum** is the point of attachment of funiculus to the body of the ovule.
- The funicle continues along the side of the ovule as a ridge called **'raphe'**.
- **Most important part** of the ovule is **embryo sac** because embryo and endosperm are formed in this structure.
- Embryo sac is called **female gametophyte.**
- The opening of the ovule is called **micropyle**.
- The place of the ovule where integuments and nucellus join each other (at the apex of funicle) is called **chalaza**.
- The ovule lacking the funicle is called **sessile**.
- Ovules having single integument are called **unitegmic ovule**. It is **common in gamopetalae**.
- Ovules **having 2 integuments** are called **bitegmic ovule**. Example - members of polypetalae and monocots.
- When nucellus is not surrounded by integuments, the ovule is called **ategmic**, example - *Santalum album, Balanophora*.
- Any ovular structure which directs the growth of pollen tube towards micropyle of ovule is called **obturator**. It **acts as a type of bridge for pollen tube**.
- Obturator **develops from funiculus** or **placenta.**
- Group of lignified cells below embryo sac in nucellus is called **hypostase**.
- Hypostase is **found in** families like **amaryllidaceae**, **liliaceae**, **euphorbiaceae** and **zingiberaceae**.
- **Depending upon position of micropyle in relation to chalaza and funiculus**, **ovules are of 6 types** in angiosperms. These are – orthotropous, anatropous, hemianatropous, campylotropous, amphitropous and circinotropous.
- **Orthotropous or atropous or straight** is the **most primitive** and **simplest type** of ovules in angiosperms.
- This is erect (*i.e.,* micropyle at upper end) and here micropyle, chalaza and funiculus are in the **same straight line**, e.g., in polygonaceae and piperaceae.
- **Anatropous** or **inverted** is the **most common type** of ovule **found in angiosperms** *(i.e.*, in 82% of angiosperm family). Here **body of the ovule gets inverted** and **micropyle is on lower side**. Further **micropyle and funiculus lie side by side** and **micropyle is close to hilum**.
- In **hemianatropous** or **hemitropous** ovule, **nucellus** and **integuments** (*i.e.*, body of ovule) is **at right angles to stalk or funiculus**, e.g., in primulaceae and *Ranunculus*.
- In **campylotropous ovule**, the **body of the ovule gets curved** and **micropyle is directed downwards**. Further, micropyle is not in line with chalaza, *e.g.*, in capparidaceae, chenopodiaceae and cruciferae etc.
- In **amphitropous** (**amphi-both**) type, **curvature is observed both in the body of ovule and embryo sac**. The embryo sac assumes **horse shoe-shape**. *e.g.,* in papaveraceae, alismaceae and butomaceae etc.
- **Circinotropous** is **characteristic type of ovule**. It is **found in family cactaceae**, *e.g., Opunita*. Here the ovule **straight first**, due to more growth on one side the ovule gets **inverted**, but this unilateral growth still continues till the ovule becomes straight again. In this manner, the funiculus takes a **complete round around the body of ovule**.

- On the basis of the **quantity of the nucellus** ovules are of two types : **tenuinucellate** (**nucellus is very small**) and **crassinucellate** (**nucellus is massive**).
- Formation of megaspore (n) from megaspore mother cell (2n) inside the ovule is called **megasporogenesis**.
- In the hypodermal region of nucellus towards the micropylar end develops a **primary archesporial cell**.
- The primary archesporial cell **divides periclinally to form outer parietal layer** and **inner sporogenous cells**.
- The sporogenous cell **functions as megaspore mother cell** (MMC), which **undergoes reduction division to form 4 haploid megaspores**.
- Only **one megaspore remains functional** and the **other 3 degenerates**.
- The **functional megaspore** enlarges and **divides thrice to form 8 nuclei**.
- Megaspore is the **initial cell or beginning of female gametophyte or embryo sac**.
- The nucleus of megaspore undergoes divisions and gives rise to embryo sac or female gametophyte which is called **megagametogenesis**.
- **3 celled egg apparatus** towards the micropylar end, **two middle polar nuclei** and **three antipodals** at the chalazal end **constitute the egg apparatus**.
- The **three micropylar cells** are **collectively known** as **egg apparatus**.
- **One cell** is larger and is called the **egg** or **oosphere** and the **other two** are called **synergids**.
- **Synergids** are short-lived (one of them degenerates long before fertilization and second after entry of pollen tube into embryo sac).
- These **synergids help** –
  - **In growth of pollen tube towards egg by secreting chemotropically active substances**.
  - **In nutrition of embryo sac by absorption and transport of food from nucellus through their filiform apparatus**.
- Filiform apparatus in the form of finger like projections from cell wall is **present in upper part of each synergid**.
- The filiform apparatus is **useful for the absorption and transportation of materials from the nucellus to the embryo sac**.
- Hook like structures help in **easy penetration of pollen tube** and **liberation of male gamete from the pollen tube**.
- Egg is the **constant feature of embryo sac**. It fuses with one male gamete to form zygote (syngamy) and hence embryo.
- The central cell **consists of two polar nuclei**.
- Two polar nuclei fuse to form **single diploid secondary nucleus or definitive nucleus.**
- The chromosomal condition of the secondary nucleus is **diploid (2n).**
- The 3 cells present towards the chalazal end are **antipodal**.
- **Polygonum**, **Allium** and **Adoxa** types of embryo sacs are **8 nucleated**.
- **Oenothera type of monosporic embryo sac** develops from single functional megaspore of micropylar end (not chalazal).
- Oenothera embryo sac is **four nucleated having egg apparatus** and **a single polar nucleus in centre**. Antipodals are absent.
- **Tetrasporic embryo sac** is of **6 types** *viz*. Pepromea, Penea, Fritillaria, Plumbigella, Plumbago and Adoxa.

Pollination

- The transfer of pollen grains from anther to the stigma is called **pollination**.
- This process of pollination occurs only in **gymnosperms** and **angiosperms.**
- Pollination in angiosperms gererally takes places at **2-celled** stage (rarely 3-celled stage) of microspores or pollen, *i.e.,* vegetative cell and generative cell.
- If the pollen grains are transferred to the micropyle of the ovule directly, the pollination is called **direct pollination.** eg. gymnosperms.
- Since the ovules are enclosed in the ovary in angiosperms, the pollination is called **indirect pollination**.
- Pollination that occurs in closed flowers is called **cleistogamy** and the flowers are called **cleistogamous flowers.**
- If the pollination occurs in opened flower, which expose their sex organs, it is called **chasmogamy** and the flowers are called **chasmogamous flowers.**
- Pollination is of **two types** – **self pollination** and **cross pollination**.
- The transfer of pollen grains from anther to stigma of same or genetically similar flower is called **self pollination**. It **occurs always in crops with**

bisexual flowers, eg wheat, barley etc.

- Self pollination is **a rule in cleistogamous flowers**.
- Self pollination is of **two types - autogamy** and **geitonogamy**.
- **Autogamy** is the transfer of pollen grains from anther to stigma of same flower.
- **Homogamy** is the process when **anthers and stigma of a bisexual flower mature at the same time**, eg wheat, rice, potato etc.
- **Geitonogamy** is the transfer of pollen grains from the anther to the stigma of a flower present in the same inflorescence or in the same plant.
- Geitonogamy **occurs between bisexual flowers or unisexual flowers of the same plant**.
- Geitonogamy is **genetically equivalent to self pollination** but **ecologically it is cross pollination**.
- **Advantages of self pollination** are –
  - It maintains the parental characters or **purity of race** indefinitely.
  - It **eliminates bad recessive characters**.
- **Disadvantages of self pollination** are –
  - Vigour and vitality of the race decreases with prolonged self pollination.
  - Immunity to diseases decreases.
  - Variability and adaptability to changed environment are reduced.
- In *Gloriosa superba*, stamens and stigmas are projected in different directions to **prevent self pollination.**
- In *Hibiscus*, the essential organs are **placed at different levels** to prevent self-pollination.
- **Cross pollination or allogamy** is the process when pollens are transferred from anther to stigma of different flower on different plant. It is **also called xenogamy**.
- **Dichogamy**, **dicliny**, **herkogamy**, **heterostyly** and **self sterility** are the **main reasons or adaptations for cross pollination in bisexual flowers**.
- **Dichogamy** is the condition of bisexuals flower in which male and female reproductive parts mature at different times.
- **Dichogamy** is of **two kinds** – protandry and protogyny.
- When the **androecium matures earlier than gynoecium**, it is called **protandry** and the flowers are called **protandrous**. Eg : *Clerodendron, Saxifraga, Phlox, Asteraceae, Gossypium.*
- When **gynoecium matures earlier than androecium** it is called **protogyny** and the flowers are described as **protogynous**. Eg : *Solanum. Scrophularia, Helliborous.*
- The phenomenon of production of unisexual flowers is called **dicliny or unisexuality.**
- In **maize** the male flowers and female flowers are present in the same plant at different regions.
- Plants with both kinds of flowers are called **monoecious plants**.
- When two types of unisexual flowers are present on two different plants, this condition is called **dioecious**.
- Here the male plant bears **staminate flowers**, and female plant bears **pistillate flowers**, *e.g.,* papaya, hemp, *Asparagus*, date palm, spinach, etc.
- When some physical barrier is present between male and female reproductive parts of a flower which prevent self-pollination, is called **herkogamy**, eg. in *Calotropis,* **gynostegium disc is such barrier**.
- **Dichogamous flowers** are **structurally bisexual** and **functionally unisexual** hence cross pollination takes place.
- Occurrence of styles of different lengths is called **heterostyly.** It was first discovered by **Darwin.**
- **Heterostyly** is of **two kinds** – **diheterostyly** (occurrence of styles of two different lengths) and **triheterostyly** (occurrence of styles of three different lengths).
- **Cross pollination** occurs between the stamens and styles of equal length, eg. *Lythrum, Biophytum, Oxalis.*
- When the pollen of the flower reach the stigma of the same flower, pollen grains do not germinate and the phenomenon is called **selfsterility** (self incompatibility). Eg : *Malva, Abutilon* and *Passiflora.*
- When the self-pollen and the foreign pollen are deposited on the stigma, the foreign pollen germinates quickly and completes fertilization and the phenomenon is called **pollen prepotency**. Eg. members of leguminosae (*Dolichos, Pisum*).
- The expression of relationship between the agent and structure of flower is called **pollination mechanism.**
- For **cross pollination**, agent is a must.

Some other mechanism of pollination

- **Mimicry** - Male wasp of *Calpa aurea* visits the flowers of *Ophrys* mistaking them as female wasps and pollinate them.
- In *Salvia* (Sage plant), a number of family labiatae, pollination occurs by bees and there is a special mechanism called **"Turn pipe mechanism"** or **"Lever mechanism"** of pollination.
- **'Fly trap mechanism**' of pollination occurs in *Aristolochia*. Flies are attracted by foul-rotten tobacco like odour.
- **'Trap door mechanism'** of pollination occurs in *Ficus* species (having hypanthodium inflorescence).
- In orchid (*Ophrys speculum*) pollination occurs by **act of pseudocopulation** by the wasp called *Colpa aurea*. Appearance and odour of *Ophrys* is similar to female wasp and hence male wasps are mistaken and they land on *Ophrys* flowers to perform act of pseudo-copulation and thus pollination takes place. This plant-insect relationship is **useful only to plant**.
- In *Yucca*, pollination occurs by a moth called *Tageticula*. There is **obligate symbiotic relationship** between *Yucca* and moth, *Tageticula* (*i.e.*, this moth cannot complete its life cycle without association of *Yucca* and *Yucca* has no other pollinator).

Agents of cross pollination

Abiotic	**Biotic**
* **Anemophily** (by wind) eg. Palm.	* **Entomophily** (by insects) eg. *Aristolochia*, *Salvia* (bee)
* **Hydrophily** (by water) eg. *Vallisneria*	* **Ornithophily** (by birds) eg. *Bombax*, *Bauhinia* (by humming birds)
	* **Chiropterophily** (by bats)
	* **Malacophily** (by snails & slugs) eg. aroids
	* **Myrmecophily** (by ants) eg. rubiaceae.

- **Advantages of cross pollination** are –
  - It induces genetic recombination and hence variation in progeny.
  - It increases the adaptability of offsprings.
  - Plants produced are more disease resistants.
  - New and more useful varieties are produced.
- **Disadvantages of cross pollination** are –
  - A factor of chance is always involved.
  - Some undesirable characters may creep in the race.
  - It is a highly wasteful process as large number of pollen grains have to be produced.

Fertilization

- The fusion of male gamete with female gamete (egg) is called **fertilization**.
- The **phenomenon of fertilization** was **first reported** by **Strasburger** (1884) in *Monotrapa*.
- The male gametes are brought to the egg containing female gametophyte by a pollen tube, the phenomenon is known as **siphonogamy**.
- The pollen tube eats its way through the solid part of the stigma and style by secreting **pectinase** and **hydrolytic enzymes**.
- In angiosperms the female gametophyte is seated deep in the **ovarian cavity** quite away from stigma.
- The partially developed **male gametophytes** (pollen grains) are normally held at the stigma.
- To effect fertilization the pollen grains **germinate on the stigma** by putting forth pollen tube which grows through the style and reach the ovules where they discharge the male gametes in the **vicinity of egg**.
- Fertilization occurs in **four steps**. *viz*
  - Germination of pollen on stigma
  - Growth of pollen tube
  - Pollen tube entry into embryo sac
  - Fusion of gametes.
- The first requirement for pollen to germinate is their **hydration** which takes from a **few seconds to a few minutes**.
- Pollen absorbs **secretion of stigma** (sugar, gum, resins and other liquid) and swells up. Exine ruptures and intine comes out in the form of **pollen tube**.
- Secretion of stigma is **sticky** and also prevents pollen as well as stigma from desiccation.
- The stigmas which secrete exudates are called **wet stigmas** (*Petunia*) and those which do not are called **dry stigmas** (cotton).
- The pollen tubes pierces through stigmatic papilla into tissue of style.
- Styles are of three types – **open, half closed and closed**.
- **Open style** is hollow and pollen tubes creep on the surface of special cells lining the stylar canal, e.g., papaveraceae and most monocots.

- In **half-closed style,** the canal is surrounded by a rudimentary transmitting tissue, e.g., cactaceae.
- In **closed style,** no open canal is present but instead a solid core of elongated cells with rich protoplasm, through which pollen tube moves is present, e.g., *Datura*, cotton.
- The **pollen tube enters the ovule in either of 3 ways** –
  - The process of entry of pollen tube through micropyle is called **porogamy**, eg. angiosperms.
  - The process of entry of pollen tube into the ovule through chalaza is called **chalazogamy**, eg. *Betula*, *Casuarina*.
  - The process of entry of pollen tube through integuments or funiculus is called **mesogamy**, eg. *Cucurbita* (through integuments) and *Pistacia* (through funiculus).
- The pollen tube **always enters the embryo sac at the micropylar end**.
- Inside the embryo sac, **one male gamete fuses with the egg** to the form zygote (2n), the process is known as **syngamy** or **generative fertilization**.
- The **second male gamete fuses with 2 polar nuclei or secondary nucleus to form triploid primary endosperm nucleus, the process** is known as **triple fusion** or **vegetative fertilization**.
- The **zygote develops into embryo** and **primary endosperm nucleus develops into endosperm**.
- The occurrence of syngamy and triple fusion simultaneously in angiosperms is called **double fertilization**.
- Double fertilization was **first reported by S.G. Nawaschin (1898)** in *Fritillaria* and *Lilium.*

Table : The transformation of part of flower

Before fertilization	After fertilization
Calyx, Corolla, Androecium, style Stigma	Wither
Ovary	Fruit
Ovary wall	Pericarp
Ovule	Seed
Integuments	Seed coats
Outer integument	Testa
Inner integument	Tegmen
Micropyle	Micropyle
Funicle	Stalk of seed
Nucellus (persistent)	Perisperm
Egg cell	Zygote (oospore)
Synergids	Disintegrate and disappear

- **Polyspermy** is the process when **more than 2 male gametes reach inside a single embryo**.
- Egg may be fertilized by more than one male gamete to form **polyploid zygot**e.
- The extra male gametes fuse with **synergids** or **antipodals** to give rise to **polyembryo**.
- When egg is fertilized with male gamete of one pollen tube and polar nuclei are fertilized by male gamete of other pollen tube, the phenomenon is called **heterofertilization**.

Endosperm and Embryogeny

- Post fertilization changes in plants involve **embryology** and **endosperm formation.**
- In angiosperms, the **zygote** develops into an **embryo** simultaneously with the development of the **endosperm**.
- Fertilized egg is known as **zygote** (2n), **which gives rise to embryo** after predetermined mode of divisions. This process of development of embryo is called **embryogenesis.**
- **Endosperm** is the **nutritive tissue which provides nourishment to the embryo in seed plant**.
- In angiosperm, endosperm tissue is **triploid** (3n). It is a **product of triple fusion**, a result of a fusion of two polar nuclei (n+n) and one of the male gametes (n) involving double fertilization.
- **No endosperm is formed in** members of families **orchidaceae, podostemaceae** and **trapaceae**.
- **On the basis of development**, **endosperm** are mainly of **three types** –
  - **Nuclear type**, e.g., *Cocos nucifera*, *Primula, Mangifera, Malva*
  - **Cellular type**, e.g., *Adoxa*, *Peperomia*, *centranthus*,
  - **Helobial type**, e.g., *Eremurus* (liliaceae).
- **Nuclear endosperm** is the most common type of endosperm found in angiosperms and is reported in **161 families** out of 288 for which record is available.
- In nuclear endosperm first and further divisions of primary endosperm nucleus are not followed by cytokinesis or wall formation and thus these **free nuclear divisions** lead to formation of a large number of free nuclei in embryo sac. At maturity, **centripetal wall formation** (from periphery towards centre) may occur to make the **tissue partly cellular**.
- In **cellular endosperm** first and further divisions

of primary endosperm nucleus are accompanied by cytokinesis or wall formation and thus the endosperm tissue is completely cellular. It is **reported in about 72 families** of angiosperms (**mostly dicots**).

- **Helobial endosperm** is restricted largely to the **monocotyledons.**
- In helobial endosperm the primary endosperm nucleus moves to the chalazal end of the embryo sac where it divides forming a large micropylar chamber and a small chalazal chamber. In the micropylar chamber, as a rule, free-nuclear divisions and cell formation, if any, start at a much later stage. In the chalazal chamber the nucleus either remains undivided or divides only a few times. If later is the situation, the divisions are usually free-nuclear.
- Endosperm of coconut is unique in sense that it is both **nuclear and cellular**.
- When surface of endosperm is uneven or having ridges and furrows it is called **ruminate endosperm**, eg. rubiaceae.
- When the tissue of endosperm is not homogenous, but there are patches of different colours, it is called **mosaic endosperm**, eg. *Zea mays*.
- Endosperm is **generally triploid** but it is **2n** in *Oenothera,* **9n** in *Pepromea*, **5n** in *Fritillaria*.
- **Seeds without endosperm** are called **exalbuminous seeds** or **non-endospermic seeds**, eg. pea, gram.
- **Seeds with endosperm** are called **endospermic** or **albuminous seeds**, eg. wheat, rice.
- A **dicot embryo** has an embryonal axis and 2 cotyledons attached to it laterally.
- **Epicotyl** is the portion of embryonal axis above the point of attachment of cotyledons.
- **Hypocotyl** is the portion of embryonal axis below the point of attachment of cotyledons.
- **Plumule** is at the **terminal end of epicotyl**.
- Hypocotyl at its end bears **radicle**.
- **Monocot embryos** have **single cotyledons**.
- Seeds are **matured ovules**.
- Integuments of ovules forms seed coat, outer integument forms **testa** and inner integument forms **tegmen**.
- Fertilized ovary is called **fruit**.
- In angiospermic plant, there are 2 phases in life cycle – the **sporophytic** and **gametophytic**.
- The sporophytic and gametophytic phase alternate with each other in a definite sequence, the process is called **alternation of generation**.

PARTHENOCARPY, APOMIXIS AND POLYEMBRYONY

- Development of fruits **without fertilization** is called **parthenocarpy**.
- The term parthenocarpy was coined by **Noll (1902)**.
- The parthenocarpic fruits are **seedless**. Eg. banana, guava, apple, pineapple etc.
- Parthenocarpy **can be induced artificially** by –
  - Spraying auxins (applied after anthesis) and gibberellins (applied at anthesis)
  - Delayed pollination
  - Use of foreign pollen grains
  - Use of powdered pollens and pollen extracts
  - Cutting style from base and applying chemical like IAA, IBA etc. in lanolin paste at cut surface.
- The substitution of sexual reproduction by asexual process, a form of reproduction which does not involve syngamy and meiosis is called as **apomixis**.
- The term apomixis was given by **Winkler (1908)**.
- Apomixis **occur by vegetative reproduction** (*described earlier also*) **and agamospermy**.
- Agamospermy is of **threee types** – **recurrent apomixis**, **adventitive embryony** and **non-recurrent agamospermy**. (*See flow chart on page 455*).
- The archesporium develops inside the nucellus of ovule which gives rise to megaspore mother cell, which directly develop into diploid embryo sac. This phenomenon is called **diplospory**.
- The phenomenon of **having more than one embryo** is called **polyembryony**, eg. onion, groundnut.
- Occurrence of polyembryony due to fertilization of more than one egg is called **simple polyembryony**.
- Formation of **extra embryos** through sporophytic budding is called **adventive polyembryony**.
- Polyembryony was **first discovered by Leeuwenhoek** (1719) and was **confirmed later by Schnarf** (1929).
- Polyembryony phenomenon is **more common in gymnosperms** than angiosperms. In **angiosperms**, it is **generally present as unusual feature** except few cases like *Citrus*, mango etc.

Types of Apomixis

- **Vegetative reproduction**
  There is no requirement ofseed for production of new plant.
  New plant is produced from buds, leaves & stem.
- **Agamospermy**
  Embryo & seeds are produced without involvement of fertlization and meiosis.
  - **Recurrent Apomixis**
    A diploid (2n) embryo sac is formed having diploid egg cell which grow into diploid embryo.
    E.g. apple, *Allium*.
    - **Diplospory**
      Diploid megaspore mother cell
    - **Apospory**
      Diploid nucellar mother cell
  - **Adventitive embryony**
    When one or few extra embryos are formed from a diploid cells of nucellus or integument but never from egg. Eg *Citrus*, *Opuntia*.
  - **Non-Recurrent Apomixis**
    Embryo developed Parthenogenetically from haploid egg, synergid, antipodal cells.
    - **Apospory**
      (Sporophyte $\xrightarrow[\text{directly}]{\text{form}}$ Gametophyte)
      Aposporous formed gametophyte are generally diploid
      Apospory leads to polyploidy formation
      Hence new species in pteridophytes & bryophytes.
    - **Apogamy**
      (Gametophyte $\xrightarrow[\text{directly}]{\text{form}}$ Sporophyte)
      No gametic fusion involved.
      Such sporophytes are not viable if produced from haploid gametophytes.

- There are **two types of polyembryony** such as **false** and **true polyembryony.**
- In false polyembryony more than one embryos arise in **different embryo sacs in the ovule**.
- In true polyembryony, **more than one embryos are formed in the same embryo sac** in the ovule,
- The **cause of polyembryony** may be –
  - Cleavage of proembryo, e.g., family orchidaceae,
  - Development of many embryos from other cells of embryo sac except egg, e.g., *Argemone*
  - Formation of many embryos due to presence of more than one embryo sac in same ovule, e.g., citrus
  - Formation of many embryos from the structure outside the embryo sac, (adventitive polyembryony), e.g. mango, *Opuntia*.
- A special and interesting case of polyembryony is found in *Allium odorum*, where **5 embryos develop by different methods**, *e.g.*, 1 → Zygotic, 1 → synergidal , 2 → from antipodals, and 1 → from integuments.
- **Maximum number of embryos, *i.e.*, 40** are reported inside single seed of *Citrus unshiu*.
- Polyembryony is **practically important because genetically uniform parental type seedling are obtained from nucellar embryos**.
- Nucellar embryos are **superior to those obtained by vegetative propagation** because nucellar embryos seedlings are **disease free and maintain their superiority for long time**.
- **Most important theory of cause of polyembryony** is **necrohormone theory** given by **Haberlandt** (1921), *i.e.*, a stimulus for polyembryony is provided by degenerating cells of nucellus.
- **Parthenogenesis** is the formation of embryo from the unfertilized female gamete.

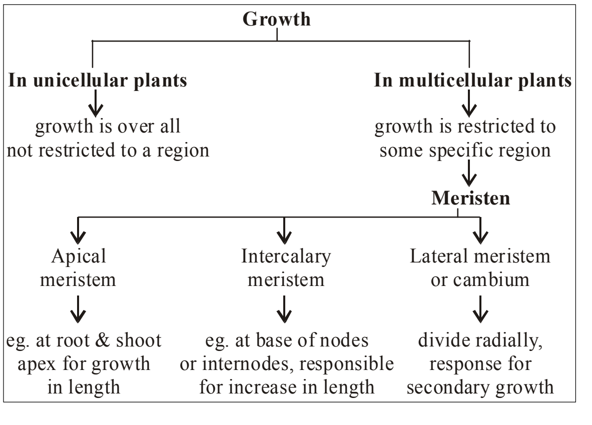
End of the Chapter

Chapter 47

Plant Growth and Movement

PLANT GROWTH AND DEVELOPMENT

- **Growth** is irreversible increase in dry weight, size, mass or volume of a cell organ or organism.
- Growth is **intrinsic in living beings**.
- The growth that take place between seedling emergence and flower initiation in a plant is called **vegetative growth**.
- Vegetative growth **takes place in vegetative parts of the plant.**
- **Reproductive growth** constitutes initiation of flowering, development of sex organs, fertilization and seed formation.
- In multicellular plants growth is restricted to some specific region (called **meristems**).
- The **growing region** in plants are **apices of shoot and root where meristems are present**.
- Meristems are classified into 3 types - **apical**, **lateral** and **intercalary**.
- The **apical meristem** is terminal in position and is **responsible for apical growth of plant**, e.g., shoot and root apices.
- **Lateral meristem** is **responsible for lateral growth or secondary growth** that increase the thickness of plant.
- The **intercalary meristem** is **responsible for localized growth of plant**, eg., in bamboo and mint.
- **Plant growth** takes place in **three steps** -
  – **Formative phase** or **cell division phase** (cells of apical meristem divide).
  – **Enlargement phase** or **cell elongation phase** (proteins, protoplasm, cell wall material is synthesized).
  – **Differentiation phase** or **cell maturation phase** (secondary walls are laid down).
- The **primary work** on **growth measurement** was done by **Sachs** (**1873**).
- When rate of growth is plotted in terms of length, size, area, volume or weight, **growth curve** is obtained.
- The rate of growth is represented against definite period of time.
- **S shaped** or **sigmoid** growth curve is exhibited by numerous annual plants.
- The **period** during which the **growth shows increase** is called **grand period of growth.**
- There are **three primary phases** which can be detected in a growth curve – **lag phase** (or slow phase), **log phase** (or exponential phase) and **steady phase**.
- In **lag phase**, the growth is slow, the growth increase during **log phase** and become steady or constant in **steady phase**.
- The **various methods for measurement of growth** in terms of increase in weight or length or volume are – **direct method** in which growth is measured directly by a scale at regular intervals from beginning to end, **horizontal microscope** or travelling microscope, **Bose crescograph**, **auxanometer** (arc auxanometer, pfeffer's auxanometer), **space marker disc.**
- The **various factors that affect the growth** are – food supply, water supply, oxygen supply, temperature, light-intensity, quality and duration, and growth hormones.



- Water, oxygen and nutrients are very essential element for growth.
- Plant cells grow in size by cell enlargement which in turn requires water.
- Turgidity of cells helps in extension growth.
- Water also provides the medium for enzymatic activities needed for growth.
- Oxygen helps in releasing metabolic energy essential for growth activities.
- Nutrient (macro and micro essential elements) are required by plants for the synthesis of protoplasm and as source of energy.
- Every plant organism has an optimum temperature range best suited for its growth.
- Environmental signals such as light and gravity also effects certain phases/stages of growth.
- The cells derived from root apical and shoot apical meristems and cambium differentiate and mature to perform specific functions. This act leading to maturation is termed as differentiation.
- During differentiation, cells undergo few to major structural changes both in their cell walls & protoplasm.
- The living differentiated cells, that by now have lost the capacity to divide can regain the capacity of division under certain conditions, the phenomenon is termed as redifferentiation.
- **Development** is a term that includes all changes that an organism goes through during its life cycle **from germination of the seed to senescence**.

Meristematic cell → Cell division → Plasmatic growth → Differentiation
↓
Cell elongation
↓
Cell maturation
↓
Mature cell → Senescence → Cell death

Photoperiodism

- **Photoperiodism** is the response to durational and timings of light and dark periods in terms of flowering.
- It was **first studied by W.W. Garner and H.A. Allard** (1920) in Mary land Mammoth (mutant variety of tobacco).
- The hours of light that a plant has been exposed is called **photoperiod**.
- The length of uninterrupted photoperiod that has to be always exceeded in long day plants and must not exceed in short day plants is called **critical day length**, eg. *Xanthium* is a short day plant and its critical length is 15 hrs *i.e.* below 15 hrs flowering will take place.
- **Depending on the length of photoperiod requirement for flowering**, the plants are classified into– (a) short day plants, (b) long day plants, (c) day neutral plants, (d) short long day plants, (e) long short day plants, and (f) intermediate plants.
- **Short day plants** (SDP) or **long night plants** are those plants where flowering take place when they are **exposed to shorter photoperiod**, *i.e*, day length is less than the critical length, for eg. Maryland Mammoth tobacco (*Nicotiana tobaccum*) *Xanthium, Crysanthemum*, rice, sugarcane, potato, soyabean (*Glycine max*), *Aster*, *Dalhia* etc.
- **Long day plants** (LDP) or **short night plants** are those plants where flowering takes place when they are **exposed to longer photoperiod** *i.e.*, more than critical day length, for eg. spring barley, sugarbeet, henbane (*Hyoscyamus niger*), wheat, radish, oat, spinach, lettuce etc.
- **Day neutral plants** or **day length indifferent plants** are those plants where day length does not influence flowering. These plants **flower in both shorter and longer photoperiod**, for eg. maize, cotton, tomato, cucumber, sunflower, pepper etc.
- **Short long day plants** (SLDP) require short photoperiod for initiation of flowering and long photoperiod for blossoming, eg. *Trifolium repens.*
- **Long short day plants** (LSDP) require long photoperiod for initiation of flowering and short photoperiods for blossoming, eg. *Bryophyllum*, *Cestrum*.
- **Intermediate plants** (IP) flower within a definite range of photoperiod, eg. wild kidney bean.
- Phenomenon of producing photoperiod influence on the production of flower is **photoperiodic induction** or **photoinduction**.

Phytochrome

- The pigment that played a role in seed germination in *Letuca sativa*, was named **phytochrome** by Butler.
- Phytochrome is glycoprotein in nature with a light absorbing portion called chromophore.
- Phytochrome in plants **occur in two inter-**

convertible forms namely $\mathbf{P_r}$ **($\mathbf{P_{680}}$) and $\mathbf{P_{fr}}$ ($\mathbf{P_{730}}$)**.

- $\mathbf{P_r}$ form of pigment **absorbs red light** and $\mathbf{P_{fr}}$ form of pigment **absorbs far red light.** Two forms can be **represented** as — $P_r \underset{\text{far red light}}{\overset{\text{red light}}{\rightleftharpoons}} P_{fr}$.
- The **$\mathbf{P_r}$ form is inactive** and **$\mathbf{P_{fr}}$ is the active phase** of the pigment related to photomorphogenesis.
- P_{fr} form is **needed for flowering in LDP** and **seed germination** and P_r form **helps in flowering of SDP**.
- Phytochrome is widely distributed and is associated with membrane. It is **found in angiosperm, gymnosperms, bryophytes**, **some green algae**, **red algae** and **brown algae**.
- Different phytochrome activities are flowering, elongation of leaf, stem petiole, development of root rhizome, bulb, germination of pollens, unfolding of hypocotyl hook and grass leaf, differentiation of stomata & tracheary elements.

Vernalisation

- Low temperature induction of flowering is called **vernalization**.
- In vernalization, by **cold treatment winter varieties are transferred into spring or summer varieties.**
- The **stimulus for vernalization** is perceived by **buds, meristems, seeds, seedlings** & even **embryo**.
- Nullifying the effect of vernalisation is called **devernalisation.**
- German plant physiologist **George Melchers** (1937) has proposed the existence of a stimulus of vernalisation and coined it a **vernalin**.
- Vernalisation **help in shortening the vegetative period** of plant. It **prepares the plant for flowering**.
- Vernalisation **increases yield, resistance to cold and diseases**.
- **Gibberellins**, a plant hormone **can replace the requirement of vernalisation**.
- **Florigen** (a flowering hormone) is synthesized in older leaves and then transferred to flowering region. It initiates the floral bud initiation.

Seed germination

- **Seed** is fertilised and ripened ovule which contains a dormant embryo, reserve food for its future development and protective covering.
- The formation of seedling from dormant embryo of seed after resumption of its active growth, is called **germination**, or in other words the activation and growth (rejuvenation) of the embryo into a seedling during favourable conditions is called germination.

Physical and physiological changes during germination

- First physical process during germination is **absorption of water by imbibition**.
- First biochemical reaction during germination is **hydrolysis of reserve food.**
- In cereals and millets reserve food (carbohydrate) is hydrolysed by **amylase**.
- In pulses, reserve food (protein) is hydrolysed by **proteases**.
- In oil seeds like coconut, castor etc reserve food (fat) is hydrolysed by **lipase**.
- In the presence of water enzymes are activated.
- By the action of hydrolytic enzymes, complex reserve food materials are degraded and converted into simple, soluble, osmotically active substances. The embryo absorbs these simple food substances and grow in size by repeated cell division.
- Meanwhile the seed coat ruptures and the growing embryo is exposed to air and light.
- **Rate of aerobic respiration increases rapidly** and cells of the primary axis (of the embryo) synthesize proteins and DNA.
- Newly formed cells elongate rapidly.
- Radicle emerges out of the seed first and develops into root system. Due to elongation of hypocotyl region the plumule comes above ground and later, develops into shoot system.
- First structure that comes out during germinations is **radicle**.
- Respiration rate is **increased in germinating seeds**.

Types of seed germination

- Germination is basically of **two types** depending upon behaviour of cotyledons, these are **epigeal** and **hypogeal.**
- When due to hypocotyl growth or elongation, cotyledons are pushed out of soil, the germination is called **epigeal germination**.
- Epigeal germination is seen in **legumes, cucurbits,** *Ricinus* etc.
- When due to epicotyl elongation, plumule comes out of the ground and cotyledons remain underground, the germination is called **hypogeal germination.**

- Hypogeal germination is seen in **cereals, millets, grams, coconut**, *Mangifera* etc.
- Germination of seed before dispersal is called '**vivipary**' (or) ***in situ*** **germination**.
- Vivipary is a **characteristic feature of mangroves**, eg., *Rhizophora, Avicennia* etc.

Factors affecting seed germination

- Seed germination is directly affected by many external (environmental) and internal (physiological) factors.
- **External factors** – Among many external factors that affect seed germination **water**, **temperature**, **oxygen** and **light** are important.
- **Water**
  - Seeds are the driest structures of the plant, they contain minimum amount of water.
  - Water activates the enzymes which digest the complex reserve foods of the seed.
  - It maintains the turgidity of the embryonal cells and helps in cell elongation.
  - It helps in the rupturing of the seedcoat.
  - It is the medium for all physiological processes.
  - If the water content of the seed goes below a critical level, seeds fail to germinate.
- **Temperature**
  Seeds fail to germinate at very low and high temperatures. Low temperature inactivates the enzymes and high temperature denatures the enzymes. The optimum temperature for seed germination varies from plant to plant. A temperature range of 15º - 30ºC is favourable for germination in most plants.
- **Oxygen**
  Oxygen is **highly essential for germination**. In the beginning, germinating seed respires anaerobically. When the seed coat ruptures, the embryo is exposed to air and carries on aerobic respiration at a higher rate. In the absence of O_2 oxidation of food materials is stopped and the embryo fails to grow.
- **Light**
  - Seeds of most of the plants usually do not require light for germination. However, seeds of epiphytes, *Ficus aurea*, *Digitalis purpurea*, *Salicoira*, *Nicotiana*, *Rumex*, *Viscum* (mistletone) poa grass etc., require light for germination.
  - Seed which germinate only in presence of light, are called **photoblastic seeds**.
- **Internal factors** – The important internal factors which interfere with seed germination are :
  - **Seed viability** – The capacity of a seed to germinate and develop into a seedling is called **seed viability**. The viability of seeds varies in different plants. It **depends on the method of storage, healthiness of the parent, age of the seeds, maturity of the seeds** etc.
  - **Longest seed viability is reported in** *Nelumbo nucifera (= Nelumbium speciosum)* or **Indian lotus** (**Kamal**).
  - **Seed vigour** – The ability of a seedling to establish itself in the soil and lead independent life is called **seed vigour or germinating vigour**.
  - **Completion of seed dormancy** - Many seeds require a dormancy or resting period after harvesting and germinate only after resting period.
  - **Food availability** - Sufficient amount of food is required for growing embryo.
  - **Maturity of embryo**.

Seed dormancy

- Seeds of some plants like rice, maize, germinate immediately after reaching the ground. Seeds of *Citrus* and *Rhizophora* show **vivipary**. But in majority of plants seeds remain in an inactive state and germinate only after a specific period of rest. Such inactive state is called **dormancy** or **quiscence**.
- Dormancy may be defined as "**the inactive state of the seed in which growth of the embryo is temporarily suspended for a specific length of time.**"

Causes of dormancy

- **Tough and thick seed coats**
  Seed coats of some plants like mustard, shephard's purse, *Lepidium* (pepper grass) etc., are very tough. The growing embryo fails to emerge out due to the resistance of the thick seed coat. Therefore, such seeds remain dormant until their seed coats become soft and thin due to ageing.
- **Impermeable seeds coats**
  Seed coats of some plants are thick and impermeable either to water (seeds of Malvaceae, Leguminosae, achenes of *Nelumbium*) or oxygen (seeds of

Compositae - *Xanthium*). As a result seeds remain dormant. In nature, such seed coats become soft and permeable due to microbial action and fluctuations of temperature and moisture.

- **Immature (rudimentary) embryos**
  In some orchids, the seed contains an immature or incompletely developed embryo, at the time of shedding. Immature embryo may be in the zygote stage or a few celled proembryo stage. Such seeds germinate only after the embryo completes its development.
- **After ripening effect**
  Seeds of apple, peach etc., contain fully developed (mature) embryos by the time they are shed. But these seeds fail to germinate even if favourable conditions are provided. Dormancy of this type is due to physiological immaturity of the embryo. Such seeds undergo '**after ripening**' in nature and then only germinate.
- **Dormancy due to light requirement**
  Photoblastic seed, eg, lettuce, donot germinate in absence of light.
- **Germination inhibitors**
  Seeds of some plants like tomato fail to germinate due to the presence of growth inhibitors like **abscissic acid (ABA)**, **caffiec acid**, **ferulic acid**, **coumarins** etc. These inhibitors prevent the germination of the embryo. In nature, these inhibitors are gradually washed off from the seeds.

Methods of breaking domancy

- **Mechanical scarification :** Mechanical rupturing of seed coat.
- **Chemical scarification :** Weakening of seed coat by acid, water, solvents etc. Dormancy can be broken by treating the seeds with strong acids (H_2SO_4) or dipping in boiling water or rubbing on a rough surface. This is called chemical scarification.
- **Chilling treatment** – Seeds are stored at low temperatures (0° - 10° C) for two - three months in open places in alternate layers with sand. This is called **stratification**, eg., Peach, Cherry.
- **Counteracting inhibitors** – Dormancy can be broken by soaking seeds in KNO_3 thiourea, repeated soaking and washing of the seeds in water. Plant hormones like **gibberellins also break this type of dormancy**.
- **Vigorous shaking**
- **Exposure to red light** – It induces germination in lettuce.
- **Providing high pressure** – 2000 kg for 5 – 20 mins.

Seed certification

- Good seed always gives better yield. Selection of good seeds is an important aspect of present day agriculture. Modern plant breeding techniques also aim at producing **quality seed**. Seeds that give rise to high yielding, disease and drought resistant, early maturing plants are called **quality seed**. Quality of the seed determines the yield. The qualities of better seed are :–
  - High rate of germinating vigour
  - Short duration of the crop
  - Disease resistance
  - Pest resistance
  - Limited vegetative growth
  - High yield.
- In order to supply such seed to the farmers, **Central Seed Certification Agency** was started in 1966.
- Andhra Pradesh state seed certification agency classified the seeds into four types depending on the generation of the seed – breeder's seed, foundation seed, registered seed and certified seeds.

Senescence

- **Senescence** is the stage in the life history of an individual when the rate of metabolic activities decline that leads to ageing and then eventually death.
- Plant senescence is of **four types** -
  - whole plant senescence
  - shoot senescence
  - sequential senescence
  - simultaneous or synchronous senescence.
- **Whole plant senescence** is found in **monocarpic plants** where flower and fruit formation take place only once in their life cycle, eg. rice, wheat.
- In **shoot senescence**, aerial organs die but underground organs survive, for eg. *Gladiolus*.
- In **sequential senescence**, senescence of organ continues throughout the year. The older leaves and lateral organs show senescence and die, for eg. mango, *Eucalyptus*.
- In **simultaneous senescence**, shedding of leaves take place in autumn, for eg. Maple, elm.

- Senescence occurs in **non-meristematic cells**, and **meristematic cells donot undergo senescence**.
- **Abscission** is the natural shedding of leaves from the plants without any response to injury, but due to change in hormonal balance.
- **Abscission zone** is the special narrow zone that develops in the area of abscission.
- Two distinct layers develop in the abscission zone are– **separation layer** (**upper layer**) and **protective** (**lower layer**).

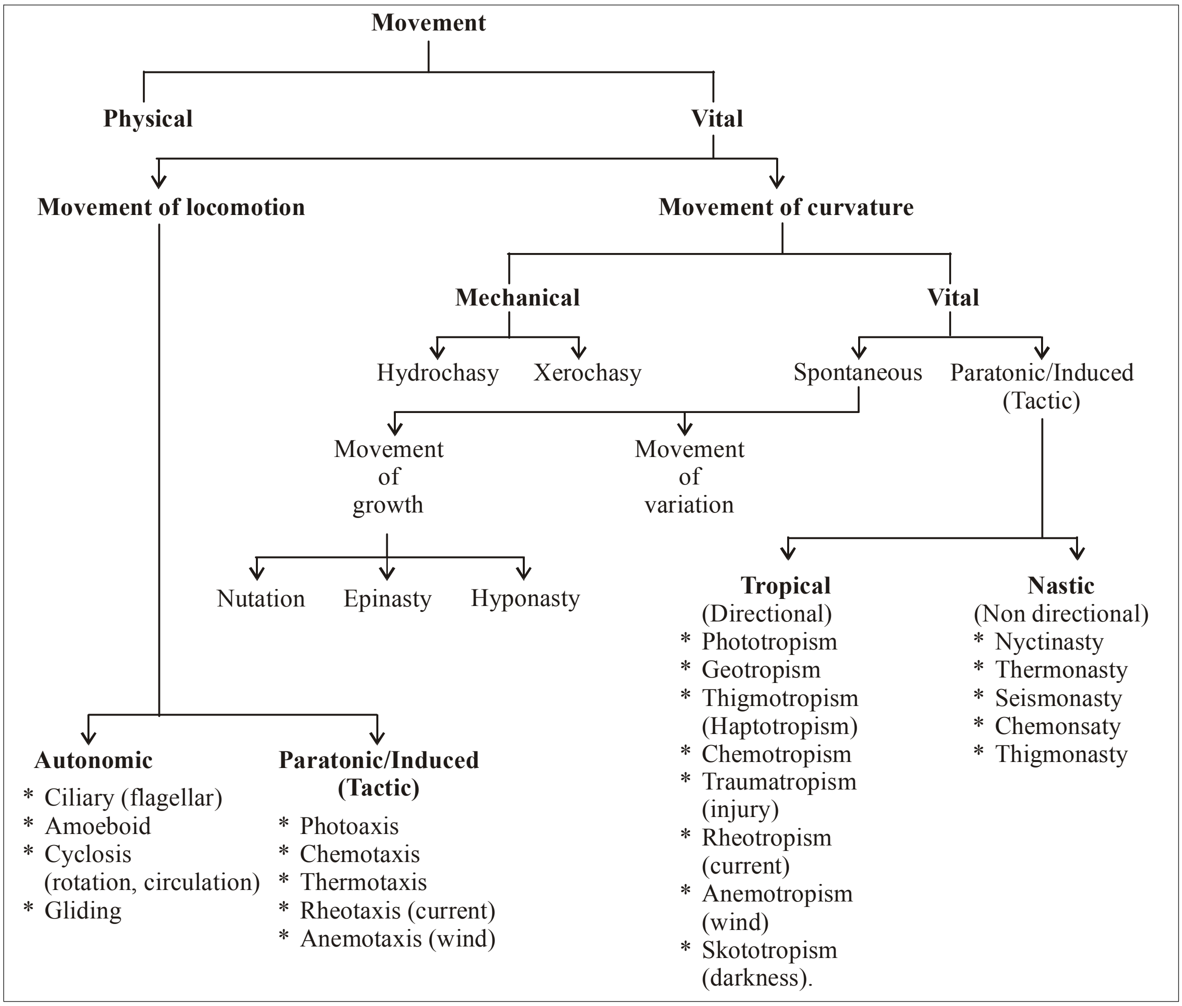
PLANT MOVEMENT

- The capacity of plants to change their position in response to external or internal stimuli is known as **plant movement**.
- **Stimulus** is the any change in the environment of an organisms or of part of it which is intense enough to produce a change in the activities of the living material, without itself providing energy for the new activities.
- Stimulus is defined by **Verworn.**
- Sensitiveness to stimulus is called **irritability**.
- The specific region or site where the stimulus is received for changing position is called **perception site**.
- The minimum period for which stimulus should be given for inducing plant movements is called **presentation time**.
- **Conditions that are necessary for plant movements** are water, temperature, oxygen, hormones, non-fatigued tissue or organ.
- There are **two broad kinds of movements of plants – movements of locomotion** and **movements of curvature.**
- Movement of whole organisms or cellular constituents is referred to as **movement of locomotion**.
- The **two types of movements of locomotion** are– **spontaneous** (**or autonomic**) and **paratonic** (**or induced or tactic**).
- **Spontaneous movements of locomotion** occurs due to internal cause and are without any influence of external stimuli.
- **Common spontaneous movements of locomotion** are – ciliary or flagellar movements, amoeboid movements, cyclosis or streaming of protoplasm, excretory movement.
- Movements of mobile algae, gametes and zoospores having cilia or flagella takes place automatically and are known as **ciliary movements**.
- Movements that can be observed in the plasmodia of slime moulds (*Myxomycetes*) are **amoeboid movements.**
- Cytoplasm of eukaryotes show perpetual locomotion called **cyclosis or streaming movement**.
- Cyclosis is of **two types - rotation** and **circulation**.
- Cyclosis around a single central vacuole in clockwise or anticlockwise direction is **rotation**, eg. observed in leaf cells of *Hydrilla* and *Vallisneria.*
- Cyclosis around many vacuoles of a cell in clockwise or anticlockwise directions is called **circulation**, eg., in staminal hair of *Tradescantia* and shoot hair of gourds.
- In *Oscillatoria*, apical part shows oscillation due to excretions of some substances. This type of movement is called **excretory movement**.
- Induced movements of locomotion are due to **external causes or stimuli**.
- **Depending on the nature of stimulus**, taxis or tactic movements may be **chemotaxis** (when influenced by chemical substances), **phototaxis** (when influenced by light), **thermotaxis** (when influenced by temperature).
- **Chemotaxis** is locomotory movements **in response to presence of chemicals**, e.g., spermatozoids towards sucrose, malic acid in archegonia of moss and fern.
- **Phototaxis** is a locomotion **in response to direction and intensity of light**, like small algae moving towards moderate light.
- Chloroplast present in palisade cells of higher plants also move in accordance with the **intensity of light**.
- Movement of motile algae from cold water to slightly warm water is **thermotactic in nature**.
- Movement of plant parts in relation to others are called **movements of curvature**.
- Movement of curvature are **caused by unequal growth in different parts of plant**.
- Movements in curvature are **mechanical** and **vital**.
- **Mechanical movements** take place in the non living organs of the plant. Such movements are possible **due to the imbibition of water** (**hydrochasy**, eg. spore dispersal in moss) or **loss of water** (**xerochasy**, eg. bursting of explosive fruits).
- **Vital movements** are **observed in living part** and

are **two types - spontaneous** (or autonomic) **paratonic** (or induced).

- **Spontaneous movement of vital movements** are of two kinds – **movement of variation** and **movements of growth.**
- **Movement of variation** takes place **due to variation in the turgidity of cells**. This type of movement is exhibited by the pulsation of the two lateral leaflets of *Desmodium gyrans* and movements of leaves of *Mimosa pudica.*
- **Movement of growth** is a **slow movement** and it **occurs in growing organs** due to the difference in the ratio of the growth of different parts of the growing organs.
- Movement of growth are – **nutation**, **epinastic** and **hyponastic.**
- **Nutation movement** is the growth in the apex of the stem in zigzag manner due to alternate change in growth rate on opposite side of the apex.
- A nutational movements may be **circumnation** when the apex of the stem makes rotational growth around its long axis. It is **found in stem tip of twinners**.
- When movements occurs due to faster growth on the upper side of the organ then it is called **epinastic movement**, eg. opening of flower.
- When the movement occurs due to the faster growth on the lower surface of the growing organ then it is called **hyponastic movement**, eg. closing of flower, rolling of leaves.
- **Induced movements of vital movements** are of two kinds : **tropic or directional,** and **nastic or non-directional.**
- **Tropic movement** take place under the influence of unidirectional stimulus and the response may be related to the direction of the stimulus.
- Important tropic movements are **phototropism, geotropism, hydrotropism, thermotropism, thigmotropism** and **chemotropism.**
- When the tropic movement is induced by unidirectionally supplied light, then it is **phototropism**.
- If the curvature movement is **towards the source of light**, then it is called **positive phototropism** and if **away from the source of light**, then it is called **negative phototropism**.
- The leaves of many plants grow at right angles to the incident ray, hence they are called **diaphototrophic**.
- Root is **negatively phototropic** and stem is **positively phototropic**.
- **Examples of phototropism** are flower heads of sunflower and leaves of *Neptunia olearacea* that show movement in accordance with the angle of the sun *i.e.*, they show movement from **east to west**.
- **Only blue wavelengths of light are effective** in producing phototropic response.
- **Geotropism** is a tropic movement in which curvature takes place in the stem or the root under the influence of unidirectional stimulus of gravity.
- **Stem** are **negatively geotropic** and **roots** are **positively geotropic.**
- When some plants grow horizontally *i.e.*, at right angle to gravity (for eg. runners, stolons etc.) then it is called **diageotropism**.
- The stem and root branches **growing at an angle of 45°** from the vertical axis are termed as **plageotropic** or **plagiogeotropic**, eg. secondary lateral roots.
- **Thigmotropism** is a directional curvature movement of growth which is produced in response to stimulus of contact, eg. tendrils of *Passiflora*, pea etc.
- **Hydrotropism** is directional growth movement of curvature which is caused by unilateral stimulus of water.
- Roots are positively hydrotropic.
- **Chemotropism** is a directional paratonic movement of curvature that occurs in response to chemical stimulus.
- Growth of pollen tube is the style, ovary and ovule is a chemotropic movement.
- The roots of *Lupinus albus* show **positive chemotropism** with sodium mono hydrogen phosphate and negative chemotropism with KNO_3, $Ca(NO_3)_2$, NH_4NO_3 etc.
- Responses which do not have relation with the direction of stimulus are called **nastic movement** or **nastic responses.**
- Nastic movements are **caused by turgor changes** (swelling or shrinkage of living cells due to change in osmotic potentials).
- Important nastic movements are **nyctinasty**, **thermonasty**, **seismonasty**, **photonasty**, **thigmonasty**.
- **Nyctinasty movement** or **sleep movement** is induced by alternation of day and night (diurnal changes).

- Nyctinasty is caused by the daily rhythms of action of **light and dark**.
- Nyctinasty is **observed in many leguminous plants** such as *Albizia, Cassia* etc.
- Movements induced by **temperature variation** is called **thermonasty**, eg. flowers of *Crocus* and *Tulip* which open in warm normal temperature and close in cool temperature.
- In **seismonastic movement** response is made to **mechanical shocks** such as blows, shaking or pressure.
- **Movements of leaves or leaflets of sensitive plant** like *Mimosa pudica,* is an **example of seismonastic movement**.
- Seismonastic movement is **due to turgor changes in the cells of pulvinus or swollen area** lying at the base of the petiole, pinnae and pinnules. **Drooping** is **caused due to loss of turgidity of lower portion of pulvinus**.
- **Thigmonastic movements** are exhibited by some insectivorous plants as *Dionaea,* venus fly trap etc. The plants have tentacles which are sensitive to the stimulus of touch.
- **Photonastic** or light induced opening and closing of flowers is seen in *Oxalis* and sunflower.



End of the Chapter

Chapter 48

Phytohormones

- A **plant hormone** or **phytohormone** is a chemical substance produced naturally in plants which is translocated to another region for regulating one or more physiological reactions when present in low concentration.
- **All phytohormones are growth regulators** but **all growth regulators are not phytohormones**.
- The **same hormone may produce a different response in different organ** as auxin concentration promotes shoot growth but inhibit root growth.
- A similar response may be produced by different plant growth hormones, eg., both auxins and gibberellins promote cell enlargement.
- Phytohormones can be **broadly divided into two groups based on their functions in a living plant body** – **growth promoters** and **growth inhibitors**.
- **Auxin**, **gibberellins** and **cytokinin** are **growth promoters** and **ethylene** and **abscisic acid** (**ABA**) are **growth inhibitors**.
- Growth promoters are **involved in growth promoting activities**, **such as cell division**, **cell enlargement**, **pattern formation**; **tropic growth**, **flowering**, **fruiting** and **seed formation**.
- Growth inhibitors are **involved in various growth inhibiting activities such as dormancy and abscission** and also play an important role in plant responses to wounds and stresses of biotic and abiotic origin.
- The **gaseous plant hormone ethylene** could fit either of the groups, but is **largely an inhibitor of growth activities**.

AUXIN

- **F.W. Went** first named the chemical substance 'auxin' (means to grow) **derived from Greek word auxein**.
- Auxin is **weakly acidic growth hormone** having an unsaturated ring structure and **promotes cell elongation especially in shoots**.
- **Auxins obtained from plant** are called **natural auxin**.
- **IAA** (Indole acetic acid) is a **natural auxin** obtained from *Rhizopus scinus* and *Avena* coleoptile.
- **Tryptophan** is the **precursor of IAA** and **zinc is required for its synthesis**.
- Many auxins have been synthesized and some examples of **synthetic auxins** are **indole-3-butyric acid (IBA), naphthalene acetic acid (NAA), 2,4-dichlorophenoxy acetic acid (2,4-D), 2,4,5-trichlorophenoxyacetic acid (2, 4, 5 -T)**.

Agent Orange

Mixture of two phenoxy herbicides in ester form, 2, 4-D and 2, 4, 5–T (dioxin) is given the name agent orange which was used by USA in Vietnam war for defoliation of forests (*i.e.* in chemical warfare). Phenoxy agents work by mimicking a plant growth hormone, 1AA. When sprayed on broad leaf plants they induce rapid uncontrolled growth eventually killing them.

- **Free auxins** are those which **are easily diffusible** *i.e.*, they move out of tissues easily, e.g., IAA, indole-3 ethanol etc.
- **Bound auxins** are those which **are not diffusible** and **they can be removed from the plant tissues by the application of some special techniques like enzymolysis** etc., e.g. auxin glycosyl esters.
- **Active sites of auxin synthesis** are shoot tip region and **its synthesis occurs rapidly in green leaves in the presence of light than in dark**.
- Indole acetic acid is **destroyed by enzymatic oxidation** and **photo-oxidation**.
- **IAA oxidase**, an enzyme, which oxidises IAA was isolated in 1947 by **Yang and Bonner**.
- **F. Skoog** had reported that auxin is inactivated under

the influence of X-rays and gamma radiations and ultraviolet light brings about inactivation of IAA.

- Translocation of auxins is **polar.**
- **Auxin transport** is **basipetal in stem** and **acropetal in roots**.
- Transport of auxin is **energy consuming** and is **drastically reduced in the absence of oxygen**.
- Compounds that inhibit the polar auxin transport are called **antiauxins**. Eg. 2,3,5-triiodobenzoic acid (TIBA), α-naphthylphthalamic acid (NPA).
- **Ethylene** (a gaseous hormone) **also inhibits auxin polar transport**.
- The use of living material for testing the effect of biologically active substances is called **bioassays**.
- **Avena curvature test** (given by F. W. Went) and **split pea stem curvature test** are the bioassays that are generally used for auxins.

Physiological effects of auxin

- The cell enlargement is induced by auxin by
  - increase in **osmotic content** of the cell.
  - increase in **cell membrane permeability** to water.
  - reduction in wall pressure.
  - synthesis of wall material.
  - increase in respiration.
  - synthesis of specific RNA and proteins which result in increase in cell wall plasticity.
- Auxin **initiates** and **enhances cell division** by inducing **meristematic activity** and **cambial cells activity**.
- Auxin **induce early differentiation of xylem and phloem in tissue culture experiments**.

  Auxin + 2% sucrose – **Xylem–differentiation**
  Auxin + 3% sucrose – **Xylem and phloem differentiation**
  Auxin + 4% sucrose – **Phloem differentiation**
- In tissue culture growth of callus requires the presence of auxin, e.g., 2, 4-D.
- It has been suggested that **traumatic acid** (wound hormone) is produced which **increases cell division resulting in callus formation**.
- Auxin **causes root initiation but high concentration of auxin inhibits the root growth and the number of branches of roots are also decreased**.
- **IBA**, a synthetic auxin is a **potent root initiator**. Other auxins used as rooting agent are NAA, IAA etc.
- **Apical dominance or bud inhibition** is the phenomenon of suppression of growth of lateral buds by apical buds. When apical buds are removed, lateral buds develop into branches.
- Apical dominance is **due to the presence of high concentration of auxins in apical buds**.
- Auxin **enhances the size of carpel** and **hence earlier fruit formation**.
- **Hitchock and Zimmerman** for the first time showed that flowering in *Nicotiana* can be stimulated by auxin.
- Auxin **increases the number of spikelets in wheat and flowering in pineapple**.
- **NAA** induces the formation of more fertile branches in cotton plants.
- IAA promotes **formation of female flowers** (feminization).
- Flowers are borne only on dwarf shoot in apple tree but NAA increases the number of dwarf shoot and therefore more flower and fruits are borne.
- The development of fruit without pollination and fertilization is called **parthenocarpy**, and such fruits are obtained by spraying with dilute solution of IAA & IBA.
- Auxins like **IAA**, **IPA**, **NAA** and **IBA** are commerically **used to induce parthenocarpy in banana, orange, citrus, grapes, guava etc**.
- Auxin **delays abscission of leaves and fruits**.
- 2,4-D, NAA, 2,4,5-T (2,4,5 trichlorophenoxy acetic acid), MCPA (2, methyl-4 chlorophenoxy acetic acid) are **used as effective weedicides or herbicides**.
- **2,4-D** is a **selective weed killer** as it is **toxic to broad leaved plants** and in low concentration it is useful in preventing preharvest fruit drop of orange and apple.
- According to **Cholodny-Went theory auxins are responsible for phototropism and geotropism**.
- IAA is known to **stimulate nodule formation**.
- Few auxins are used to **prolonging the life of storage products** like corm, tuber, rhizomes etc., e.g. NAAM (**Naphthalene acetamide**).

GIBBERELLINS

- Gibberellins are **weakly acidic plant growth hormone** that **possess a gibbane ring structure** and are **able to promote cell elongation** of the stem, leaves and also internodal length of genetically dwarf plant.

- They are named after fungus *Gibberella fujikuroi* which produces **foolish seedling disease of rice** or **bakanae disease**.
- **Yabuta**, **Hayashi** and **Kahnbe** first isolated the active principle toxin secreted by the fungus which was called **gibberellin** by them.
- Chemical nature of Gibberellins was established in 1954 and till now more than 100 different types of gibberellins have been isolated.
- Chemical gibberellins are related to **terpenoids** and its precursor is **kaurene.**
- Gibberellins are found in **angiosperms, gymnosperms, ferns, algae** but **rarely in fungi** and **bacteria.**
- **Sites of gibberellin synthesis** are young leaves (**major site**), root tips and immature seeds.
- Gibberellins **move readily in all directions and in all tissues including phloem and xylem**.
- **Translocation of gibberellins** is **passive**, **non polar** and **diffuse type**.
- Techniques used for the **bioassay of gibberellins** are – **dwarf pea elongation technique**, **barley endosperm digestion technique**.
- Compounds that inhibit the action of gibberellins are **antigibberellins or gibberellins retardants**. Examples are phosphon D, Amo 1618, paclobutrazol, cycocel (CCC), maleic hydrazide etc.

Physiological effects of gibberellins

- Gibberellins **enhances seed germination** by enhancing amylase synthesis and thus overcomes dormancy.
- **In the aleurone layer of barley** the gibberellins **increase the transcription of genes that code for protease and amylase enzyme**.
- Gibberellins **stimulate conversion of storage polymers into sucrose or mobile amino acids** during germination to facilitate their translocation *via* phloem into and through out the young root and shoots.
- The **cold treatment** which breaks the natural bud dormancy **increases the endogenous level of gibberellins**.
- Gibberellins **play important role in elongation of internodes in rosette plants** (e.g. Henbane, cabbage) which is called **bolting**. Flowering takes place after bolting.
- Gibberellins **causes etiolation** (elongation) **in plants when kept in dark**, as flavonoids which are inhibitors of GA are not formed in dark.
- Gibberellins **induces cell division and cell elongation** when bolting take place.
- Genetic dwarfism is caused by mutation of a single gene. If gibberellins is sprayed on these single gene dwarf plants, **genetic dwarfism is overcome** and plants become long, eg. in maize, pea etc.
- Gibberellins play an important role in the **initiation of flowering in vernalised and long day plants during short day condition**, eg. cabbage.
- **Synthesis of florigen** which is a flowering hormone is mediated through gibberellins.
- Gibberellins promotes **male flowers production** *i.e.*, on female plant, male flowers are produced by application of gibberellins, e.g., *Cannabis.*
- Exogenous application of gibberellins also **induces the production of parthenocarpic fruits**. Examples are plants belonging to family rosaceae, as stone fruits and pome.
- When gibberellins are sprayed on the plants their leaves become expanded. It **results in an increase in the total photosynthetic area and biomass**.
- Commercially gibberellins are employed to
  - **increase the size of seedless grape fruits**,
  - **increase the height of sugar cane plant** and **thus enhances the yield of sugar**.
  - **used in storage of orange as it prevents rind disorder by delaying senescence**.

CYTOKININS

- Cytokinins are **mildly basic growth hormones** which are usually **amino purine derivatives** and **promote cell division in plants**.
- **Miller** in 1955 isolated an active substance from autoclaved DNA from Herring sperms which stimulated cell division. He named this substance as **kinetin**.
- Chemically kinetin was identified as **6-furfurylamino purine.**
- **Zeatin** is a **naturally occurring cytokinin**. **Letham obtained zeatin** in pure crystalline form in unripe maize grains.
- Zeatin **occurs in the roots, stem and leaves** but it is **present in abundance in its milk kernels**.
- **Synthetic cytokinins** are substances that show cytokinins like activities. The examples are **6 aminopurine** (adenine), **benzimadazole**,

6-benzyladenine, 2 ip (isopentanyl adenine).

- **Beauchene** and **Bontarel** in 1963 prepared a compound **N^6-isopentanyl adenine** which **is ten times more active than cytokinins**.
- Precursors of cytokinin is either **adenine** or **adenosine**.
- Cytokinins are **found in abundance in young roots, leaves** and **young fruits** and are **synthesised in the meristematic regions of the plants**.
- **Translocation of cytokinin** takes **place through xylem**. Mobility is **polar** and **basipetal**.
- **Zeatin**, **dihydrozeatin** and **isopentanyl adenine** are **physiologically active cytokinin**.
- Some of the **bioassays for cytokinins** are
  - **excised radish cotyledon enlargement test**
  - **chlorophyll preservation test** or **delay in senescence test**
  - **tobacco pith culture**.

Physiological effects of cytokinin

- **Cell division activity** and **cell enlargement** is enhanced by cytokinins.
- Cytokinins are **essential for cytokinesis** though chromosome doubling can occur in their absence.
- **In the presence of auxin**, cytokinins **bring about division even in permanent cells**.
- Cytokinins control morphogenesis *i.e.*, **control initiation of plant organs**.
  - **High cytokinins to auxin ratio** causes differentiation of shoot.
  - **Low cytokinins to auxin ratio** causes differentiation of root.
  - **Intermediate cytokinins to auxin ratio** causes differentiation of both root and shoot.
  - **Intermediate cytokinins to low auxin ratio** leads to callus formation.
- Cytokinins are quite effective in **breaking the dormancy of seeds and some other plant organs**. For e.g., seeds of *Lectuca sativa.*
- Cytokinins **counteract the phenomenon of apical domimance** and it **induces lateral bud formation even in presence of apex**.
- Cytokinins **induces plastid differentiation, lignification of tracheary elements** and **differentiation of interfasicular cambium**.
- Cytokinins **delay the senescence of leaves and other organs**. It is called **Richmond Lang effect** after its discover who worked with detached leaves of *Xanthium.*
- Cytokinins, like auxins, **promote femaleness in male flowers**.
- Cytokinins **enhance chloroplast development** and **chlorophyll synthesis**. There is **increase in rate of protein synthesis** on kinetin treatment.
- When detached leaves are treated with cytokinins it leads to **delay of degradation of proteins and chlorophyll**.
- Cytokinins **induce flowering in short day plants** like *Lemna, Wolffia.*
- Cytokinins **influence the physiological properties** of **RNA** and **DNA**.
- Cytokinins **help in phloem transport**.
- Cytokinins **mobilise solutes and other nutrients**.
- **Commericial use of cytokinins** (CK) are–
  - CK **increases shelf life of vegetables and cut flowers**.
  - CK **improves yield and quality of fruits**.
  - A combination of cytokinin (6-benzyl-adenine) and gibberellins (GA_4GA_7) called **pomalin** is particularly effective in **increasing apple size**.

ETHYLENE

- Ethylene is a **naturally occurring volatile hormone.**
- **Crocker** (1930) **reported presence of ethylene from plant organs** and named it as **gaseous hormone**.
- **Burg** (1962) established that **ethylene** is the **only gaseous growth regulator.**
- **Production of ethylene** by various organisms can be detected by **gas chromatography.**
- **Algae do not** produce ethylene.
- **A small number of bacteria** and a large number of **fungi** produce ethylene.
- **All parts of seed plants produce ethylene**. The **shoot apex** produces **maximum amount of ethylene**.
- Flowers and leaves **before withering produce considerable amount of ethylene**.
- **Maximum ethylene is formed** in ripening fruits and senescing tissues.
- Molecular weight of ethylene is **28.06** and freezing point is **–186°C**.
- **Biosynthesis of ethylene** occurs from **methionine** which is a sulphur containing amino acid.
- **Inhibitors of ethylene synthesis** are – **amino-ethoxyvinylglycine** and **amino-oxyacetic acid.**

- An increased concentration of CO_2 inhibits many effects of ethylene. Besides CO_2, a more effective **inhibitor** of **ethylene action** is **silver ion (Ag^+)**.
- **Bioassays** for ethylene are **triple pea test** and **pea stem swelling test**.

Physiological effects of ethylene

- Ethylene **enhances abscission** and **senescence.**
- Ethylene **induces cellulase activity leading to promotion of leaf abscission**.
- Ethylene **induces femaleness in monoecious flowers** as in cucurbits like cucumber, *Cannabis* etc.
- Ethylene **inhibits phenomenon of geotropism (graviperception), growth of lateral buds** and **expansion of leaves**.
- **In low concentration** ethylene **induces root initiation**.
- Ethylene **breaks bud** and **seed dormancy** in some species.
- Ethylene **promotes elongation of stem and petiole in submerged and partially submerged aquatic plants**, eg., *Ranunculus*.
- Ethylene **enhances activity of chlorophyllase** which causes degreening phenomenon.
- **Maximum rate of ethylene production** occurs during the period of **maximum respiration** just **before senescence** in many fleshy fruits. This is **climacteric rise and it acts as trigger for the conversion of unripe fruits to ripened fruits**.
- Term climacteric was given by **Kidd and Went** (1930).
- **Examples of climacteric fruits** are – apple, banana, mango, pear, peach, plum, tomato and **nonclimacteric fruits** are – citrus, grape, pineapple, strawberry, watermelon, cherry.
- Ethylene is a **fruit ripening hormone** and it stimulates all the biochemical changes which take place upto fruit ripening.
- Ethylene as **ethaphone** (2 chloroethyl phosphonic acid) is used in artificial ripening and colour changes in climacteric fruits.
- Ethylene **induces flowering** in mangoes, pineapple etc.
- **Excess of auxin causes ethylene synthesis** whereas **ethylene lowers synthesis and transport of auxin**.
- Ethylene **causes petal discolouration**. Highest rate of release of ethylene has been reported from fading flowers of *Vanda*.
- Ethylene **induces epinasty** or downward bending of leaves. In rose the effect appears even at concentration of 1 ppm.
- Ethylene **inhibits root and stem elongation** but **induces root hair formation**.
- Ethylene **induces seismonasty**, synthesis of β-1, 3 glucan.

ABSCISIC ACID

- **Carns** and **Addicott** had identified abscisic acid in 1963 while working on cotton balls and called the compounds as **abscisin I** (**from old cotton balls**) and **II** (**from young cotton balls**).
- **Wareing and coworkers** discovered **dormin** from buds and leaves of *Acer* (Birch) plants which induces dormancy in buds, underground stems etc.
- **Abscisin I, II and dormin** are all the same compounds and term **abscisic acid (ABA)** was used for these compounds.
- Abscisic acid is mildly 15-C sesquiterpene multi role plant hormone which **act as an inhibitor because it opposes the growth promoting effect of auxin, gibberellins, and cytokinin** thus keep their activity under control.
- Abscisic acid is **found in vascular plants, some mosses, some fungi and some green algae**.
- **Site of synthesis of abscisic acid** is many parts of the plant but **more inside the chloroplasts of green cells**.
- ABA is a **naturally occurring growth inhibitor** in plants.
- **Biosynthesis** of abscisic acid **takes place through mevalonic acid or xanthophylls** (violaxanthin).
- **Translocation of abscisic acid takes place in xylem** and **phloem** and also parenchyma cells outside vascular bundles.
- **Bioassays** for **abscisic acid** are – **rice seedling growth inhibition test** and **inhibition of α amylase synthesis in barley endosperm**.

Physiological effects of abscisic acid

- Abscisic acid **induces dormancy** in buds.
- Abscisic acid **enhances the process of abscission** and **senescence**.
- Abscisic acid **induces flowering in some short day plants** like *Ribes, Fragaria* etc., during long days and inhibits flowering in long day plants.
- Abscisic acid **stimulates the release of ethylene**.
- Abscisic acid **counteracts many effects of gibberellins like induction of hydrolases and α-amylases in barley seedlings**.

- The **buds** and **seeds sprout only** when **abscisic acid is overcomed by gibberellins**.
- Abscisic acid (ABA) is called **antigibberellin**.
- ABA **promotes ageing** of leaves by stimulating breakdown of proteins and nucleic acid through promoting activity of their hydrolases.
- ABA **promotes cold hardiness** and **inhibits growth** of **pathogens**.
- ABA has been found to **induce parthenocarpic development in rose**.
- Use of abscisic acid **promotes roots** in many stem cuttings.
- Excessive production of abscisic acid **stops the synthesis of RNA and proteins which causes senescence**.
- Abscisic acid **stops mitosis in vascular cambium** towards the approach of winter.
- Abscisic acid is also known as **stress hormone** as it is produced under conditions of stress and causes **partial closure of stomata** under drought and thus **acts as antitranspirant**.
- **Leaves makes** large amount of **abscisic acid during drought and it functions as messenger that enables plant to conserve water during drought**.

Morphactins

- These are a group of artificially synthesized substances, which affect morphology and hence called **morphactins** (by **Schneider**).
- These contains '**fluorene ring**' in their structure.
- Generally these are **growth inhibitors**.
- **Physiological effects of morphactin** are –
  - Formation of **cornets** (fusion of leaf with stem) and **ochria** (fusion of calyx with other floral parts).
  - Induction of gamopetalous condition.
  - Induction of parthenocarpy.
  - Root growth and shoot growth is inhibited by morphactines, *i.e.*, leads to shortening of plants.
  - **Depot effect :** First morphactins are accumulated in plants and after sometime show their effect.
  - Seed germination is inhibited.

Wound hormone or Traumatic acid

- **Haberlandt** (1913) reported that injured plants cells release a chemical substance (wound hormone), which stimulate the adjacent cells to divide rapidly in order to heal up the wound.
- **English** *et. al.* (1939) finally isolated and crystallized this wound hormone and named it as **traumatic acid**.

End of the Chapter

Chapter 49

Human Reproduction

- **Reproduction** is the process by which living organisms produce young one of their own type and **reproductive system** is a system of organs which takes part in this process.
- Reproduction is an essential life process which **not only helps in survival but also helps in continuity of that race and group immortality**.
- **Four basic processes** of reproduction are – **DNA replication, cell division, formation of reproductive units** and **development of new individuals**.
- Animal reproduction is of **two types** – **asexual** and **sexual**.
- **Rate of reproduction is faster** in asexual reproduction.
- In **asexual reproduction** progeny arise from the single existing organism without involving the formation and fusion of gametes.
- Asexual reproduction **involves only mitotic divisions**.
- It is **absent in higher metazoans**.
- Asexual reproduction is **found in lower organisms** like **protistan protozoans** (*Amoeba, Paramecium*), **sponges** (*Scypha*), **coelenterate** (*Hydra*), certain **flat worms** (*Planaria*), **some worms** and **tunicates** (*Salpa*).
- Asexual reproduction is of **four types - fission, budding, fragmentation** and **cyst & spores**.
- In **fission**, body of an individual undergoes division to produce 2 or more equal sized daughters.
- Fission is of **two types** – **binary fission** and **multiple fission**.
- **Binary fission** involves the division of the nucleus followed by that of the cytoplasm, breaking the body into two young ones.
- Binary fission may be **irregular** (*Amoeba*), **longitudinal** (*Euglena*), **transverse** (*Paramecium* and *Planaria*) and **oblique** (dinoflagellates).
- In **multiple fission** the nucleus divides into several daughter nuclei, followed by the simultaneous division of cytoplasm.
- Multiple fission is **found in algae** among plants, *Plasmodium* (malarial parasite) and *Amoeba*.
- **Budding** is an unequal division of the parent where the identity of the parent body is still maintained.
- Budding **is in contrast to binary fission** where parent body divides equally into two and no identity of the parent is left.
- Budding is the formation of multicellular or unicellular outgrowth (called **bud**) on or inside the parental body.
- Bud formed inside the body is called **gemmules** or **statoblasts** and formed on external surface is called **exogenous bud** (eg. *Hydra*).
- Budding is found in **sponges** (*Scypha*), **coelenterate** (*Hydra*), **annelids** (*Syllis*) and **tunicates** (*Salpa*) among animals and among **fungi** it is formed in *Yeast*.
- In **fragmentation** the body may break into two or more fragments, and each fragment develops into a complete individual, eg. *Spirogyra*.
- It is found in some **flat worms** (*Microstomum*), sea anemones among **coelenterate** and **echinoderms**.
- **Cysts** and **spores** are minute propagules which **function as dissemules as well as penetrating structures**.
- In **sporulation** which **occurs in many protozoa and bacteria** the asexual reproduction occurs by the division of nucleus into several daughter nuclei and then each daughter nucleus gets enclosed by small amount of cytoplasm to form a spore.
- Asexual reproductive propagule is called **blastos**.
- An individual produced through asexual reproduction is **ramet**.
- **Clone** is a group of all genetically similar individuals which are formed through asexual reproduction.

- Asexual reproduction **involves only one parent** hence called **uniparental reproduction**.
- **Parthenogenesis** is the development of an unfertilized ovum into a new individual genetically identical with the parent. Such developments is fairly **common among insects** and in many cases may be induced artificially by various chemical or physical stimuli.
- Parthenogenesis is a **modified form of sexual reproduction**.
- In **incomplete parthenogenesis** there is **no biparental sexual reproduction**. There are no males and therefore such individuals are represented by females only, eg. rotifers and certain wasps.
- On the **basis of sex of the offspring**, parthenogenesis may be **arrhenotoky**, **thelotoky**, **amphitoky**.
- In **arrhenotoky**, only males are parthenogenetically produced, e.g. arachnids.
- In **thelotoky**, only females are parthenogenetically produced, e.g. gall fly.
- In **amphitoky**, parthenogenetic eggs may develop into any sex, e.g. aphids.
- **Mictic females** produce haploid eggs which can be fertilized by males.
- **Amictic females** produce diploid eggs which developed parthenogenetically.
- **Sexual reproduction** is a mode of multiplication in which new individuals are formed through the process of formation and fusion of gametes.
- Sexual reproduction involves **meiosis during gametogenesis** and **mitotic division during development of zygote**.
- Rate of reproduction is **slower in sexual reproduction**.
- Sexual reproduction **generally involves 2 parents** (male and female), so called **biparental reproduction.**
- It is found in **higher plants** and **animals**.
- **Syngamy** and **conjugation** are **two types of sexual reproduction**.
- **Syngamy** involves the formation and complete fusion of gametes to form zygote (diploid).
- **Endogamy** (also known as **self fertilization**) involves the fusion of male and female gametes of same parent (*Taenia*).
- **Exogamy** (also known as **cross fertilization**) involves the fusion of male and female gametes from different parents (rabbit).
- **Autogamy** is a type of reproduction in which the fusing nuclei/gametes are derived from the same cells.
- **Conjugation** correspond to cross fertilization of higher animals. It involves temporary union of two parents of same species which exchange their male pronuclei to form synkaryon and then separate to produce daughter individuals. Eg. *Paramecium*.
- **Hologamy/macrogamy** is a type of reproduction in which the fusing gametes are similar to somatic cells/individuals, eg. helizoan, *Actinophrys*.
- **Microgamy/merogamy** is syngamy in certain protistans where the fusing gametes are much smaller than the normal.
- **Isogamy** involves the fusion between morphologically and physiologically similar gametes.
- When 2 fusing gametes are morphologically or physiologically different from each other then they are called **anisogamy** or **heterogamy**, e.g. microgamete and macrogamete.
- The **gametes** are of **two types** : one is smaller and motile called **sperm,** another is large, food laden and non-motile called **ovum.**
- Development of an organism from zygote through embryo formation is **embryogenesis**.
- Mammalian reproductive system consists of
  (i) **Primary sex organs** (also called **gonads**) *viz.* testes and ovaries which produce gametes
  (ii) **Secondary sex organs**, such as **prostate** and **seminal vesicles** in male, and **uterus** and **fallopian tubes** in female; and
  (iii) **Accessory** or **external sex characters,** which distinguish the two sexes of a species in appearance.
- Gonads are **derived from mesoderm**.
- The **onset of reproductive life** is called **puberty.** It is the time when the **gonads develop both endocrine and gametogenic function**.

MALE REPRODUCTIVE SYSTEM

- **Male reproductive system** consists of a pair of **testes**, a paired duct system consisting of **epididymis, vasa efferentia, vas deferens, ejaculatory duct** and **urethra**.
- **Secondary sex organs** of males are **seminal vesicles, Cowper's glands, prostate gland** and **penis**.

- Male reproductive system **performs two major functions:** (i) **spermatogenesis** (formation of spermatozoa), and (ii) **transfer of sperm** to the reproductive tract of the female.
- The **testis** consists of two flat, oval bodies, one on each side, remaining inside the scrotum.
- **Scrotum** is the sac of skin, situated outside the body cavity and allows sperms to develop at the optimum temperature, which is slightly lower than body temperature.
- Removal of testes is called **orchidectomy**.
- The testis is attached to the scrotum by a band of connective tissue known as **gubernaculum testis** and the scrotum communicates with the abdominal cavity through **inguinal canal**.
- **Spermatic cord** (elastic cord) connects testes with abdominal cavity.
- In early foetal life, **testis remain within the abdomen.** During the **third week of gestation**, the testes move caudally from their position high in the abdomen, then gradually migrate and **descend in the scrotum** by the time the child is born.
- **The temperature of scrotum is 2°C below the body temperature,** which is **essential for the formation of sperms** in the testes.
- **Failure of testis to descend in scrotum** from abdominal cavity is called **cryptorchidism**.
- Cryptorchidism **produces sterility** as spermatogenesis does not occur at the higher temperature of the abdominal cavity.
- The testis is covered by a tough, compact fibrous capsule called **tunica albuginea**, which is externally covered by peritoneal layer of flat cells called **tunica vaginalis** which is supplied by a network of blood capillaries called **tunica vasculosa**.

Variations in Position of Testes

- In some mammals (lion, bull, horse), the testes remain permanantly in the scrotum and keep functioning throughout the year as in man.
- In certain seasonally breeding mammals, such as bat, otter and llama, the testes enlarge, become functional, and descend into the scrotum in the breeding season, but thereafter ascend into the abdominal cavity, and become reduced and inactive.
- In a few cases (elephant, whale, seal) the testes remain permanently in the abdomen.

- The lobules present in the gland are filled up with convoluted **seminiferous tubules,** each about 500 mm long.
- Several seminiferous tubules unite to form a **straight tubule** which again unite forming the **rete testis**.
- **Rete testis join up to form** the **vasa efferentia** as a fine ciliated ductules which finally combine to form the **duct of epididymis** (caput epididymis).
- Each **seminiferous tubule** is **lined by a germinal epithelium** which is **formed of 2 types of cells** - **germ cells** and **sertoli cells**.
- **Germ cells undergoes spermatogenesis** to form **spermatozoa**.
- **Sertoli cell** (also called **subtentacular cells**), the functional component of seminiferous tubule **functions as nurse cells for differentiating spermatozoa**.
- Sertoli cell **produce androgen binding protein** (ABP), **inhibin** (which inhibit FSH secretion) and **mullerian inhibiting substances**.
- Inside the stroma and between the seminiferous tubules, groups of polyhedral cells are found which are called **interstitial cells of Leydig.**
- Interstitial cells of leydig are **abundant in early foetal life**, then gradually **diminish during childhood**, **increase again at puberty** and **diminish in old age**.
- **Leydig cells** comprise less than 10% of the testicular volume and **secrete about 7-8 mg of testosterone (male sex hormone) per day**.
- Epididymis is **divided into three parts** - anterior **caput epididymis,** middle **corpus epididymis** and posterior **cauda epididymis.**
- Testis and epididymis together are called **testicle.**
- Epididymis is **involved in storage (temporary), nutrition** and **physiological maturation and motility of sperms.**
- Spermatozoa are **concentrated and stored in the lower of the epididymis (cauda) untill ejaculation**.
- **Ejaculation** is the **discharge of semen** due to powerful rhythmic contractions of urethra.
- **Prostate, Cowper's** and **seminal vesicle** secretes fluids which mix with sperms to form semen.
- **Semen**, containing sperms, is a milky viscous and alkaline fluid **ejaculated** by male reproductive system **during orgasm**.

- Semen **provides a fluid medium for the transmission of sperms into the vagina, nourishes and activates the sperm** and **its alkalinity neutralize the acidity of the urethra** and **protects the sperms from the acidity of the vagina**.
- The **duct system** conduct the semen to the exterior.
- **Vas deference** is large duct which **arises from cauda epididymis** and reach up to seminal vesicles.

In frog the vas deference is absent and the sperms pass through **Bidder's canal**, a collecting duct in kidney.

- **Vasectomy** is the cutting of vas deferens and tying, its two ends separately **(bilateral ligation)**.
- **Ejaculatory ducts** are short, straight muscular tubes each formed by union of vas deferens and duct of seminal vesicle. They **have contractile mechanism** that aids in the emission of seminal fluid.
- **Urethra** leads from the urinary bladder through the prostate glands & into the penis.
- Urethra consists of **4 parts** - urinary, prostatic, membraneous & penile.
- **Membraneous and penile form** of urethra **forms the outflow pathway for the urine & for the seminal fluid**.
- **Seminal vesicles,** also called **uterus masculina,** is a elongated musculoglandular sac like **structure between the urinary bladder and rectum**.
- Secretion of seminal vesicle, **formed of citric acid, prostaglandins, stimulates vaginal contraction to help in fusion of gametes** and also contain **fructose which acts as a source of energy for stored sperms.**
- **Cowper's glands**, also called **bulbourethral gland,** is a pair of pea sized gland that **lie beneath the prostate gland and whose secretion neutralize the acidity of urine in urethra**.
- **Perineal gland**, present near the Cowper's gland and rectum, produce pheromones.
- **Prostate gland** is a large pyramidal gland which lies at the base of the bladder & surrounds the first part of the urethra. It **provide milky alkaline fluid for the nutrition of sperms in seminal vesicle**.
- **Corpora amylacea** is a small acidophilic concreations present in the lumen of prostate gland.
- **Penis,** male **copulatory organ** is supported by 3 tissues - 2 posterior **fibrous ligamentous corpora cavernosa** and one anterior **highly vascular and spongy corpus spongiosum.**
- **Glans penis** is the tip of penis, which is **highly sensitive to stimulation**.
- **Prepuce** is a loose, retractile foreskin which covers glans penis.
- Inside the prepuce, there are modified oil glands called **glands of Tyson**.

FEMALE REPRODUCTIVE SYSTEM

- The **purpose of the female reproductive system is the continuation of the human species** by the production of offsprings.
- The female reproductive system includes the **ovaries, fallopian tubes, uterus, vagina, accessory glands** and **external genital organs.**
- **Ovaries**, the **primary sex organ** in human female are **responsible for producing female sex hormone** (estrogen, progesterone etc.) and **gamete (ova)**.
- The ovaries are attached to the abdominal wall by an ovarian ligament called **mesovarium** (or fold of peritoneum).
- The **region of attachment** is known as **hilus.**
- Ovary is covered by a layer of cubical epithelium called the **germinal epithelium** which is further covered by **visceral peritoneum**.
- Beneath this epithelium, a layer of connective tissue called **tunica albuginea** is present.
- The **outer region of the ovary is composed of developing follicles** and the **middle is composed of stroma**, which contains connective tissue, blood vessels and mature follicles.
- The stroma consists of **dense outer layer** called the **cortex** and a less dense **inner portion** called the **medulla**.
- **Scattered throughout the cortex** are many ovarian follicles of different developmental stages.
- The **medulla** is a loose connective tissue with abundant blood vessels, lymphatic vessels and nerve fibres.
- **Follicles** are specialized structure in which **oocyte** (a female germ cell) **growth** and **meiosis I occur**.
- These **follicles are initially formed during embryonic development** by proliferation of primordial germ cells of germinal epithelium but **start maturing (once a month) after puberty** only.
- The follicles continues to grow under the influence of follicle stimulating hormone (FSH) and the follicular cell proliferate to form several layers of granulosa cells around the primary oocyte.
- Contained within each primary ovarian follicle is an **oocyte, the potential ovum or egg cell**.

- At birth, a female's ovaries contain some **2 million follicles**, each with an ovum that has begun meiosis but which is **arrested in prophase of the first meiotic division**. At this stage, the ova are called **primary oocytes.**
- **Primordial follicles** which consist of a primary oocyte surrounded by a single layer of flattened cells, develop in the foetus and are the stages that is present in the ovaries at birth and throughout childhood.
- **Mature follicles** are known as **Graafian follicle** which occupy a single cavity called **antrum** and **contains a secondary oocyte ready for ovulation**.
- Mature follicle **has 3 distinct layers** - outer **theca externa** (fibrous), middle **theca interna** (cellular) and inner **membrana granulosa**.
- **Theca interna** and **theca externa** are **derived from cortex**.
- The **cells of theca interna** of the follicle **are the primary source of circulating estrogen** under the influence of LH.

  Theca interna cells have many LH receptors. LH acts on theca interna *via* cAMP to increase conversion of cholesterol to androstenedione. Some of the androstenedione is converted to estradiol which enters the circulation.

- **Ruptured Graafian follicle** is called **corpus luteum**, a yellow endocrine gland, which secretes progesterone hormone.
- Corpus luteum loses its yellow colour and become inactive and transformed into a small cell mass called **corpus albicans**.
- A female child at birth possess **80,0000 follicles** in her ovaries, but about **400 mature** and discharge their ova, the rest undergo degeneration.
- Degenerated follicles are also called **atretic follicle.**
- The mass of granulosa cells enclosing the mature ovum projects into the antrum, forming a **hillock**, **the cumulus oophorous** or **discus proligerous**.
- The ovum is surrounded by the prominent glycoprotein layer, **zona pellucida**.
- Zona pellucida develops as a jelly coat around the primary oocyte & is surrounded by the granulosa cells.
- The **corona radiata** is a well defined, radially arranged layer of columnar cells **immediately surrounding the zona pellucida**.
- **Cytoplasm of the ovum** is called **ooplasm.**
- **Yolk is absent in the ovum**, thus human eggs are **alecithal.**
- **Oviducts or fallopian tubes** are about 12cm long and **carry eggs from the ovaries to the uterus**.
- Each oviduct is **differentiated into four parts** - infundibulum, ampulla, isthmus & uterine part.
- **Fimbriae** are situated in a dilated funnel shaped free end of fallopian tube called **infundibulum.**
- Fimbriae, found on the lateral end of each tube, are fringe like protrusions that **generate currents in the fluid surrounding the ovary and pull the ovum into the fallopian tube**.
- **Ampulla** is a part behind infundibulum where **fertilization of ovum takes place**.
- Cilia lining the oviduct beat and smooth muscle contracts causing peristaltic movements which move the egg down the oviduct to the uterus.
- **Tubectomy** is the cutting of oviduct and tying its two ends separately **(tubal ligation)**.
- The **uterus** in human is about 7.5 cm long and 5 cm wide and is about the size and shape of an inverted pear.
- Uterus **lies behind the urinary bladder**.
- Uterus is the **site for implantation** of the pre-embryo and for the subsequent embryonic and foetal development.
- The **cervix** is the narrow, lower end of the uterus that opens into the vagina.
- Uterus walls is composed of three layers - outer **perimetrium,** middle **myometrium** and inner **endometrium.**
- The surgical removal of uterus is called **hysterectomy**.
- The **myometrium** is **thickest layer** and **contains areolar connective tissue** and **smooth muscle fibres**.
- During pregnancy the cells of the myometrium increases in size to accomodate the growing foetus and contracts during labor and delivery at the end of gestation.
- The endometrium is composed of two layers – **basilar** and **functional**.
- **Basilar layer** is permanent, vascular and very thin.
- The **functional layer** of endometrium is regenerated and lost during each menstrual cycle.
- During pregnancy the **endometrium forms the maternal section of the placenta**.
- Estrogen and progesterone from the ovaries stimulates the growth of blood vessels to thicken the functional layer in preparation for a possible embryo.

Mammals other than primates (e.g., hamster, rabbit) have more complex female reproductive tracts, where part of the uterus divides to form uterine "horns" each of which leads to an oviduct.

- **Vagina** is a muscular tube about 8 - 10 cm long whose walls contain elastic tissue.
- Vagina is **located posterior to the urethra and anterior to the rectum**.
- The vagina **receives sperm** from the male's penis during sexual intercourse, **serves as the exit for blood during menstrual flow** and **serves as the birth canal during child birth**.
- The opening of the vagina in young females is partially closed by a thin membrane called **hymen**.
- During reproductive life the vagina contains *Lactobacillus acidophilus* which keeps the vaginal **pH between 4.9 – 3.5** by producing lactic acid from glycogen. This acidity helps to **prevent vaginal infections**.
- The space between vaginal wall and the cervix is called **fornix.**
- The **external female genitalia**, also called the **vulva** are the **accessory structure** of the female reproductive system that are external to the vagina.
- The vulva includes the **clitoris, labia majora, labia minora** and **Bartholin's gland**.
- **Clitoris** (present in front of urethral opening) in female and **penis** in male are **said to be homologous structure** due to their same embryonic origin (they differ only by the presence or absence of testosterone).
- Clitoris, **contains erectile tissue** and many nerve endings in a sensitive glans within a **prepuce** which totally encloses the glans. This is the **most sensitive point for female sexual stimulation**.
- Clitoris is very sensitive as it contains numerous sensory structures (e.g., *Meissener's corpuscles*).
- The sides of the vulva have two small fleshy folds, the **labia minora** (lesser lips) which are hidden by larger hairy folds the **labia majora** (greater lips).
- **Labia majora are homologous** to **scrotal sacs** of a **male**.
- Paired **Bartholin's glands** are situated on each side of the vaginal opening.
- Bartholin's glands correspond to the **Cowper's gland of male**.
- Secretion of Bartholin's gland **help in lubrication during copulation** and **counteracting urinary acidity.**
- **Mammary glands** are **compound saccular modified sweat glands**.
- Mammary gland, which are located in the breast overlying the pectoralis major muscles are present in both sexes but usually **functional only in females**.
- **Gynaecomastia** is the overgrowth of breast in male. It is a one symptom of Klinefelter's syndrome.
- Externally, each breast has a raised nipple, which is surrounded by a circular pigmented area called the **areola**.
- The nipples are **sensitive to touch**, due to the fact that they contain smooth muscle that contracts and causes them to become erect in response to stimulation.
- Internally, the adult female breast contains 15 to 20 lobes of glandular tissue that radiate around the nipple.
- A **lactiferous duct** collects the milk from the lobules within each lobe and carries it to the nipple.
- Just before the nipple the lactiferous duct enlarges to form a **lactiferous sinus (ampulla)**, which **serves as a reservoir for milk**.
- **Mammary gland function** is **regulated by hormones**. At puberty, **increasing levels of estrogen stimulate the development of glandular tissue in the female breast**.
- Progesterone **stimulate the development of the duct system**.
- During pregnancy these hormones (estrogen & progesterone) enhance further development of the mammary glands. **Prolactin** (from the anterior pituitary) **stimulates** the **production of milk** within the glandular tissue, and **oxytocin** (from the posterior pituitary) **causes** the **ejection of milk from the glands**.

Menstrual cycle

- The activity of the hormones of the ovaries and anterior pituitary gland and the resultant changes in the ovaries and uterus are known as the **menstrual cycle**.
- Menstrual cycle is a **period of cyclic changes** that occur in the reproductive tract of human females and other primates **with a periodicity of 28 days**.
- Menstrual cycle is controlled by **FSH, LH, estrogen** and **progesterone**.
- A woman's reproductive cycles **last from menarch to menopause**.

- 1st menses is called **menarche** while the onset of menses and development of secondary sexual character is called **puberty**, usually at age of 13.
- If puberty starts early then it is known as **precocious puberty.** Earliest known puberty was found in a 6 year old child.
- **Menopause** (**climacteric**) is stopping of ovulation and menses. Its average age is 51 years. Post menopausal effects include hot flashes, irritability, fatigue, anxiety, decreased strength of bones, etc.
- Menopause is **marked by decreased levels of ovarian hormones** and **increased levels of pituitary follicle stimulating hormone (FSH) and luteinizing hormone (LH)**.
- Menstrual cycle consists of **menstrual phase, proliferative phase** (follicular phase) and **seccretory phase** (luteal phase).
- **Days 1-5** of the cycle are known as the **menstrual phase**.
- During menstrual phase, **menstruation occurs**. At the beginning of this stage, blood levels of progesterone and estrogen have dropped dramatically because of the degeneration of the last cycle's corpus luteum. This triggers the shedding of all but the deepest layer of the endometrium.
- The **detached portion of the endometrium as well as blood** will pass through the vagina **as the menstrual flow (menses)**.
- Menstruation, is often **described as the funeral of the unfertilized ovum** or as **the weeping of the uterus** for the lost ovum.
- During this phase, FSH levels are rising and as a result, follicular development has begun to proceed and follicle secretion of estrogen has begun.
- **Day 5-14** are known as the **proliferative phase**.
- Proliferative phase **consists of growth of endometrium of uterus, fallopian tube and vagina**.
- In ovary, a Graafian follicle grows, matures and secretes estrogen during this phase.
- **Estrogen** is the hormone **active during proliferative phase**.
- As follicular development proceeds, blood estrogen levels rise. This estrogen causes the regeneration of the stratum functionalis. The endometrium grows thicker and becomes more vascularized and glandular. At this time, cervical mucus begins to get less viscous.
- The **follicular phase ends with ovulation**.
- **Ovulation**, prompted by luteinizing hormone from the anterior pituitary, occurs when the mature follicle at the surface of the ovary ruptures and releases the secondary oocyte into the peritoneal cavity.
- The follicle that ruptures at the time of ovulation promptly fills with blood forming **corpus haemorrhagicum**, which will eventually be absorbed.
- Ovulation **occurs at the end of the proliferative phase** *i.e.,* 14th day or midday during menstrual cycle and coincides with the beginning of the next phase.
- After ovulation and in response to luteinizing hormone, the portion of the Graafian follicle that remains in the ovary enlarges and is transformed into a **corpus luteum** containing yellow substance (called **lutein**) and the luteal phase begins.
- The **corpus luteum** is a glandular structure that **secretes progesterone and some estrogens.**
- If **fertilization does not take place**, the corpus luteum remains functional for about 10 days then it begins to degenerate into a **corpus albicans** by losing its yellow colour, which is primarily scar tissue, and its hormone output ceases.
- It **fertilization occurs**, the corpus luteum persists and continues its hormone functions until the placenta develops sufficiently to secrete the necessary hormones.
- The **fall in FSH level and arise in LH** causes ovulation.
- **Increased level of estrogen** in blood stimulates the pituitary to secrete another hormone **LH.**
- If the ovum is not fertilized, **the higher level of progesterone inhibits the production of LH**.
- The withdrawal of LH **causes regression of corpus luteum** and **a fall in progesterone level**.
- The **ovum lives for approximately 72 hrs**, after it has extruded from the follicle.
- Human ovum **loses its ability to be fertilized about 24 hrs after ovulation**.
- The subsequent 14 days (*i.e.*, 15 to 28) in which corpus luteum is active is referred to as the **secretory phase**.
- During secretory phase, **the endometrium prepares for the implantation of an embryo and the corpus luteum is active and secretes progesterone**.
- The progesterone acts to thicken the uterus even more and become even more vascular and glandular. The endometrium also begins to secrete nutrients into the uterine cavity, so as to support an embryo prior to implantation.
- The rising progesterone also causes cervical mucus

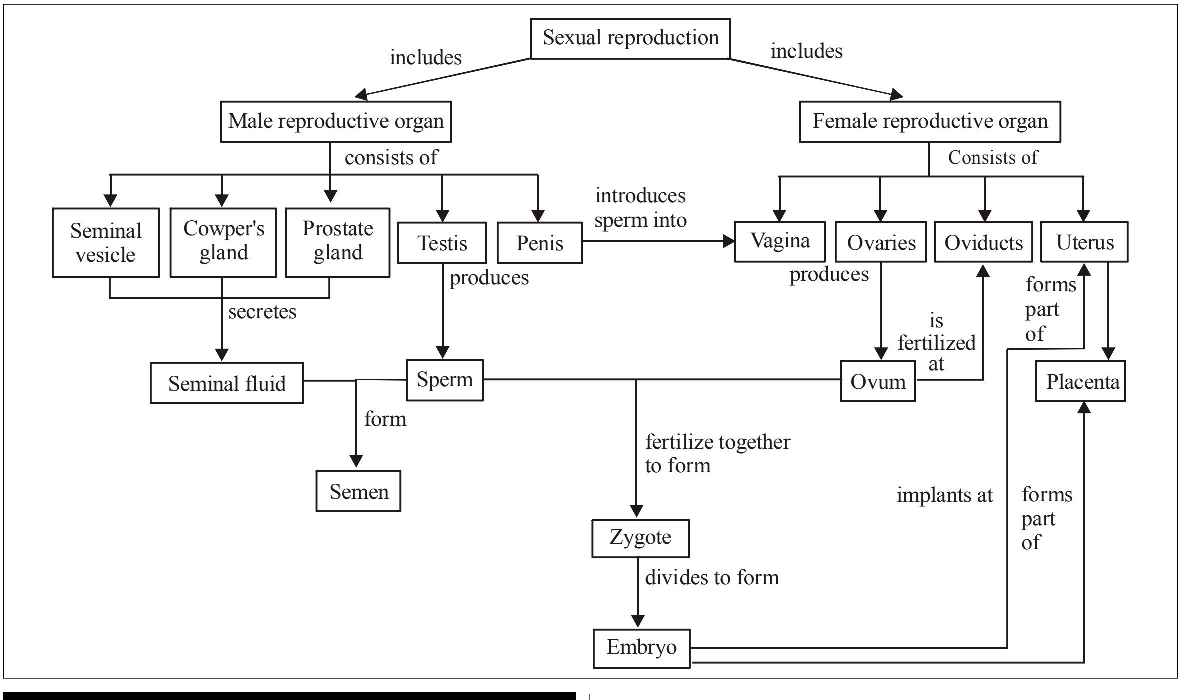
to become viscous again (forming the cervical plug), which helps prevent bacteria or any more sperm from entering the uterus.

- As progesterone levels rise, they inhibit the release of LH. Without LH, the corpus luteum begins a steady decline.
- **At the end of secretory phase**, corpus luteum degenerates in the ovary, progesterone secretion fails, the overgrown uterine endometrium breaks down and menstruation takes place.
- As the progesterone declines, the endometrium begins to synthesize vasoconstrictive chemicals. The spiral arteries become constricted and the outer endometrial cells are devoid of oxygen. More and more endometrial cells begin to die and eventually the endometrial capillaries will rupture and blood and dead cells will begin to slough off through the vagina. This is menstruation and the cycle then repeats.
- Menstruation is **absent during pregnancy**, may be **suppressed during lactation** and **permanently stops at menopause**.
- **Menstruation blood** is **predominantly arterial**, with only 25% of the blood being of venous origin. It contains tissue debris, prostaglandins, and relatively large amounts of **fibrinolysin** from endometrial tissue.

Estrous cycle

Mammals, other than primates do not menstruate, and their sexual cycle is called an estrous cycle. There are **four phases of estrous cycle**.

(a) **Anestrous or Diestrous** - This is the resting period when there is no sexual activity.
(a) **Proestrous** - This is preparatory phase during which the ovarian follicle is developing under the influence of FSH.
(c) **Estrous** - The period of heat or estrous coincides with the greatest development of the Graafian follicles.
(d) **Metestrous** - After estrous, there is a degenerative metestrous but this is generally merged into the state of pregnancy.



DISORDERS OF REPRODUCTIVE SYSTEM

- **Prostatitis** is an inflammation of the prostate gland. When the prostate gland swells, it frequently blocks the urethra and makes urination painful or difficult. Untreated prostatitis can lead to kidney damage. After an age of sixty the prostate gland often becomes enlarged leading to hypertrophy.
- **Prostate cancer** is an extremely common

malignancy. Malignant prostate cells are usually stimulated by testosterone, so treatment often involves removal of the testes, thereby preventing production of the hormone.

- **Sterility**, in males is the inability of sperm to fertilize an ovum. In females it is the inability to conceive due to the inadequacy in structure or function of the genital organs.
- **Disorders of ovulation**
  - **Oligomenorrhoea** is a erratic periods or short (oligo) menses.
  - **Amenorrhoea** is the absence of menstruation**.** It may be physiological (*i.e.* prior to puberty or due to pregnancy, lactation, or the menopause), or secondary due to a gynaecological disorder or systemic disease.
  - **Primary amenorrhoea** is the failure to establish menstruation. The most common cause of primary amenorrhoea associated with normal secondary sexual characteristics is an anatomical abnormality of the genital tract, e.g. absent vagina and uterus.Common causes of primary amenorrhoea with associated delayed puberty are Turner's syndrome gonadotrophin deficiency and constitutional delay.
  - **Secondary amenorrhoea** is defined as the absence of menstruation for 6 consecutive months in a woman who has previously had regular periods.The commonest cause is pregnancy and polycystic ovary syndrome; hyperprolactinaemia; premature ovarian failure and weight-related amenorrhoea are other common causes.
  - **Dysmenorrhoea** is painful menses.
- **Polycystic ovary disease** is a condition where there are multiple tiny cysts in the ovaries. The LH level is characteristically high with normal FSH. and estrogen levels.There is often oligomenorrhoea or amenorrhoea and also characterised by hirsutism, acne, infertility etc.
- **Hyperprolactinaemia :** The level of the hormone prolactin is very high while the levels of F.S.H. and estrogen are lowered. This condition is known as hyperprolactinaemia. There is either oligomenorrhoea or amenorrhoea. Discharge from the nipples is also a symptom of this condition as this is the hormone responsible for milk production.
- **Ovarian cysts** are fluid filled tumor of the ovary. Such cysts sometimes rupture and regress (get smaller) during pregnancy, but in older women they sometimes must be removed surgically. Some grows to very large sizes and have to be removed.
- **Impotence or erectile dysfunction (ED)** is the inability of the male to produce an adequate erection for satisfactory sexual intercourse. Damage to nerves, arteries, smooth muscles, and fibrous tissues, often as a result of disease, is the most common cause of ED.
- **Pelvic inflammatory disease (PID)** is a long lasting (chronic) infection affecting the womb (uterus), the tubes which deliver eggs to the womb (fallopian tubes) and the nearby structures in the lower abdomen. Pelvic inflammatory disease is most likely to occur between the ages of 15 and 25, in sexually active women. PID occurs when disease causing organisms migrate upward from the urethra and cervix into the upper genital tract. The major symptoms of PID are lower abdominal pain and abnormal vaginal discharge.Other symptoms such as fever, pain in the right upper abdomen, painful intercourse, and irregular menstrual bleeding can occur as well.
- **Sexually transmitted diseases** or venereal diseases (V.D.) are spread primarily through sexual contact. These are –
  - **Gonorrhoea.** It is caused by a bacterium, *Neisseria gonorrhoeae*.
  - **Syphilis.** Syphilis is caused by the spirochaete (spiral bacterium) *Treponema pallidum*.
  - **Genital herpes.** Genital herpes is caused by a virus, *herpes virus hominis, type 2*.
  - **AIDS** (Acquired Immune Deficiency Syndrome). This disease which results in a breakdown of a person's immune system, may be caused by a viral infection. AIDS is caused by the human immunodeficiency virus (HIV). AIDS, a commonly fatal disease, has been on the increase in the world. High risk groups include gay (homosexual) men, heroin addicts and haemophiliacs. The disease may be transmitted *via* blood transfusion, the use of dirty hypodermic needles and through sexual contact.

End of the Chapter

Chapter 50

Embryonic Development

- **Embryology** deals with the developmental changes that a zygote undergoes till the formation of an adult form.
- **Gametogenesis, fertilization, cleavage, blastulation, gastrulation** and **organogenesis** are the **phases of embryonic development**.

GAMETOGENESIS

- **Gametogenesis** is the process of gamete (sperm or egg) formation which includes spermatogenesis and oogenesis.
- Gametogenesis is divided into the following phases – **extragonal origin of primordial germ cells**; **proliferation of germ cells by mitosis** and **meiosis**; **structural and functional maturation of ova and spermatozoa**.

Spermatogenesis

- **Spermatogenesis**, is the process of producing sperms with half the number of chromosomes (haploid) as somatic cells.
- Spermatogenesis is a **continuous process**.
- Spermatogenesis **occurs in seminiferous tubules at the time of puberty** and **continues throughout life**.
- Cells involved in spermatogenesis are – **sertoli cells** (nurse cells) and **Leydig cells**.
- Sertoli cells **provide support and environment for germ cells to develop and mature in association with producing hormones - estrogen and inhibin** (which suppresses pituitary FSH).
- From outside inwards the following five layers are found in seminiferous tubule - the **spermatogonia, primary spermatocytes, secondary spermatocytes**, **spermatids** and **spermatozoa**.
- During spermatogenesis **one spermatogonium produces 4 sperms.**
- Spermatogenesis completes through the following phases – **multiplicative phase**, **growth phase**, **maturation phase** and **spermiogenesis**.
- In **multiplicative phase** the **sperm mother cells** divide by mitosis and **produce spermatogonia**.
- The spermatogonia grow in size to form **large primary spermatocytes by getting nourishment from sertoli cells in growth phase**.
- **Maturation phase** involves **meiosis I** in which primary spermatocytes divide to produce **secondary spermatocytes** and **meiosis II** which produce **spermatids**. Thus each primary spermatocyte gives rise to **four haploid spermatids**.
- **Spermiogenesis** or **spermateleosis** is process of formation of flagellated spermatozoa from spermatids.
- Spermiogenesis **begins in the seminiferous tubule but usually completed in epididymis**.
- The process by which spermatozoa are shed into the lumen of seminiferous tubule for transport are called **spermiation**.
- The main structural divisions of a typical sperm are – **head**, **neck**, **middle piece** and **tail** all of which are contained by a continuous plasma membrane.
- The **head** contains **two main parts** – **nucleus** and the **acrosome** – performing two main functions respectively – genetic and activating.
- Acrosome **forms a cap in front of nucleus containing lytic agent which dissolves egg membrane during fertilization**.
- Acrosome of mammalian sperm produces **sperm lysins** called 'hyaluronidase'.
- If **acrosome is removed from a sperm**, it **will fail to penetrate into ovum**.
- **Neck** is very short **containing proximal and a distal centriole**.
- The two centrioles of the spermatids become arranged one after the other behind the nucleus.
- The **anterior one** is known as the **proximal centriole**.

Acrosome contents and their functions

- **Hyaluronidase -** It is a hydrolytic enzymes. It lyses the glycosaminoglycans in the extracellular matrix holding the cells of the corona radiata together. As the coronal cells become more loosely associated, sperm cells can propel themselves inward, toward the zona pellucida by making a receptive cone or fertilization cone through the cytoplasm of the egg.
  - Hyaluronidase may also be involved in breaking down the zona pellucida.
  - It is used in medicine to increase the absorption and diffusion of drugs administered by injection or application.
- **Neuraminidase** – It is also a hydrolytic enzyme, removes neuraminic acid (sialic acid) from glycoproteins. In experimental studies, a neuraminidase-treated zona pellucida cannot be penetrated by sperm cells. Thus the acrosomal neuraminidase may aid in preventing more than one sperm from entering on ovum (polyspermy).
- **Zona lysins** – These are proteolytic enzymes that are capable of degrading the zona pellucida, perhaps easing the passage of sperm cells to the ovum.

- The proximal centriole is usually **located on the neck of spermatozoa**. During fertilization, it is introduced to egg.
- The proximal centriole is **required for the first cleavage**.
- The **posterior centriole** is **known as the distal centriole**. It **changes into basal bodies**.
- Distal centriole **gives rise to the axial filament** (**of the sperm**) which passes through the middle piece and extends into the tail.
- **Middle piece contains spiral rows of mitochondria** which **provide energy and strength to the sperm for locomotion**.
- **Tail** or **flagellum** is a **fine vibrating posterior portion of sperm** which **helps in swimming**. Tail is **made up of axial filament and small amount of cytoplasm**.
- In man, the sperm released from the testis takes this route to reach the ureter - **vasa efferentia, epididymis, vas deferens and urethra.**
- The human sperm was first seen by **Hamm** and **Leeuwenhoek**.
- **Hormones that affect spermatogenesis** are **testosterone, estradiol, inhibin, FSH, LH** and **GnRH**.
- Sperm take **74 days to form** and **a further 26 days to mature** and pass through the epididymis and vas deferens before ejaculation.
- Human sperms **move at a speed of about 3 mm/min through female genital tract**.
- **Temperature** is very **crucial factor for the development of sperms**. For any reason if the testes fails to descend from the abdominal cavity spermatogenesis does not takes place and leads to sterility.

Oogenesis

- **Oogenesis** is the **discontinuous process** involved in the development of mature ovum in ovary.
- Oogenesis **begins** before birth, **stops** in midprocess and **only resumes** year after menarch (the first menstrual bleeding).
- Oogenesis occurs through the following phases – **multiplicative phase** (formation of oogonia mitotically from the primary germ cells), **growth phase** (growth of oogonia into primary oocyte) and **maturation phase** (formation of mature ova from primary oocyte through meiosis).
- Oogonia **undergo mitosis only in embryo.**
- Maturation phase produce two haploid cells - larger one called **secondary oocyte** and the smaller one called **polar bodies (1st polar body)**.
- Meiosis II of secondary oocyte r**esults in the formation of functional egg or ovum and a second polar body**. The first polar body may also divide to form two polar bodies of equal sizes which do not take part in reproduction and ultimately degenerates.
- **First maturation division** may be c**ompleted in the ovaries** just prior to ovulation but **second** one (final) is **completed outside the ovary after fertilization**.
- **Secondary oocyte** is female gamete **in which the 1st meiotic division is completed** and **second meiotic division (metaphase stage) has begin**.
- Secondary oocyte **complete the second meiotic division only after fertilization** by the sperm in fallopian tube.
- The egg is **released at secondary oocyte stage** under the effect of LH.
- Oogenesis **ends at menopause**.
- Polar bodies are **formed only in oogenesis** at the time of the formation of secondary oocyte.

Eggs

On the basis of distribution of yolk

- **Isolecithal** – Yolk is uniformly distributed throughout the cytoplasm of egg, e.g., protochordates and echinoderms
- **Telolecithal** – Yolk is concentrated towards vegetal pole, cytoplasm and nucleus lie near animal pole, e.g. birds and reptiles
- **Centrolecithal** – Yolk is concentrated in the centre of egg with cytoplasm surrounding it, e.g. insects.
- **Discoidal or Meiolecithal** – Almost whole of the egg is occupied by the yolk except small disc of active ooplasm, e.g., birds and reptiles.

On the basis of amount of yolk

- **Alecithal** – Eggs without yolk, e.g., mammalian eggs.
- **Microlecithal** – Eggs with very little yolk, e.g., sea urchin, starfish.
- **Mesolecithal** – Eggs containing moderate amount of yolk, e.g., frog
- **Megalecithal or Macrolecithal** – Eggs containing large amount of yolk, e.g. reptiles and birds.

On the basis of presence or absence of shell

- **Cleidoic** – Surrounded by water proof porous shell, allows diffusion of oxygen and CO_2, e.g., birds, reptiles.
- **Non-cleidoic** – Shell is absent, e.g., human egg.

- **Vitellogenesis** is the process of laying down of yolk in the primary oocyte. It **takes place in prophase I**.
- The **mature ovum or egg** or secondary oocyte is spherical in shape, contain nucleus & the **largest cell** in the body.
- **Zona pellucida** is the thick non-cellular membrane that develops around the oocyte within the ovarian follicle. It is penetrated by atleast one spermatozoan at fertilization and persists around the blastocyst until it reaches the uterus.
- **Corona radiata** is a layer of follicle cells that surrounds a freshly ovulated ovum & adhere to the outer surface of the zona pellucida when the ovum is set free from the follicle.
- The membrane forming the surface layer of cytoplasm is called **vitelline membrane**.
- The cell substance (cytoplasm) of the ovum is called **yolk or ooplasm**, the haploid nucleus is the **germinal vesicle** & the nucleolus is the **germinal spot**.
- A narrow **previtelline space**, present in between the zona pellucida and plasma membrane (vitelline membrane, inner one), consists of 1-3 polar bodies.
- The side of the ovum which extrudes polar bodies is termed as **animal pole** and the opposite end is **vegetal pole**.
- **Primary egg membrane** is the vitelline membrane and is produced by the egg itself. Types of primary egg membranes are - **jelly envelope** (echinoderm), **vitelline membrane** (mollusca, amphibians & birds), **zona pellucida** (mammals) and **zona radiata** (shark, some amphibians & reptiles).
- **Secondary egg membrane** is the one which is secreted outside the primary egg membrane by a layer of follicular cells that surrounds the oocyte. It **occurs in the form of a chitinous shell surrounding the egg** in insects, ascidians and cyclostomes and is called chorion.
- **Tertiary egg membrane** are formed by the cells of oviducts or other accessory parts of the maternal genital tract while the egg is passing from the ovary to the exterior.
  Eg. (i) The albumen layers (hen's egg), shell membranes and outermost calcareous shell of reptiles and birds.
  (ii) Three concentric layers of albuminous jelly found around the egg of frog (secreted by oviducts).

FERTILIZATION

- **Fertilization** is the process of fusion of the sperm with an ovum to form a diploid cell called zygote.
- Fertilization **activates the secondary oocyte cell to complete the division**.
- Fertilization **normally occurs when sperm and egg interact in the upper third of the oviduct (ampulla)**.
- Sperm gain entry through a species-specific mechanism of contacting the vitelline membrane then fusing with the egg plasma membrane before the sperm nucleus enters the cell. Once the sperm and egg nuclei fuse, fertilization is accomplished.
- Only single sperm penetrates into the ovum. Fertilization of egg with only one spermatozoa is known as **monospermy**.
- **Polyspermy** is the entry of more than one sperm nucleus into an ovum at fertilization.
- After fertilization the fertilized ovum moves down the uterus for implantation.
- Fertilization may be **external** (outside the body) or **internal** (inside the body of female).
- In **mammal**, fertilization is **internal** as it take place in fallopian tube.
- Fertilization involves the following steps : **approximation of sperm and ovum, acrosome reaction, egg reaction, penetration of sperm, activation of ovum, fusion of sperm and egg nuclei.**
- **First step in the approximation of sperm and ovum** during process of fertilization is **fertilizin-antifertilizin reaction.**
- **Fertilizin** (**glycoprotein** or **mucopoly-saccharides**) is a chemical secretion produced in egg to attract the sperms for fertilization.
- **Acrosome reaction** in sperm is triggered by **release of fertilizin.**
- **Antifertilizin**, **acidic protein** is produced by sperm on the surface of cytoplasm.
- **Capaciation** is the preparation of sperm to fertilize the ovum. It is the **final stage in the maturation process of spermatozoan**. It **takes place inside the genital tract** as the sperm penetrates the ovum.
- Capaciation is associated with removal of adherent seminal plasma proteins, reorganization of plasma membrane lipids and proteins. It also seems to involve an influx of extracellular calcium, increase in cyclic AMP, and decrease in intracellular pH.
- Capaciation **occurs while sperm resides in the female reproductive tract for a period of time**, as they normally do during gamete transport. Most importantly capaciation appears to destabilize the sperm's membrane to prepare it for the acrosome reaction.
- The sperm enters the ovum by passing through the corona radiata, the zona pellucida and the vitelline membrane.
- When the acrosome of the spermatozoa touches the surface of egg, the cytoplasm of the egg bulges forward forming **receptive cone** or **fertilization cone**.
- The **receptive cone** is the **region where sperms enters the egg**.
- Penetration of zona pellucida is probably facilitated by release of **hyaluronidase** from the acrosomal cap.
- After a sperm has penetrated an ovum, entry of other sperm is prevented by **development of fertilization membrane** (formed by zona pellucida) in the egg.
- Extrusion of second polar body from egg nucleus occurs **after entry of sperm before completion of fertilization.**
- **Cortical reaction** is a massive exocytosis of cortical granules (containing mixture of enzymes like proteases) to diffuse and alter the structure of zona pellucida **inducing zona reaction**.
- **Zona reaction** represent the **major block to polyspermy**.
- In human **both the head and the tail** of the spermatozona **enter the cytoplasm of the oocyt**e.
- The fusion of gametic pronuclei is called **karyogamy** while the mixing of two sets of chromosomes of two gametes is called **amphimixis.**
- A **single ejaculation contain many billion spermatozoa** inspite of requiring one for fertilization as very few survive the swim through the female reproductive system to fertilize an egg. Because some dies in the acidic vaginal fluid, some lost in the recesses of the cervical wall etc.
- Fertilization is **important to initiate the embryonic development of the egg** and to **restore the chromosomes number of the species**.

In Vitro Fertilization (IVF)

In vitro fertilization is a fertility process first succeeded in 1978 by Late British gynaecologist Dr. Patrick Steptoe and his coresearcher, embryologist Robert Edward.

The technique of IVF involves removing eggs from a woman, fertilized in a culture medium, outside the female body and then transferring the fertilized egg (now called zygote) into the uterus through vagina between the 2 and 8 cell stages. So the pregnancy starts in the woman and further development of the child continues in the womb till it is born. The whole procedure is called as development of **test tube baby.**
The IVF technology is a boon to childless couple. First attempt to produce a test tube baby was made by an Italian scientist Dr. Petrucci in 1959. But this human embryo survived for only 29 days. The **World's first test tube baby** (a baby girl) named as Louise Joy Brown was born on July 25, 1978 in Great Britain. **India's first test tube baby** was born in Calcutta on October 3rd, 1978. Her name is Durga.

Table : Abnormal fertilizations

Polyspermy	Penetration of many sperms into an ovum simultaneously. Only one set of the spermatozoa will be successful in uniting with female pronuclei.
Polygyny	When two female pronuclei unite with a male pronucleus.
Polyandry	Conjugation of two or more male pronuclei with a female pronucleus.
Gynogenesis	Activation of egg by sperm, but there is no fusion of its pronucleus.
Androgenesis	Non-participation of female pronucleus in fertilization.
Somatic fertilization	Common in angiosperms, characterized by involvement of two pronuclei of male, one of which fuses with the egg nucleus and the other with two polar nuclei. The second fusion forms the triploid endosperm nucleus.

CLEAVAGE, IMPLANTATION, GASTRULATION

- **Cleavage**, **also called segmentation**, is a rapid mitotic division of the zygote to form multicellular blastula.
- **Holoblastic cleavage**, when whole of the egg is divided, is **found in microlecithal** and **mesolecithal egg**.
- Holoblastic cleavage may be **equal** (blastomeres are of equal size, eg. starfish, *Amphioxus*) and **unequal** (blastomeres are of unequal size called micromeres and macromeres, eg. amphibians and lower fishes).
- **Equal holoblastic cleavage** occurs in microlecithal or isolecithal eggs and **unequal holoblastic cleavage** occurs in mesolecithal or telolecithal egg.
- **Meroblastic cleavage**, when a part of egg is divided, is found in **polylecithal eggs**. It may be **discoidal** (*e.g.* birds) or **superficial** (*e.g.* insects).
- **On the basis of fate of blastomeres**, cleavage may be **determinate or mosaic cleavage** (in which blastomere is fixed and has its characteristic position and unalterable fate and complete embryo is formed only when all the blastomeres are present, eg annelida, mollusca) and **indeterminate or equipotential cleavage** (in which fate of blastomere is not rigid and have no characteristic position and alterable fate and even an isolated group of blastomeres can form a complete embryo, eg echinoderm and chordate).
- Cleavage in fertilized egg of humans **starts in fallopian tube** about 14 or 15 hours after fertilization during its passage through the fallopian tube to the uterus.
- Basically both cleavage and mitosis are identical because these lead to the formation of two cells with diploid number of chromosomes.
- Cleavage **occurs more readily in the active cytoplasm**.
- Cleavage **restores the cell size** and **nucleoplasmic ratio of the species**.
- Cleavage in **human is equal holoblastic**.
- **Morula** looks like a little mulberry. Morula is the solid ball of 32 cell stage without cavity which is **formed after Vth cleavage and 31 cell division**.
- Morula changes to blastula **due to rearrangement of blastomeres.**
- A morula can be **differentiated from blastula in absence of cavity.**

- **Blastula** is typically a hollow, multicellular ball like embryo **produced at the end of cleavage.**
- A fluid filled cavity of blastula is called **blastocoel** or **segmentation cavity** or **blastocystic vesicle**.
- **Blastula** is divided into **4 types** - **stereoblastula** (solid blastula without blastocoel, eg. *Nereis*), **coeloblastula** (blastula with a prominent blastocoel, e.g. frog), **discoblastula** (occurs in polylecithal egg, a blastula having many layered disc of blastomeres above the yolk, develops as a result of meroblastic division, eg. hen), **superficial blastula** (having a single layer of blastomeres around central yolk, blastocoel absent, eg. insects).
- Blastula formation is called **blastulation**.
- Mammalian blastula with a large blastocoel is called **blastocyst** (in humans).
- As a blastocyst is formed, zona pellucida becomes thinner and finally disappears. By this time the developing embryo reaches the uterus and implants into the uterine lining.
- Blastocyst has **3 parts** - **trophoblast**, **inner cell mass** and **blastocoel**.
- **Trophoblast** is the outer cellular wall of blastocyst that **forms hCG** (secretion of hCG begins the day the trophoblast is embedded in the endometrial lining), **villi, chorion, amnion, and foetal parts of placenta**.
- **Inner cells mass** (**embryoblast**) forms the body of embryo.
- **Blastocoel** is fluid filled cavity which **helps in rapid expansion of blastocyst of blastodermic vesicle**.
- Fate mapping is **done at late blastula stage** to determine the fate of cells of blastula.
- **Implantation or nidation** is the embedding of a fertilized mammalian egg into the wall of the uterus (womb) where it will continue its development.
- The **site of implantation determines the position of the placenta.**
- **Implantation** (of blastocyst) **occurs** in the endometrium near the fundus, **generally between 6th to 9th days after fertilization**.
- The **site of implantation determiners the position of the placentr**.
- Implantation begins first with attachment (adplantation) of the blastocyst through the outer trophoblast cells of the uterine lining.
- Implantation outside the womb (like ovary, abdomen etc.) and too low down within the uterus results is abnormalities like **ectopic pregnancy** and **placenta praevia** respectively.
- In **humans implantation is of interstitial type** in which the embryo is buried in the uterine epithelium which completely surrounds it.
- The **embryo in human female gets implanted** in the uterus after **about 7 days of fertilization**.
- Upon implantation, the endometrium undergoes changes referred to as the **decidual reaction**, during which endometrium thickens and its stromal cells enlarges to become decidual cells which secrete prolactin.
- Decidual reaction **helps prevent invasion of trophoblast beyond the endometrium**.
- **Gastrulation**, characterised by cell movement or morphogenetic movement, is a process by which single layered blastula is transformed into gastrula larva with three primary germ layers.
- During gastrulation, blastocoel is obliterated and a new cavity **archenteron** or **gastrocoel** is formed from chordamesoderm (= the area of mesoderm that forms the notochord).
- Gastrulation **begins with the formation of blastopore** and **ends with the development of neural tube**.
- Primary germ layers are **ectoderm, mesoderm and endoderm**.
- **Endoderm** in a mammalian embryo is **formed as the second layer by delamination of cells from the inner cells mass**. The endodermal cells **line the lumen of primitive gut (or archenterone)**.
- Formation of **mesoderm** initiates only after the formation of endoderm as a distinct layer. Mesoderm **proliferates from caudal end of embryonic disc**.
- After the emergence of the mesodermal layer, the rest of cells of embryonic disc orient themselves in layer to form **ectoderm**.
- Following gastrulation, the **embryo passes through the phase of neurulation**, during which the primordium of nervous system, the neural plate is laid down.
- After gastrulation the cells of the 3 primary germ layers give rise to the rudiments of future tissues and organs.
- The **establishment of the germ layers initiates the final phase of embryonic development**, *i.e.,*

organogenesis. The **organogenesis** involves differentiation and specialization of groups of cells in the individual germ layers.

- **Epiboly** involves the gradual growth and movement of the prospective ectodermal blastomere, *e.g.* telolecithal eggs of *Amphioxus* and frog.
- **Emboly** involves the morphogenetic movement like migration of ectoderm, mesoderm and notochord cells from surface to interior.
- **Invagination** is the infolding of endodermal cells into the body of blastula so as to form a cavity, the archenterone.
- Active enrolling of endodermal and mesodermal cells into interior of embryo is **involution.**
- **Delamination** means formation of second layer by tangential division of surface cells.
- **Convergence** is the actual migration of blastomeres from the outer surface to the external margin of blastolip.
- **Complete obliteration of blastocoel cavity** marks the end of gastrulation.

EXTRA-EMBRYONIC MEMBRANE

- **Foetal membranes**, also known as **extra-embryonic membrane**, are formed from trophoblast in amniotes (reptiles, birds, mammals).
- **Four extra embryonic membranes** are - **amnion, chorion, allantois** and **yolk sac**.
- **Amnion** is the **inner foetal membrane** that invests the embryo and forms a space called amniotic cavity. It is filled with fluid called **amniotic fluid**.
- **Amniotic fluid** is **useful for studying chromosomal abnormalities of foetus as well as sex determination**.
- **Chorion** is the **outer foetal membrane** that also takes part in the formation of placenta.
- **Allantois** is sac like, develops from gut of embryo, supplies blood vessels to placenta. It **helps in respiration, nutrition** and **excretion**.
- **Allantois acts as extra embryonic kidney** in reptile, bird and prototheria and **chorion acts as extra embryonic lung** in reptiles, birds and prototherians.
- The chorion contributes the placenta on the foetal side, while uterine tissues supply the placenta on the maternal side.
- **Yolk sac** (the **first extra embryonic membrane)** is the membranous sac attached to embryo near allantois having yolk in egg laying animals and forms corpuscles in mammals till liver takes over.

PLACENTA

- **Placenta** is an intimate, mechanical connection between foetus and uterus of mother for **nutrition**, **respiration** and **excretion**.
- Placenta contains minute finger-like projections called **villi**. The uterine wall forms corresponding depressions called **crypts**.
- The **human placenta** is **haemochorial placenta** (in which maternal blood bathes foetal chorionic villi directly), **nondeciduous** and **metadiscoidal**.
- Placenta also **acts as an endocrine organs** as it secretes hormones such as estrogen, progesterone and hCG that are essential for maintaining a maternal physiological condition appropriate for continued development of the conceptus.
- In **simplest type of placenta**, **six barriers separate maternal blood from foetal blood**, **Three barriers are lost in human placenta**.
- **Umbilical cord** is a flexible cord like structure connecting the foetus at the navel with the placenta and containing two umbilical arteries and one vein that nourish the foetus and remove its wastes.
- The umbilical cord carries gases and nutrients to the foetus from the placenta.
- Both type of blood vessels in umbilical cord are surrounded by **Wharton's jelly**.
- The delivery of child or child birth is called **parturition.**
- **Parturition** is controlled by **oxytocin** and **relaxin**.
- **Gestation period** is the length of time from conception to birth.
- Gestation period in humans is **9 months.**
- Gestation period of 280 days is calculated from time of **last menstruation** (hence 266 days).
- In mammals, the onset of pregnancy **inhibits further ovulation.**
- Two offsprings developed in the same uterus but from fertilization of different ova are called **fraternal twins.**
- When foetus fails to come out then the baby is delivered by a surgical procedure called **cesarian**. This **procedure was first performed** on Caesar's wife during the Roman era.
- **Abortion** or **miscarriage** is the loss of embryo. It can be due to breakdown of endometrium due to lowering of progesterone secretion from corpus luteum.
- Stages of labor in parturition are – (1st) dilation of cervix, (2nd) delivery of baby, and (3rd) delivery of placenta.

Types of placenta in Mammals

- *According to the nature of foetal membranes*
  - **Yolk sac placenta,** eg., Kangaroo & Opossum
  - **Chorio-allantoic placenta,** eg. eutherians
- *According to the degree of connection of maternal and foetal tissues*
  - **Epithelio-chorial placenta,** e.g., horse, pig and ass
  - **Syndesmochorial placenta,** eg., camel, goat, sheep, buffalo, cow, giraffe
  - **Haemo-chorial placenta,** eg., dog, cat, lion, tiger
  - **Haemo-endothelial placenta,** eg., rat, rabbit.
- *According to nature and distribution of villi*
  - **Non-deciduous placenta** (weak connection)
    - **Diffuse placenta,** eg., pig (villi are diffused)
    - **Cotyledonary placenta,** eg., cattle, sheep (villi form cotyledons)
    - **Intermediate placenta,** eg., camel, giraffe (villi are diffused & cotyledons both)
  - **Deciduous placenta** (strong connection)
    - **Zonary placenta,** eg., dog, lion, tiger (villi form girdle)
    - **Discoidal placenta,** eg. bat, bear, rat, rabbit (villi form disc)
    - **Metadiscoidal placenta,** eg., man, monkey (villi first scattered & afterwards form disc)
  - **Contra-deciduate placenta** (too strong connection) eg., *Perameles*, Talpa

- **Lactogenesis** is initiation of milk secretion under the influence of prolactin hormone.
- **Galactopoiesis** is the maintenance of established lactation.
- During lactation period **woman does not concieve** because **prolactin antagonizes the action of gonadotropins on ovaries**.
- The sensory stimuli of suckling inhibits dopamine (or prolactin inhibiting hormone) secretion by the hypothalamus which increases the release of prolactin from the anterior pituitary which in turn stimulates milk production.
- **Colostrum (foremilk) releases first** after the birth.
- Three to eight weeks old human embryo is most sensitive to external factors (cigarette smoke, alcohol).
- **Gynaecology** is the branch of medicine that deals with the diseases and hygiene of women.
- **Obstetrics** is the branch of medicine dealing with the care of women during pregnancy, child birth and the period during which they recover from childbirth.
- **Teratology** is the study of abnormal foetal development. Major birth defects are found in approximately 3% of all deliveries. A teratogenic agent is any chemical (drug), infection, physical condition, or deficiency that, on foetal exposure, can alter foetal morphology or subsequent function. Teratogenicity appears to be related to genetic predisposition, (both maternal and embryonic), the developmental stage of the foetus at the time of exposure, and the route and length of administration of teratogen.

  Teratogenic agents are - ionizing radiation, drugs and medication, maternal disorders like phenylketonuria, diabetes.

End of the Chapter

Chapter 51

Growth, Repair, Regeneration, Ageing & Death

- Growth is **divided into periods of embryonic and post-embryonic growth**.
- Early embryonic developmental stages constitute **prefunctional state.**
- In **post-embryonic period of organism's life**, the cells of the tissues and organs get differentiated for specific functions. These cells lose the capacity of division and perform physiological functions for the survival of the organisms.
- **Growth**, **regeneration and ageing** may be described **as the post-embryonic developmental events**.
- **Growth** is irreversible increase in size, increase in weight, synthesis of new protoplasm.
- Substances synthesized during growth are **protoplasmic** (nucleus and cytoplasm) and **apoplasmic** (substance present outside the cell like matrix of bone marrow or fibres of connective tissue or even water).
- Growth is **always associated with differentiation**.
- **Differentiation** is a change in the anatomy or physiology of a single cell or cell or group of cells (tissue) in multicellular organisms as it matures into a specialised cell or tissue.
- Growth occurs when **anabolism** (synthetic activities) **is higher than catabolism**.
- **Degrowth** takes place when **catabolism is higher than anabolism**.
- **Quantitative growth** may be **defined in terms of individual growth** (a permanent increase in the biomass of a cell or organism) or **population growth** (an increase in the number of individual in a population).
- The **steps involved in cellular growth** are **- cell division, cell enlargement** and **cell differentiation**.
- Cell division is **cell multiplication** (e.g., lens cells grows by multiplication), cell enlargement is **increase in volume of cell without division** (eg., cardiac & skeletal muscles, neurons which grows by extension & growth of axon and dendrites).
- Cell growth occurs **during post-mitotic phase and interphase**.
- During interphase, cells grow by synthesis of new materials such as nucleic acids and proteins.
- Cell multiplication and growth can be studied well in tissue or in culture of unicellular organisms.
- The growth of multicellular organism falls under three categories – **auxetic**, **multiplicative accretionary growth** and **appositional growth**.
- **Auxetic growth** is growth in which volume of body increases due to the growth of cells without any increase in the number of cells. It **occurs in nematodes, rotifers** and **tunicates**.
- **Multiplicative growth** is the growth of the body due to increase in the number of cells. The cells divide mitotically to increase their number but their size remains the same. Eg. the prenatal growth or embryonic development of higher vertebrates.
- Growth due to mitotic multiplication of reserve cells occurring in specific locations of the body is **accretionary growth**. Eg. post-embryonic growth of animals.
- **Examples of accretionary growth** are erythropoietic tissue, matrix secreting chondrocytes and osteocytes.
- **Appositional growth** involves the addition of new layers on the previously formed layers. *For example*, the addition of lamellae in the formation of bone. It is the **characteristic mode of growth in rigid materials**.
- **On the basis of body proportions**, **pattern of growth** are of **two types** - **isometric growth** (an organ grows at the same rate as the rest of the body, as the organisms grows, the external form of body

does not change, eg., fish and certain insects) and **allometric growth** (an organ grows at a rate different from that at which the body grows, as the organisms grows, the external form of body changes, eg. mammal).

- The usual s**hape of growth curve** is **sigmoidal**.
- Growth curve is the **graphic representation of growth against time**.
- The increase in weight of an animal if plotted against time, a characteristic **S shaped curve** is obtained. It is called **sigmoid curve or growth curve**.
- The sigmoidal or S-shaped growth curve is the **characteristic growth curve of all higher animals** including man.
- The sigmoid curve **represents the growth pattern of all organisms**, **plants or animals**, **unicellular or multicellular forms at various interval**.
- The sigmoid curve consists of the following stages – **lag phase** (**little growth** means slow increase in body weight); **exponential/acceleration phase/log phase** (**maximum growth**, the point where the exponential growth begins to slow down is known as **inflexion point); senescent/decelerating phase** (**declining growth** *i.e.* growth with decreasing rate); and **steady phase** (**no growth**).
- **Exponential growth** of cells is characteristic feature of **tissue culture cells.**
- **Auxanology** is the study of growth.
- **Maximum growth in human foetus** occurs at the age of **four months**.
- Growth in the first 10-13 years of age is controlled by **thymosin**.
- Growth at the end of childhood and during puberty is controlled by **thyroxine and GH.**
- In human beings, **growth stops completely at the age of 22-23 years**.
- As compared to adult male, the **female has more fat**.
- In human beings **brain shows the minimum increase in weight from birth to adulthood.**
- As compared to the whole body the **head of the new born human baby is 1/4**.
- In human beings **muscles shows the maximum increase in weight from birth to adulthood.**
- In animals growth rate is **differential**.
- **Healing of cuts and wounds** is called **repair**.
- Repair is **effected by cell proliferation & migration**.
- **Regeneration** is the ability to restore lost or damaged tissues, organs or limbs. It is a **common feature in invertebrates**, but far more limited in most vertebrates.
- Two principal **categories of animal regeneration** are: **reparative regeneration** and **restorative regeneration**.
- **Reparative regeneration** is **common in both invertebrates and vertebrates**.
- Animals with higher and complex organization have reparative regeneration only.
- **Restorative regeneration** is **common in some invertebrate groups**.
- Animals with simple organization have greater power of restorative regeneration.
- *Hydra and Planaria* have the **power of repetitive regeneration**.
- **Based on cellular mechanism**, regeneration is of two types : **morphallaxis** and **epimorphosis**.
- **T. H. Morgan** for the **first time recognise the following two mechanisms of regeneration in animals**.
- **Morphallaxis (morphallactic regeneration)** is the reconstitution of the whole body from small fragments.
- Morphallaxis occurs mainly by the re-pattening or remodelling of existing tissues and the re-establishment of boundaries. It involves little new growth, e.g. regeneration of *Hydra* and *Planaria* from a segment of the animals.
- **Epimorphosis (epimorphic regeneration)** is the regeneration of lost body part through dedifferentiation of adult structures, cell proliferation and differentiation, e.g. regeneration of lost limb in salamander (amphibian).
- During epimorphosis, the epidermis spreads and covers the wound. In the next few days a mass of cells forms a **regeneration bud** or **blastema**. Finally the blastema undergoes differentiation to restore internal and external structure of lost limb.
- **Blastema** is the accumulation of cells and formation of a bud at the site of amputation.
- Regeneration of a limb or a tail is an **example of epimorphosis.**
- Regeneration of a lost limb occurs in two major steps - **first** de-differentiation of adult cells into a stem cell state similar to embryonic cells and **second**, development of these cells into new tissue more or less the same way it developed the first time. Some animals like *Planarians* instead keep clusters of non-differentiated cells within their bodies, which migrate to the parts of the body that need healing.

- **Phases of wound healing** are - preblastema stage, phase of blastema formation (includes phase of de-differentiation and pseudodifferentiation) and redifferentiation and morphogenesis.
- The **process of regeneration** was **first discovered** in *Hydra* by **Trembley**.
- **Liver possesses good regenerating power in mammals**.
- **Regeneration is controlled** by the **neural and hormonal factors.**
- **Sponge** has the **greatest regenerating capacity**.
- The voluntary casting off a part of the body when an animal is attacked is known as **autotomy.**
- Autotomy is **recorded in legs of crabs, tail of lizards** and **arms of star fishes**.
- Salamander is capable to regenerate **limbs, tail and external gills**.
- **Regeneration is possible in tadpoles** for **amputated tail and hindlegs.**
- Regeneration that produces a part different from the lost part is called **heteromorphosis**.
- Power of **regeneration in flatworm** is **highest at head region** and **lowest towards the tail end**.
- To take over the function of one removed organ is a type of **compensatory regeneration** or **compensatory hypertrophy** (eg. mammalian liver).
- Human body regularly loses cells in the region of **skin surface, lining of gut and red blood cells**.
- **During regeneration,** differentiation, cell division, cell movement and tissue differentiation takes place.
- **Ageing** is the time related deterioration of the physiological functions necessary for survival and fertility. It is largely caused by wear and tear.

Table : Regenerative ability in animals

Animals	Parts regenerated
Sponges, *Hydra*, and *Planaria*	The whole body
Earthworms	Few body segments
Mollusca	Parts of eye, eye-stalk, head, foot, etc.
Insects, crustaceans and spiders	Limbs
Starfishes	Arms
Salamander and Axolotl	Limbs, tail, external gills, jaws, intestine, etc.
Tadpoles	Tail and hindlegs
Fishes	Fins
Lizards	Tail
Birds	Beak
Mammals	Liver

- **Pigment of ageing** is **lipofuschin.**
- With ageing an impairment of physiological functions occurs. It is called **senescence**.
- The number of years an individual can expect to live is known as **life expectancy**.
- During ageing different organs and organ systems show decline in functioning like –
  - Heart grows slightly larger with age and maximal O_2 consumption during exercise declines.
  - The vital capacity of lungs decline by 40% between the age of 20 and 70.
  - Brain loses some cells (neurons) and other become damaged.
  - Kidney gradually becomes less efficient and bladder capacity declines.
  - There is a redistribution of fat to deeper part of the body. In woman it occurs in hips and thighs and in man it is in abdominal area.
  - There is a decline in muscle mass.
  - Difficulty in focussing close up in the 40s and inability to distinguish fine details may begin to decline in 70s.
  - Impairment in hearing ability with age.
- The **bones of old persons become brittle** due to **accumulation of calcium**.
- **During ageing**, **collagen** present in intercellular spaces **become less permeable, rigid and insoluble.**
- Disappearence of elastic fibres in association of collagen protein **results in wrinkling of the skin in old age.**
- **Vitamin C** is **required for collagen synthesis** thats why vitamic C is much required in old age for the maintenance of long bones, teeth and cartilage.
- On an average, 20% of nerve cells in the brain die at the age of 70 years.
- Ageing is characterised by decline in **metabolic activity.**
- The **pumping capacity of heart** in 70 years old person as compared to 30 years old person is 65%.
- In an **ageing person,** there is an increase in collagen rigidity of connective tissue and gradual alteration of components of connective tissue.
- The **part of the lung affected by ageing** are **pulmonary arteries, pulmonary veins and alveoli.**
- Ageing is **faster in human males** than in human females.

- **Dedifferentiation** is the ability of differentiated or specialized cells to change into cells capable of division and grow.
- There are two types of theories for ageing : **programmed theories** and **damage or error theories**.
- **Programmed theories** hold that ageing follow a biological time-table. **It has three sub-categories** –
  – **Endocrine theory** holds that biological clock act through hormones to control the pace of ageing.
  – **Programmed senescence theory** of ageing is the result of the sequential switching on and off of certain genes, causing **programmed cell death** or **apoptosis**.
  – **Immunological theory** - According to this the gradual atrophy and disappearance of thymus gland disturbs the defence mechanism of the body of combating germs and pathogens. With the disappearance of this gland, the body produces a great number of harmful abnormal cells which cause the increased rate of the change and destruction of tissues.

Thymus is ductless gland located in the upper anterior portion of the chest cavity. It is **most active during puberty after which it shrinks in size** and activity in most individuals and is replaced with fat. The thymus plays an important role in the development of the immune system in early life and its cells forms a part of the body's normal immune system.

- **Damage or error theories** maintains that the environmental assaults to our systems make the things to go wrong resulting in ageing.
- The **damage or error theories of ageing includes-** rate of living (metabolism), free radicals, crosslinking, wear and tear, error catastrophe and somatic mutation theories. Although ageing is largely caused by wear and tear, it is also under genetic control.
- **Compromise theory** advocates that ageing is an outcome of interaction between the genes present in the body of an individual and the environment in which the individual lives.
- **Metabolic theory** postulates that the animals with a high rate of metabolic activity age earlier and die sooner than with a lower rate of metabolism.
- In **wear and tear theory** an organism has to achieve a balance between the energy it puts into reproduction and the energy it puts into maintenance. The better the maintenance, the more the organism approaches immortality. However, some energy must always be put into reproduction or the species would die.
- **According to the free radical theory** more free radicals are produced with age which cause damage by reacting with nucleic acids, lipids and proteins. Free radicals, highly reactive chemical compounds, are ubiquitous in living organisms. Several enzymes (superoxide dismutase, catalase, glutathione peroxidase) and vitamins (vitamin E, C, carotenes) protect cells from oxidative attack.
- *Hydra* is an immortal organism not subjected to ageing.

Why *Hydra* is virtually immortal ?
Hydra is virtually immortal because interstitial cells, present in the growth zone below the tentacles, give rise to all other cells of body. With the formation of new cells, old cells are pushed towards the ends of tentacles and pedal disc, from where they are shed outside. This process of cell replacement is an endless process. It has been also shown that if interstitial cells are destroyed, the *Hydra* lives only for a few days.

- The branch of science which deals with the study of ageing process is called **gerontology**. Father of gerontology is **Korenchevsky**.
- **Geriatrics** is a branch of medicine that focuses on health promotion and prevention and treatment of disease and disability in later life.
- **Average life-span of women** is **longer** than that of men.
- **Death** is a biological phenomenon for maintaining the balance of nature. It **results in irreversible breakdown of the body functions**. Whatever the cause, the death results from the failure of either of heart, blood or nervous system. Natural death is preceded by ageing.
- **Clinical death** means **death of the brain** which results in no pulse or heart beat, no breathing and fixed dilated pupil with no reaction to light. Brain death occurs if no oxygen is supplied to it for approx. 3 - 5 minutes.
- **Thanatology** is the scientific study of death that almost involves death bed wishes.
- **Conditions leading to brain death** results in swelling of brain tissue and a rise in intracranial pressure, eventually shutting off all blood flow within the skull.

End of the Chapter

Chapter 52

Heredity & Variations

- **Genetics** is a branch of biology that deals with the **study** of **heredity** and **variations.**
- The term genetics was first used by **W. Bateson** (1905).
- **Gregor Johann Mendel** is called the **Father of Genetics**.
- **Archibald Garrod** is considered as the **Father of human genetics**.`

HEREDITY

- Heredity (like begets like) is the **study of transmission of characters from parents to offspring** or **from one generation to the next**.
- The characters that are passed from one generation to the other are called **hereditary characters**.
- This occurs through transfer of chromosomes from parents to offspring or individual to another. There is, therefore, **chromosomal basis of heredity**.
- The **character of heredity** are **fixed** for a particular organism.
- **Mendel used** the **term factors for the heredity unit which is now called as genes**.
- **Johannson** termed the word **phenotype** and **genotype** in addition to **genes**.
- The **physical basis of heredity** are **genes** while **chemical basis of heredity** is DNA.
- The prevailing view of heredity in pre-Mendelian era was **blending theory**. This theory states that **individual would represent the mixture of both the parents**.
- **Kolreuter** (1733-1806) for the first time obtained the experimental evidence that inherited traits tended to remain discrete, but he was unable to interpret them correctly.
- **R.de.Graaf (1641-1673)** suggested that **both the parent** should contribute to heredity.
- **Carl Nageli (1884)** was the first to propose a theory regarding heredity.
- **Davenport and Davenport (1910)** shows that skin colour in human is a polygenic trait and is due to atleast three separate genes.

Terms used in inheritance studies

- **Character** is a well defined morphological or physiological feature of an organism.
- **Trait** is the distinguishing feature of a character.
- **Gene** is the inherited factor that determine the biological character of an organism.
- A pair of contrasting characters is called **allelomorph or allele**.
- **Term allele** was **given by W. Bateson** for **alternative forms of same gene**, e.g., T and t, Y and y, R and r are pair of alleles.
- **Dominant allele** is one of the factor of an alleles pair which can express itself whether present in homozygous or heterozygous state, e.g., T (tallness in pea), R (round seed in pea).
- **Recessive allele** is the factor of an allele pair which is unable to express its effect in the presence of its contrasting factor in a heterozygote, e.g., t in Tt.
- The effect of **recessive factor** is **expressed only when it is present in the pure or homozygous state,** e.g., tt in dwarf pea plant.
- **Wild allele** is the one which was originally present in the population and is **dominant** and **widespread.**
- The **recessive allele** is **less common** and might have formed through mutation of wild allele. It is thus called **mutant allele**.
- The diploid condition in which the **alleles** at a **given locus** are **identical** is called **homozygous** or pure.
- In **homozygous condition**, organism **have two similar genes** or alleles for a particular character

in a homologous pair of chromosomes, e.g., **TT** or **tt**.

- Organisms containing **two different alleles** or individual containing both dominant and recessive genes of an allelic pair, e.g., **Tt**, is known as **heterozygous** or **hybrid**.
- When only one allelic pair is considered in cross breeding it is called **monohybrid cross**.
- When two allelic pairs are used for crossing it is called **dihybrid cross**.
- Involvement of more than two allelic pairs in a cross is called **polyhybrid cross**.
- Second stage of Mendel's experiment is called **F_1 generation** or **first filial generation**.
- Third stage of Mendel's experiment is called **second filial** or **F_2 generation**.
- **Complete penetrance** is 100% ability of an allelic combination to produce expected phenotype.
- **Incomplete penetrance** is failure of an allelic combination to provide cent percent phenotypic expression, e.g., polydactyly, diabetes mellitus.
- **Hybrid vigour** or **heterosis** is the superiority of hybrid over either of its parents in one or more traits.
- **Genotypes** is the sum total of heredity or genetic make up.
- **Phenotype** is the external feature of organism.
- When two different genotypes due to different environmental conditions give rise to same phenotype, then one is said to be **phenocopy of the other.**
- **Monohybrid ratio** is the ratio which is obtained in F_2 generation when a monohybrid cross is made and the offspring of F_1 generation are self-bred.
- **Dihybrid ratio** is a ratio which is obtained in the F_2 generation when a dihybrid cross is made and the offspring of F_1 generation are self-bred.
- **Trihybrid ratio** is the ratio obtained in F_2 generation raised from a trihybrid cross followed by selfing of F_1 individuals.
- When an individual is crossed with a parent it is called **back cross**.
- When an individual is crossed with the homozygous recessive parent it is called **test cross**.
- **Monohybrid test cross ratio** is 1 : 1 and **dihybrid test cross ratio** is 1 : 1 : 1 : 1.
- **Test cross is done for the following purposes –**
  - To prove that 2 types of gametes are produced by monohybrid, 4 types of gametes are produced by dihybrid and 8 types of gametes are produced by trihybrid.
  - That these gametes are produced in equal number.
  - Genotype of the offspring can be tested.
- If in one cross, individual X is used as male and Y as female and in the next cross Y is used as male and X as female, it is called **reciprocal cross**.
- The portion or region on chromosome representing a single gene is called **gene locus**.
- The alleles of a gene are present on the **same gene locus** on the homologous chromosomes.
- All the genotypes of all organisms in a population form the **gene pool**.
- **Pure line or pure breeding line** is a strain of individuals homozygous for all genes considered. The term was coined by **Johannsen**.
- **Punnet square** is a checker board which was devised by **R.C. Punnet** and used to show the result of a cross between two organisms.
- **Genome** is a complete set of chromosomes where every gene chromosome is represented singly as in a gamete.
- A single genome is present in **haploid cells**, two in **diploid cells** and many in **polyploid cells**.

Mendel's principles of inheritance (Mendelism)

- The first scientific study leading to formulations of law of inheritance was carried out by **Gregor Johann Mendel.**
- Mendel first represented his **rules of inheritance** in **1865**.
- Mendel was a monk in **Austria**.
- **Mendelian inheritance** or **Mendelian genetics** is a set of primary tenats that underlie much of genetics developed by G. Mendel in the latter part of 19th century.
- Mendel's laws of Heredity are described in his paper **"Experiments on Plant hybridization"** which was published in the fourth volume of **"Annual proceedings of Natural History Society of Brunn"**.
- Mendel's based his theory on experiments **involving cross pollination** between two plants or **self pollination** with a single plant.
- Mendel had **conducted hybridization experiments in garden pea**, *Pisum sativum*.

- Mendel's laws were rediscovered simultaneously by three great scientists namely **Huge de vries, Erich Von Tschermak** and **Carl correns**.
- The number of characters studied by Mendel in pea plant was **seven**.
- The number of chromosomes in *Pisum sativum* is **14 (2n).**
- Mendel restricted his experiments to one or few pairs of contrasting traits in each experiment.
- Self fertilization in pea can be prevented by removing anthers **(emasculation)** before pollen grains mature.
- **Mendel selected garden pea** for his experiment because –
  - It has a number of well defined **contrasting characters**.
  - It is having **bisexual flowers**.
  - It shows predominantly **self fertilisation** (autogamy).
  - **Hybridisation** or crossing is **easy** in pea.
  - It is having **short life span**.
- Mendel's experiment involved 4 steps as – **selection**, **hybridization**, **selfing** and **calculations**.
  - First he selected a true breeding variety.
  - Then he cross pollinated two contrasting true breeding varieties to get F_1 generation
  - Then he self pollinated F_1 offsprings to get F_2 and self pollinated F_2 to get F_3 generation.
- His results led to the formation of laws of genetics later.
- Mendel performed monohybrid and dihybrid crosses and gave **three principles** of **inheritance.**
- Mendel's **three principles** of **inheritance** are –
  - Law of dominance
  - Law of segregation or law of purity of gametes
  - Law of independent assortment.
- **Law of dominance** states that only one factor expresses itself in F_1 generation.
- F_2 expresses both the dominant and the hidden recessive factor in the ratio of **3 : 1** in the monohybrid cross.
- In a hybrid where both the contrasting alleles are present, only one factor/allele called **dominant** is able to **express** its effect while the other factor / allele called **recessive** remains **suppressed** in F_1 generation. This is called **Law of dominance**.
- **Exception to principle of dominance** are incomplete dominance and codominance.
- **Incomplete dominance** is the phenomenon where dominant allele do not completely express itself.
- Incomplete dominance is not blending inheritance because **parental characters reappear in F_2 generation**.
- This phenomenon was first studied in flower colour of *Mirabilis jalapa* or **four O'clock plant**.
- The phenotypic as well as genotypic monohybrid ratio in F_2 generation in incomplete dominance is **1 : 2 : 1** *i.e.*, pure dominant : hybrid : pure recessive.
- F_1 generation expresses a phenotype which is **intermediate** between those of the parent.
- When blue Andalusian are crossed among themselves, they produce splashed white, blue and black offspring in the ratio of **1 : 2 : 1 due to incomplete dominance.**
- **Overdominance** is another dominance relationship in which the phenotype of heterozygote is not equal to that of either homozygote.
- Heterozygote with overdominance alleles have a phenotype more extreme than either homozygote.
- In codominance, both allelic genes of a genetic trait are equally expressive *i.e.*, the dominant character is not able to suppress the recessive character and thus both the characters appear side by side in F_1 hybrids.
- **Principle of segregation** states that, "**when a pair of contrasting factor or gene are brought together in a hybrid; these factors do not blend or mix up but simply associate themselves and remain together and separate at the time of gamete formation**".
- This law can **also be stated as** alleles pairs segregate during gamete formation and the paired condition is restored by random fusion of gametes during fertilization.
- The above law is also known as "**Law of purity of gametes**" because each gamete is pure in itself *i.e.*, having either T (*i.e.*, gene for tallness) or t (*i.e.*, gene for dwarfness).
- Mendel formulated this law **with the help of monohybrid cross**.
- The third principle of heredity is called the **principle of independent assortment**.
- It states that the genes of different characters located in different pairs of chromosomes are **independent of one another in their segregation during gamete formation**.

- Independent assortment is not applicable for the genes located on the same chromosome, *i.e.*, linked genes.
- Linkage is an **exception of Mendelian principles** because characters studied in pea plant by him were located on different chromosomes or the distance separating the syntenic loci was sufficiently great so that the genes were inherited as though they were on separate chromosomes.
- The genes controlling the seven pea characters studied by Mendel are now known to be located on **four chromosomes (1, 4, 5, 7)**.
- Mendelian recombinations were mainly **due to independent assortment.**
- Test cross is also **applicable to dihybrid cross.**
- A dihybrid test cross give a **1 : 1 : 1 : 1 ratio**, indicating that two pairs of factors are segregating and assorting independently.
- **Atavism** is the phenomenon during inheritance wherein a character remains hidden for several generation and then suddenly gets expressed unchanged in one or more individuals.
- Monohybrid phenotypic ratio is **3 : 1**.
- Monohybrid genotypic ratio is **1 : 2 : 1**.
- Dihybrid genotypic ratio is **1 : 2 : 1 : 2 : 4 : 2 : 1 : 2 : 1**
- Dihybrid phenotypic ratio is **9 : 3 : 3 : 1**
- **Importance of Mendelism** are –
  - On the basis of Mendelism, different breeds in animals and varieties of plants have been produced.
  - Science of **eugenics** (development of superior progeny) is based on Mendelism.
  - On the basis of Mendelism, **heterosis** has been utilised in different organisms.
- Mendel was **successful in his experiments with pea plant** because
  - He selected pure breeding, one or two characters at one time for his breeding experiments.
  - He took those traits which did not show linkage, interaction or incomplete dominance.
  - He used statistical methods and law of probability analysing his results.
  - Pea had contrasting expression of traits.
  - Pea can be cross bred manually but itself undergoes self breeding.
  - There is little chance of pollen contamination.

Gene interaction

- Gene interaction is **the modification of normal phenotypic expression of genes due to their alleles and non allelic genes**.
- Gene interaction is a **post mendelian discovery**.
- Gene interaction is of **two types** – intragenic and intergenic.
- In **intragenic interaction**, two alleles of a gene which are present on the same gene locus on the two homologous chromosomes, react to produce modified phenotype. Eg., incomplete dominance, codominance, multiple alleles and lethal genes.
- **Intergenic interaction** is one where two or more independent genes belonging to same or different chromosomes interact to form a different expression.
- Intergenic interaction includes epistasis, duplicate genes, complementary, genes, supplementary genes, inhibitory genes etc.
- **Modified Mendelian ratio** are expressed as 9 : 7, 9 : 3 : 4, 12 : 3 : 1, 15 : 1, 13 : 3.

Incomplete dominance

- The **main objection to the Mendel's principle** of genetics **was incomplete dominance**.
- **Incomplete dominance** is the phenomenon where dominant allele do not completely express itself.
- **Correns** discovered **incomplete dominance** and **cytoplasmic inheritance**.
- Incomplete dominance is not blending inheritance because **parental characters reappear in F_2 generation**.
- This phenomenon was first studied in flower colour of *Mirabilis jalapa* or four O'clock plant.
- The phenotypic as well as genotypic monohybrid ratio in F_2 generation in incomplete dominance is **1 : 2 : 1** *i.e.*, **pure dominant : hybrid : pure recessive**.
- F_1 generation expresses a phenotype which is **intermediate** between those of the parent. Eg pink flowers are obtained when red and white flowers plants are crossed.

Codominance

- Codominance is the **phenomenon of two alleles lacking dominant recessive relationship** and both express themselves in the organisms.
- The **codominant alleles** are able to express

themselves independently when present together and co-dominance has been reported in roan characters of cattle.

- The codominant alleles are shown with same capital letter but with different superscripts like I^AI^B for allele in human blood group AB and Hb^A Hb^S for normal and sickle celled erythrocytes.

Multiple alleles

- **More than two alternate forms of a gene** present on the same locus are called **multiple alleles**.
- There is **absence of crossing over** in multiple alleles and the mode of inheritance in case of multiple alleles is called **multiple allelism.**
- The well known example of multiple allele in human is **blood group**, which also shows codominance.
- **Landsteiner** discovered the three blood groups in man (**A, B** and **O**).
- Blood group **AB** was discovered by **de Castello and Steini (1902)**.
- There are more than two alleles of the same gene e.g. 15 alleles for eye colour in *Drosophila*.
- Multiple alleles express different alternatives of the same characters.
- Different alleles show codominance, dominance-recessiveness or intermediate dominance amongst themselves.
- They however, follow Mendelian pattern of inheritance.

Lethal genes

- A lethal gene can be defined as **a gene whose phenotypic effect is sufficiently drastic to kill the bearer**.
- Lethal genes **control some vital functions of the organism and cause death of the organisms** in **pure recessive** or **pure dominant form**.
- Lethal gene were **first discovered by Cuenot**.
- In **absolute lethality** individual dies in embryonic stage. For eg. yellow fur in mice.
- In **sublethality** individual dies before reproductive maturity. For eg. sickle cell anaemia.
- In **delayed lethality** individual dies after sexual maturity.
- **Albinism** in corn is **due to lethal genes**.
- **Inhibitor** or **suppressor genes** are non-lethal gene **without any expression of its own but suppress or inhibit the expression of a non-allelic gene**.
- For example, in Rice I-gene inhibits the expression of dominant purple colour gene (P) so that the leaves are green in its presence (I-P-). Green leaves also occur when the leaf colour gene is recessive (*iipp*). A cross between IIPP and *iipp* (both green) yields hybrid greens (I*i*P*p*) which on self breeding form **3 purple to 13 green plants**.

Epistasis

- Epistasis can be defined as the **phenomenon of gene interaction whereby one gene interferes with the phenotypic expression of another non allelic gene or genes**.
- The gene or locus which suppresses or masks the action of a gene at another locus is called **epistatic gene.**
- The gene or locus whose expression is suppressed by an epistatic gene is called **hypostatic gene**.
- **Hypostastasis** is the phenomenon by which the effect of a gene gets suppressed due to the presence of a non allelic gene.
- An **epistatic hypostatic relationship** between two loci is **similar** to a dominant recessive relationship between alleles at a particular loci.
- A **dominant epistatic allele** suppress the expression of a non allelic gene, the latter may be dominant or recessive.
- The dihybrid ratio for dominant epistasis is **12 : 3 : 1**.
- In **recessive epistasis**, epistatic gene suppresses the expression of non-allelic gene only when it is in homozygous recessive state.
- Recessive epistasis or supplementary gene ratio is **9 : 3 : 4 (dihybrid ratio)**.
- **13 : 3** is dominant recessive epistasis ratio.
- In a cross between black (CCaa) and albino (AAcc) guinea pig F_2 exhibits **9 agouti : 3 black : 4 albino**.

Complementary, duplicate, supplementary and polymetric genes

- If two genes present on different loci produce the same effect when present alone but interact to form a new trait when present together are called **complementary genes**.
- **Bateson and Punnet (1906)** observe complementary gene in *Lathyrus odoratus*.
- There are two white varieties of Sweet pea (*Lathyrus odoratus*) controlled independentally by two different genes (C-pp and ccP).

Table : Expected ratios in different types of crosses with examples

	Characters	Expected ratios	Example
1.	**Monohybrid cross**	Phenotypic : 3 : 1 Genotypic : 3 : 1	*Pisum sativum* *Pisum sativum*
2.	**Dihybrid cross**	Phenotypic : 9 : 3 : 3 : 1	*Pisum sativum*
3.	**Incomplete dominance**	1 : 2 : 1	*Mirabilis jalapa*
4.	**Complementary genes**	9 : 7	*Lathyrus odoratus*
5.	**Supplementary genes**	9 : 3 : 4	Coat colour in mice
6.	**Modified supplementary genes (collaboration)**	9 : 3 : 3 : 1	Poultry birds – comb pattern
7.	**Dominant epistasis**	12 : 3 : 1	Fruit colour in *Cucurbita*
8.	**Recessive epistasis**	9 : 3 : 4	Coat colour in mice
9.	**Duplicate genes**	15 : 1	Fruit shape in *Capsella bursa-pastoris*
10.	**Polymeric gene (duplicate genes with cumulative effect)**	9 : 6 : 1	*Cucurbita pepo*
11.	**Supressor gene (Inhibitor gene)**	13 : 3	Leaf colour in rice

- Dominant gene C produces an enzyme that converts the raw material for flower pigmentation into chromagen. Dominant gene P produces another enzyme that oxidises chromagen into purple coloured anthocyanin. Therefore, the dominant alleles of both the genes are required for expression of flower colour.
- **Complementary gene ratio** is **9 : 7**.
- There are two (or more) independent genes found on different chromosomes which produce the same or nearly similar phenotypic effect in the dominant state, producing same intensity of effect even when present together, so that dominant phenotype is more abundant. Such genes are called **duplicate genes** or **pseudoalleles**.
- **Duplicate dominant gene ratio** is **15 : 1**.
- **Supplementary genes** are two non-allelic genes in which one type of gene produces its effect whether the other is present or not and the second (supplementary) gene produces its effect only in the presence of the first usually forming a new trait.
- F_2 dihybrid ratio is 9 : 3 : 4.
- **Polymeric genes** are duplicate genes with cumulative/additive effect, *i.e.*, two independent dominant genes (whether homozygous or heterozygous) having similar phenotypic affect individually but produce a new cumulative effect (similar in homozygous and heterozygous states) when present together.
- **9 : 6 : 1** is the ratio of **duplicate genes** with **cumulative effect**.

Pleiotropic genes

- When a **gene affects** many aspects of phenotype or **controls several phenotypes**, it is said to be **pleiotropic genes** and this phenomenon is called **pleiotropy**.
- When a number of related changes are caused by a pleiotropic gene, the phenomenon is called **syndrome**.
- Pleiotropy is expressed by **sickle cell anaemia, haemophilia**, etc.
- Sickle cell anaemia disease is caused when a gene responsible for haemoglobin produced by recessive alleles differs in **one amino acid**. It incorporates valine in place of **glutamic acid**.
- In human beings, **Marfan's syndrome**, characterised by long limbs, slender body, hypermobility of joints, lens dislocation and susceptibility to cardiac diseases are caused by **single pleiotropic gene**.
- **Galton** coined the term **eugenics**.

Pedigree analysis

- A record of the occurrence of a trait in several generation of a human family is called **Pedigree analysis**.

- **Male member** in pedigree are shown by square □ and **female** by circle O.
- Siblings are represented **horizontally on a line** in order of birth.
- **Solid symbols** (●) represent the traits being invested and **open symbols** O or □ represent the normal traits.
- Pedigree analysis **helps** in identifying the inheritance of specific traits and their possibility of showing up in the offsprings. It is of great significance in the study of genetics.

Quantitative (polygenic) and qualitative inheritance

- **Quantitative or polygenic inheritance** is that type of inheritance in which the complete expression of a trait is controlled by two or more genes in which a dominant allele of each gene contributes only a unit fraction of a trait and the **total phenotypic expression is the sum total/additive/cumulative effect of all the dominant alleles of genes/ polygenes**.
- In quantitative inheritance traits are **expressed in continuous fashion**.
- The genes involved in quantitative inheritance are called **polygenes** or **cumulative genes.**
- A **polygene** is defined as a gene where a dominant allele controls only a unit or partial quantitative expression of a trait.
- **Nilsson-Ehle (1908)** was first to experimentally prove quantitative inheritance.
- Polygenic inheritance is also called **quantitative inheritance** since so many grades between two extremes appear, eg. skin colour in human, intelligence etc.
- **Davenport and Davenport (1910)** shows that skin colour in human is a polygenic trait and is due to at least three separate genes.
- In quantitative inheritance **traits are expressed in continuous fashion**.
- **Qualitative inheritance** is that **type of inheritance in which one dominant allele influences the complete trait so that two such alleles do not change the phenotype**.
- **Monogene** is a gene in which one dominant allele controls the complete or qualitative expression of a trait.

VARIATIONS

- The characteristic differences exhibited by the individual of the same species, race and family is called **variations**.
- Variation caused due to genetic difference are called **genetic variation** or **heredity variations**.
- The variation caused due to environmental factors and which is not fixed is called **environmental variation**.
- Heredity variations are **transmitted from generation to generation** whereas environmental variation are **temporary and do not relate with last or next generation**.
- Heredity variation within a progeny results due to **sexual reproduction**.
- **Somatic variations** affect the somatic or body cells of the organisms and these die with the death of the individual and thus are **non inheritable**.
- Somatic variations are also called **modifications** of **acquired characters** because they are acquired by an individual during its life time.
- Somatic variations are **caused by three factors** namely **environment**, **use and disuse of organs** and **conscious efforts**.
- **Continuous variations** are **fluctuating variations** which oscillate around a mean or average of the race, variety and species.
- Continuous variations are also called **recombinations** because they are formed due to recombination of alleles caused by –
  – Chance separation/segregation of chromosomes at the time of meiosis (sporogenesis in plants and gametogenesis in animals).
  – Crossing over or exchange of chromatid segments during meiosis.
  – Chance aggregation of chromosomes during fertilization.
- Continuous variations are of **two types** –
  – **Meristic**, influencing number of parts like number of grains in an ear of wheat, number of tentacles in *Hydra*.
  – **Substantive**, influencing appearance like height, colour, yield of milk or eggs.

- **Discontinuous variations** are **mutations** which are sudden, unpredictable inheritable variations not connected with the average by any intermediate stages.
- Discontinuous variations are **source of all germinal variations and most of evolution**.
- Discontinuous variations are **caused by chromosomal aberrations, change in chromosome number and gene mutations**. Depending upon the effect, they are of two types –
  - **Indeterminate variations**, which occur in any conceivable direction and to any degree.
  - **Determinate variations**, which are variations in particular direction with selective or adaptive importance and are also called **orthogenic variations**.
- Variations make some individual better fitted in the struggle for existence.
- They help the individuals to adapt themselves according to the changing environment.
- Discontinous variations produce new traits in the organisms.
- Variations allow breeders to improve races of useful plants and animals for increased resistance, better yield, quicker growth and lesser input.
- They constitute the raw material for evolution.
- Variations gives each organism a distinct individuality.
- Because of variations species do not remain static. Instead, they are slowly getting modified forming new species with time.
- Pre-adaptations caused by the presence of neutral variations are extremely useful for survival against sudden changes in environment, e.g., resistance against a new pesticide or antibiotic.

End of the Chapter

Chapter 53

Genes & Chromosomes

GENES

- Gene is the **basic unit of inheritance that specifies the expression of a particular trait**.
- According to T.H. Morgan –'Any **particle on the chromosome which can be separated from other particles by mutation or recombination, is called a gene**'.
- Chemical nature of gene suggests that genes are catalysts which bring about reaction without being changed or consumed.
- **Ultimate unit of recombination, mutation and self reproduction is gene**.
- The total number of genes in human is about 30,000.
- Gene should be able to express in genetic expression by transcription to mRNA and finally to produce proteins.
- **Term** 'gene' was **given by Johannsen** (1909) for any particle to which properties of Mendelian factor or determiner can be given.
- Genes act by producing enzymes, *i.e.* each gene in an organism produces a specific enzyme, which controls a specific metabolic activity.
- Gene is **chemically DNA**, but the length of DNA which constitutes a gene, is controversial.
- 3 terms, *i.e.* cistron, muton and recon were given by Seymour Benzer to explain the relation between DNA length and gene.
- **Cistron** is that particular length of DNA which is **capable of producing protein molecule or polypeptide chain or enzyme molecule**.
- **Muton** is that length of DNA which is **capable of undergoing mutation**. Muton is having one or part of nucleotide.
- **Recon** is that length of DNA, which is **capable of undergoing crossing over or capable of recombination**. Recon is having one or two pairs of nucleotides.

Types of genes

Transposons or jumping genes

- **Transposons** or **jumping genes** (Mc Clintock 1951 in Maize; Hedges and Jacob, 1974) are those DNA segments which can pass from one place to another in the genome.
- At their ends, transposons have silmilar or inverted repetitive DNA sequences. The sequences can be cleaved by an enzyme **transposase**.

Retroposons

- The term retroposon was given by **Rogers (1983)** for DNA segments which are formed from RNA (RNA origin) or which are formed by reverse transcription under the influence of reverse transcriptase enzyme or RNA dependent DNA polymerase enzyme. *i.e.*,

$$\text{RNA} \xrightarrow{\text{Reverse transcription}} \text{DNA (Retroposon)}$$

Split genes or interrupted gene

- **R.J.Robert** and **P.A. Sharp (1977)** discovered split genes (gene with introns) in eukaryotes for which they were awarded **Noble Prize in 1993**.
- Split genes, present in eukaryotes **have coding gene** which are **not continuous but are interrupted by non-coding sequence**.
- **Two kinds of alternating segments** in the split genes are – exon and intron.
- **Exon contains coding nucleotides** sequence which are ultimately translated into polypeptides.
- Exons **carry genetic information.**
- **Intron contains non-coding nucleotide** sequence which are not translated into polypeptide.
- Eukaryotic genes without introns are called **exonic**

genes (non split gene), eg. histone gene, interferon gene.

- Certain eukaryotic exonic genes are called **processed genes which lack both intron and promotors**. Therefore they are nonfunctional.
- Nonfunctional or inactive DNA present in eukaryotes is known as **repetitive DNA** or **excess DNA**.
- Gene splicing is developed by **Cohen** and **Boyer (1973)**.
- **Splicing involves :** (i) removal of intron portion and fusion of exons to produce continuous gene or *m*RNA, and (ii) uniting foreign gene with bacterial genome for producing specific substances (eg. insulin).
- **Functional eukaryotic *m* RNA** transcribed by exon is formed by splicing.

Pseudogenes or false gene and multiple genes

- **Pseudogenes** are nonfunctional genes.
- Pseudogenes are **unable to produce functional products** due to inactivation of promotor region, presence of intervening nonsense codons insertions or deletions. E.g. several *Sn*RNA genes.
- Pseudogenes are useless to the organisms and considered to be **defective copies of functional genes** (cistrons).
- Pseudogenes are reported in *Drosophila,* mouse and human beings.
- **Multigenes** or **multiple gene family** is a group of nearly similar genes which produces tissue and time specific products. Eg. globin gene family.
- In a cell hardly **10%** of the gene are active and **90%** being inactive.

Inducible genes or repressible genes

- Non constitutive genes are those genes which can be switched on or off as per requirements.
- They are of two kinds – **inducible** (remain repressed but are switched on in the presence of an inducer chemical) and **repressible** (remains active till switched off by a chemical).

House keeping genes

- There are other genes which are always expressed, are called **constitutive genes** or **housekeeping genes** and their common functions are required in all types of cells, e.g. RNA-polymerase-determining genes such as t-RNA and r-RNA.

CHROMOSOMES

- Chromosomes are oval, rod or thread like DNA complexes which function as hereditary vehicles because they store, replicate and transcribe coded hereditary information.
- The relationship between the behaviour of chromosomes and the behaviours of Mendels factors was first **recognized by W.S. Sutton and Boveri in 1902** or Chromosome theory of inheritances was proposed by **Sutton and Boveri (1902)**.
- This theory states that chromosome are vehicle of **heredity information and expression** as genes are present over them.
- Chromosomes are filamentous body which are typically present in the nucleus and become visible during cell division.
- Chromosomes are not visible in the active nucleus **due to their high H_2O content**.
- Number of chromosomes in definite nucleus is **diploid.**
- Complete haploid set of chromosomes of a species is **genome.**

Prokaryotic and viral chromosomes

- **Prokaryotic chromosomes** are represented in the form of short, simple, single DNA molecule.
- **Nucleoid** is the compact mass of irregularly folded DNA molecules in bacteria.
- Plasmids were discovered by **Lederberg** and **Hayes (1952)**.
- Plasmids are the most widely used **cloning vectors** in the techniques of gene manipulation in bacterium.
- **Ti-plasmid** of *Agrobacterium* is widely used in plants.
- Plasmid can replicate, like nucleoid, independently of main genome.
- Plasmids carry **gene for sexuality** like fertility factor, **antibiotic resistance** like chloramphenicol, tetracycline etc., **Nif** (nitrogen fixation), **colicinogenic factor** for synthesis of bacteriocidal & bacteriostatic chemicals.
- The process of replication of plasmid DNA other than initiation is controlled by **bacterial gene**.
- Viral nucleoid are packed into single hereditary unit called **viral chromosome**.
- **Virion** is the unit of a virus particle composed of a nucleic acid core and a protein coat.

- The term 'virion' was introduced by **Lwoff, Anderson** and **Jacob** in 1959.
- Virion is a simple, structurally complete (mature) virus particle.
- Virus consists of a nucleic acid core surrounded by a protein coat.
- The protein coat that encloses viral genes is called a **capsid**.
- Viruses usually have only one nucleic acid either DNA or RNA. So viral genes are made of either DNA or RNA.
- One of the best studied plant virus is **Tobacco Mosaic Virus** (TMV).
- TMV was the virus **first discovered**. Genetic material of TMV is RNA.
- **DNA viruses** possess DNA as the genetic material.
- Many of the animal viruses like poxviruses, adenoviruses, herpes viruses and majority of bacteriophabge are DNA viruses.
- Most RNA viruses possessing RNA as the genetic material carry a gene for an enzyme that uses viral RNA as a template in the synthesis of more viral RNA. This enzyme is **RNA replicase**.
- Among animal viruses paramyxoviruses (Mumps and Measles), orthomyxovirus (Influenza), rhabdovirus (Rabies), togavirus (Dengue fever), reovirus (illness of respiratory tract) and picornavirus (Polio) are RNA viruses.
- **RNA - DNA viruses** are also called as **retroviruses** (*retro* = turning back), they have their genes, the genetic material in the form of single stranded RNA.
- Retrovirus possesses the gene that codes for **reverse trancriptase**, an enzyme (carried in the viral coat) that causes synthesis of a double stranded DNA molecule from single stranded RNA template.
- **Temin** (Nobel Prize 1975) discovered that the **Rous Sarcoma Virus** (RSV) do reverse transcription. There is a reverse flow of genetic information from RNA to DNA.
- Viroids were discovered by **T.O.Diener** in 1971.
- **Viroids** are small single stranded circular RNA molecules which infect higher plants.
- Viroid replication **requires host encoded RNA polymerase**.

  [*For more detail on bacteria and viruses refer Chapters 'Monera' and 'Viruses'*.]

Eukaryotic chromosomes

- Eukaryotic chromosomes were discovered by **Hofmeister (1848) in the pollen mother cells of** *Tradescantia.*
- The structures present in chromosomes are **centromere**, **secondary constriction**, **nucleolar organizer**, **telomeres**, **chromonema** and **satellite**.
- **Chromatids** are two subunits or similar threads attached to each other to form chromosomes.
- The constricted region on the chromosome is called **centromere**, **kinetochore or primary constriction**.
- **Centromere** is the central narrow **nonstainable portion** of the chromosome **to which the spindle fibres attach** during mitotic and meiotic division.
- The two parts of a chromatids/chromosomes on either side of centromere are called **arms**.
- The two arms may be equal (**isobrachial**) or unequal (**heterobrachial**).
- Depending on the position of centromere four category of chromosome are recognised *i.e.* **metacentric**, **submetacentric**, **acrocentric** and **telocentric**.
- In **metacentric** the **centromere is near the middle** of the chromosome.
- Metacentric chromosome appear **V shaped** during anaphasic movement.
- In **submetacentric** centromere is present **some distance away from the middle**.
- It appears **L** or J **shaped** during anaphase.
- In **acrocentric** centromere is situated **near the end**. It appears **J shaped** during anaphase.
- **Telocentric centromere** is **truely terminal** *i.e* centromere is situated at the tip of the chromosome. The chromatids in a telocentric chromosome are not divided in arms. The chromosomes remain rod shaped.
- Telocentric appears **I shaped** during anaphase.
- Truely telomeric chromosome was reported by **Marks (1957)**.
- In *Trillium* and *Tradescantia* all the chromosomes are **metacentric**.
- **In man, three types** of chromosomes are found– **metacentric, submetacentric and acrocentric**.
- In man chromosome number **13, 14, 15, 21, 22** and **Y** have nucleolar organizer and satellite.
- Chromosome with two or more centromeres are called **dicentric** and **polycentric chromosomes**.

- **Dicentric chromosomes** (two centromere) are **common in maize**.
- In **polycentric chromosome** the centromere lies in the diffused condition along the length of chromosome (eg. *Ascaris*).
- The chromosomes whose centromeres are diffused rather than discretely located, as they are in most chromosomes, are called **holocentric chromosome**.
- Constriction present on chromosome other than primary constriction is called **secondary constriction** and the latter involved in the breaking and fusion of chromosomes segments.
- In man secondary constriction II are found on the long arms of **chromosome 1, 10, 13, 16** and **Y**.
- **Nucleolar organizer** (called secondary constrictions I) are **necessary for the formation of the nucleolus**.
- The nucleolar organizer represents about **0.3%** of the total amount of nuclear DNA.
- **Satellite** are knob like part distal to nucleolar organizer region.
- The chromosomes bearing satellites are called **SAT chromosome** (due to pure stainability of nucleolar organizer region). SAT stands for 'Sine Acid Thymonucleinico' (without thymonucleic acid or DNA).
- The tips of chromosome are called **telomeres**.
- Telomeres have a unique property in that it **prevents the ends of the chromosome from sticking together**.
- Chromosome is **40% DNA**, **50% histone**, **8.5% proteins** and **1.5% RNA**.
- **Chromonema** is DNA histone thread or chromatin thread which **form the bulk of chromosomes**.
- Coiling in chromonema can be **pleconemic** (interwining) or **paranemic** (simple folding).
- **Chromatin** is composed mainly of coils of DNA bound to basic proteins called histones.
- The basic form of chromatin packing is commonly known as the **30 nm chromatin fibre**.
- The fundamental packing unit of chromatin is called as **nucleosome**.
- **Woodcock (1973)** showed that under the electron microscope chromatin appears to have a 'string of beads' (called nucleosomes) structure.
- Each nucleosome bead consists of a set of **8 histone molecules**.
- **Chromomere** is a small beadlike structure visible on a chromosome during prophase of meiosis and mitosis, resulting from local coiling of a continuous DNA thread.
- The portion of genomic DNA which is **genetically active** (transcriptionally active) and **pale staining** with G and C banding is known as **euchromatin.**
- **Euchromatin** is **condensed during cell division** and is relatively **rich in GC base pairs.**
- **Heterochromatin** (discovered by His) is a type of chromatin that is darkly staining, tightly packaged or coiled throughout the cell cycle and is generally **genetically inactive.**
- There are two types of heterochromatin namely **constitutive heterochromatin** and **facultative heterochromatin.**
- **Constitutive heterochromatin** is **fixed** and **irreversible** in form and function.
- **Chromosomes 1, 9, 16 and Y chromosomes** contain regions of constitutive heterochromatin.
- **Facultative heterochromatin** has the facility to **return** to the **normal euchromatic state**.
- Facultative heterochromatin is **reversible**, its heterochromatic state depending on the stage of development or the cell type examined. It becomes sex chromatin body or barr body in early embryogenesis.
- The **inactive X chromosome** is made up of **facultative heterochromatin**.
- **Barr body** (sex chromatin) is the densely staining mass that represents an **inactivated X chromosome** found in the **nuclei** of **somatic cells** of most **female mammals.**
- Number of Barr bodies is **one less than the total X chromosomes**, one in XX (normal females), two in XXX sex complement, absent in normal human males and one in males with **Klinefelter's syndrome**.

Sex chromosome

- The chromosomes which carry genes for sex determination are called **sex chromosome**, **heterosome or allosome**.
- Chromosome other than allosome are called **autosome**.
- Human beings have **22 pairs** of autosome and **one pair** of allosome.
- Sex chromosomes are those chromosome whose presence or absence on particular form determine the sex of the individual in unisexual or dioecious

animals. Eg. XX–XY, XX–XO etc.

- The two sex chromosome in an individual may be morphologically **similar (homomorphic XX)** or **different (heteromorphic XY)**.
- Individual having **heteromorphic chromosome form two types of gametes**.
- TDF (Testis determining factor) and genes for hypertrichosis are found on **Y chromosomes** hence called **holandric genes**.
- X chromosome was discovered by **Henking (1891)**.
- Y chromosome was discovered by **Stevens (1902)**.
- A set of chromosome of an individual or species is called **karyotype**.
- To study karyotype of man **WBC are cultured in aseptic condition**.
- **On the basis of length** human chromosomes can be divided into **seven groups**.
- The arrangement where the karyotype of man is arranged in a series of decreasing length is called **idiogram**.
- **Tijo** and **Levan (1956)** made the karyotype of human chromosomes.

Chromosomal staining

- Chromosomes are stained with special *flourescent dyes* that have differential affinity for different parts of the chromosomes.
- Bands are segments of stained chromosomes that appear lighter, darker or stained as compared to adjacent parts.
- **Chromosome banding** was discovered by **Caspersson** and others in 1970. With one particular dye, the chromosomes show a particular unique banding pattern, *i.e.,* the banding pattern is constant with a particular treatment.
- Banding technique of chromosome staining is highly useful in knowing various types of chromosomal aberrations or abnormalities like additions, deletions and inversions.

- **B chromosomes** are heterochromatic supernumerary chromosomes which are smaller than normal and show slower replication. In excess they result in loss of vigour. In *Tradescantia edwardsiana* there are 5 supernumerary chromosomes in addition to the twelve somatic chromosomes.
- ***m* chromosomes** are minute but functional chromosomes which are found in some bryophytes and insects.
- **L chromosomes** (also called **E chromosomes**) are found in germline cells which are eliminated during formation of somatic cells.

- Chromosomes can be stained by **Janus green B** and **acetocarmine**.
- **Q Banding** is observed when the chromosomes are stained with **quinacrine mustard**. **The regions of chromosome rich in A+T get stained intensely but G+C rich regions do not**.
- **G Banding** is observed when the chromosomes incubated in saline are stained with **Giemsa** or treated with urea or detergents. These bands **appear in the regions having S–rich proteins**.
- **R Banding** correspond to the regions on chromosomes having proteins lacking sulphur which become visible when chromosomes incubated in a **bugger** at high temperature and stained with **Giemsa**.
- **C Banding** is observed when chromosomes are treated with strong alkali followed by warm saline and then stained with **Giemsa**. It appears around **the centromeric regions**.

Giant chromosomes

- Giant chromosomes are very large chromosomes reported from few special types of cells.

Table : Karyotype or idiogram of man

	Group	Size	Position of centromere	Idiogram number
I	(A)	Large	Metacentric or submetacentric	1, 2, 3
II	(B)	Large (medium large)	Submetacentric	4, 5
III	(C)	Medium	Submetacentric	6, 7, 8, 9, 10, 11, 12, and X
IV	(D)	Medium	Acrocentric, sat (subterminal)	13, 14 and 15
V	(E)	Small (medium short)	Metacentric or submetacentric	16, 17 and 18
VI	(F)	Smallest	Metacentric	19 and 20
VII	(G)	Small	Metacentric, sat	21, 22 and Y (have not sat)

- Two main types of giant chromosomes are – polytene chromosomes and lampbrush chromosomes.
- A chromosome having many chromonemata lying side by side is called a **polytene chromosome** (P.C.).
- Polytene chromosomes were first observed by **Balbiani (1881)** in **salivary gland** of *Chironomus tantans*.
- The name polytene (*polys* - many, *lainia*-threads) was given by **Koller**.
- They are quite common in salivary glands of insects and so are called **salivary chromosomes**.
- They are **formed by endomitosis** of somatic pairing and **are in permanent prophase**.
- The chromosomes can reach a length of 2000 μm and contain 1000 to 16,000 DNA.
- They also occur in other organs of insects, antipodal cells, endosperm cells and suspensor cells.
- All the polytene chromosomes remain attached to one another at a common point called **chromocentre**.
- Polytene chromosomes show **puffs or balbiani rings** which develop lateral loops where DNA becomes active and produce copies of RNA.
- Relationship between bands of polytene chromosomes and genes was shown by **Painter (1933) and Bridges (1936)**.
- **Lampbrush chromosomes** are **diplotene bivalents** (occurs in pairs) held together by chiasmata. First description was given by **Flemming (1882)** on amphibian oocytes and a detailed study was made by **J.Ruckert (1892)** on the oocytes of sharks.
- Lampbrush chromosome **bears loops for rapid transcription and production of yolk and informosomes** (*m*RNA + proteins). Hence they occur in **oocytes**.
- Besides oocytes, lampbrush chromosomes have been reported in **spermatocytes** and **giant nucleus of** *Acetabularia*.

Functions of chromosome

- Chromosomes contain genes. All the hereditary information is located in the genes.
- Chromosomes control the synthesis of structural proteins and thus help in cell division and cell growth.
- They control cellular differentiation.
- By directing the synthesis of particular enzymes, chromosomes control cell metabolism.
- Chromosomes can replicate themselves or produce their carbon copies for passage to daughter cells and next generation.
- SAT chromosomes produce nucleoli for synthesis of ribosomes.
- Their haploid or diploid number respectively bring about gametophytic and sporophytic characteristics to the individual.
- Chromosomes forms a link between the offspring and the parents.
- Some chromosomes called sex chromosomes (e.g., X and Y or X and O) determine the sex of the individual.
- Through the process of crossing over, chromosomes introduce variations.
- Mutations are produced due to change in gene chemistry.

SEX DETERMINATION

- **Wilson** and **Stevens (1905)** put forward the **chromosome theory of sex**.
- Sex determined at the time of fertilization is known as **syngametic sex determination**.
- **Types of sex determination methods** are –
  - **XY method** - (mammals, some insects) - XX – ♀, XY – ♂
  - **ZW method** - (birds, reptiles, fishes) - ZW – ♀, ZZ – ♂
  - **XO method** - (roundworm, insects) - XX – ♀, XO – ♂
  - **ZO method** - (moths, butterfly) - ZO – ♀, ZZ – ♂
- The condition of **sex determination in ZW method** is just **opposite of XY method**.
- In **ZW method** males are homozygous whereas in **XY method** females are homozygous.
- XY determination is found in many **bryophytes**.
- Example of plants showing XY sex determination method are *Melandrium*, *Coccinia*, *Salix, Elodea* etc.
- **Allen (1940)** presented the list of plants where sex chromosomes had been reported.
- **Wastergard (1950)** gave the list of plants where heteromorphic sex chromosome were present.
- In *Melandrium album* diploids, triploids and tetraploids have **different doses of X & Y chromosomes**.

- **Sex of the baby depends upon the sperm** (andro - or gyno-) **which fertilizes the ovum** – boy if fertilized with androsperm and girl if fertilized with gynosperm. It depends upon chance which sperm fertilizes the ovum.
- **Twins are two babies given birth simultaneously by a woman**. If they **develop from two separate fertilized eggs,** they are called **dizygotic fraternal twins**. They may have the same or different sexes.
- Sometimes **twins develop from the same fertilized egg** due to breaking after the first one or a few cleavages. They are called **monozgotic twins**.
- Monozygotic twins are **identical twins with same genotype and sex**. Breaking of young embryo often results in monozygotic twins joined in various regions. They are called **siamese twins**. It was noticed by **Warmeke (1946)**.
- Plants are **male** when one or more Y chromosomes are present and **female** when Y chromosome is absent.
- **Haplodiploidy** is the sex determination method in which **one sex is haploid** while **other is diploid**, for eg. honeybees.
- **Gynandromorphs** are individuals where half the body of male and half the body of female is found in one individual.
- Gynandromorphs are of three types – **bilateral**, **anterio-posterior** and **sex piebalds**.
- In **bilateral gynanders** half lateral side is of male and half is of female.
- In **anterio-posterior** the anterior end of the animal is of one sex and posterior half of other.
- In **sex piebalds** female fly bears irregularly scattered spots of male tissue.
- **Thomas Hunt Morgan (1866-1945)** is called **Father of Experimental Genetics**.
- **Morgan** discovered **presence of gene over chromosomes**, **chromosomal theory of linkage**, **chromosome mapping**, **crossing over**, **criss cross inheritance and mutability of genes**.
- The organism selected by Morgan for his experiments was *Drosophila melanogaster*.
- **C.B. Bridges** gave **Genic balance theory for sex determination** in *Drosophila*. According to him X chromosomes are carriers of genes for femaleness and autosomes are carriers of genes for maleness, so it is the **ratio of number of X chromosomes and autosomal sets, which determine sex**.
- The **first pair** of *Drosophila* chromosome is that of **sex chromosome** as they determine sex.
- The **male fruitfly** possesses **XY sex chromosomes** while the **female** has **XX chromosomes**.
- **Diagynic inheritance** is the transfer of trait from male parent to grandson through female offspring and its *vice versa* is called **diandric inheritance**.
- A trait showing criss cross inheritance is **sex linked**.
- **Criss cross inheritance** is that type of inheritance where the gene of one parent are transferred to grand children through children of opposite sex.
- Criss cross inheritance **establishes the relationship between gene and the sex chromosomes**.
- Non criss cross inheritance is both autosomal and sex linked.
- Sex linked non-criss cross inheritance is **holandric** (if it passes directly from father to son) and **hologynic** (if it passes directly from mother to daughter).
- The **genes present** on the differential region of **Y chromosome** are called **holandric genes.**
- Holandric genes are passed directly from **male parent** to **male offspring.**
- Failure of chromosome to separate during anaphase is called **non-disjunction** which was first discovered by **Bridges (1916)** in fruitfly.
- **Meiotic nondisjunction** is the non separation of synapsed homologous chromosomes during anaphase I of meiosis.
- **Mitotic nondisjunction** is the failure of daughter chromosomes to separate during mitotic anaphase.
- **Coupling** occurs when two alleles coming from same parent tend to enter same gamete and hence transmitted together in an offspring.
- **Repulsion** occurs when two alleles coming from different parent tend to enter different gametes to remain apart in the offspring.

LINKAGE AND CROSSING OVER

- **Chromosome theory of linkage** was put forward by **Morgan** and **Castle.**
- According to chromosome theory of linkage
  - Genes show **linkage**
  - **Genes lie linearly** over the chromosome.
  - **Strength** of the **linkage** is **inversely proportional** to the **distance** between two linked genes.
- Exception to Mendel's study was proved by the phenomenon of **linkage**.

- **Linkage** is the tendency for alleles of different genes to be passed together from one generation to the next.
- Gene located on different chromosomes **cannot show any linkage**.
- Linked genes show dihybrid ratio of **3 : 1** and test cross ratio **1 : 1**.
- Linkage is of **two types** – complete and incomplete.
- **Complete linkage** is shown where no recombinant type is formed.
- **Incomplete linkage** is the tendency of linked gene to separate and form recombinant type due to crossing over.
- **Linkage group** is a group of linearly arranged linked gene which are inherited as a single unit due to their being present on a chromosome.
- Number of linkage groups in a species corresponds to its haploid number of chromosomes.
- Number of linkage group in pea, *Drosophila*, maize and human are **7, 4, 10 and 23 respectively**.
- **Importance of linkage**
  - The **possibility of variation** in gametes is **reduced** by linkage (unless crossing over occurs).
  - **Linear arrangement of genes** on chromosomes.
- Traits which are determined by genes present on sex chromosome are called **sex linked traits**, eg. haemophilia.
- Traits which are confined to express only in one sex is **sex limited traits**, eg. milk secretion in mammals.
- Traits found in a sex due to a particular sex hormone are called **sex influenced traits**, eg. beard in man.
- Genes that lie far apart on the same chromosome show **50% recombination**.
- X chromosome of human has approximately **102 genes**.
- Recombination frequency of **50%** is the maximum and gene that show this are called **unlinked**.
- **Sir Archibald Garrod** was the **first who linked alkaptonuria** to a recessive Mendelian factor.
- In population genetics, the gene frequency can be studied through **Hardy – Weinberg law**.
  $p^2 + 2pq + q^2 = 1$ (where p = dominant, q = recessive)
- **Parental types** are allelic combinations found in the parents which are passed on to the gametes and offspring unaltered due to non-occurrence of crossing over.
- **Recombinant types** are new allelic combinations different from those of parents due to crossing over in their linkage groups.
- **Crossing over** is the cytological phenomenon involving exchange of corresponding segments of non-sister chromatids of a pair of homologous chromosome by breaking and reunion following synapsis.
- Mechanism of crossing over follows **three process** : **synapsis**, **duplication of chromosome** and **chiasmata formation**.
- Crossing over (C.O.) takes place at **chiasmata**.
- **Jenssens (1909)** was the first person to discover chiasmata and related process of crossing over.
- Crossing over is observed in the **pachytene stage** of meiotic-prophase I.
- The nonsister chromatids in which exchange of segments takes place are known as crossovers or recombinants.
- Linkage and crossing over are **inversely proportional**.
- Crossing over and distance between genes are **directly proportional**.
- The **frequency of crossing over** is an index of the relative distance of gene on chromosome.
- Presence of heterochromatin **decreases the frequency of crossing over**.
- Frequency of crossing over **increases** when exposed to X-rays.
- **Frequency of recombination** is given as
  $= \frac{\text{Total no. of recombination in test cross}}{\text{Total progeny in test cross}} \times 100$
- One crossing over produces **50% recombinant type**.
- **Frequency of crossing over** is **double the frequency of recombinants**.
- **Crossing over value** is the frequency of crossing over between two linked genes present on the same chromosome.
- **Crossing over map** or **chromosome map** is a graphical representation of relative position/order and relative distances of genes in a chromosome in a form of line.
- **Morgan** or **map units** are the units for crossing over.

- 1 map unit or Morgan is equivalent to **1% recombination between 2 genes**.
- The first organism where the linkage map for various chromosome were constructed are *Drosophilia* and maize.
- **Recombinant frequency** tends to be **lower near centromere** and **higher near telomere**.
- Total number of recombination can be calculated as $2n$ (n = no. of chromosome).
- **Factors influencing crossing over** and **linkage** are distance between genes, temperature fluctuation (increased), X rays, age, sex, chemicals, interference of cross over heterochromatin.
- **Tetrad analysis** is analysis of products of individual meiosis so as to find out (i) linkage groups (parental types) (ii) recombinations (recombinant types) (iii) segregation of genes and (iv) independent assortment of genes.

GENETIC VARIATION

- **Genetic variation** arises due to two reasons– recombination and mutation.
- **Recombination** is usually the **most immediate cause of variability.**
- Recombination can occur in atleast **three ways**: crossing over of chromosomes during meiosis; random assortment of maternal and paternal chromosomes during the production of egg and sperm; and random combination of egg and sperm at fertilization.
- Term mutation was coined by **Hugo de Vries (1901)**.
- **Bateson** called mutation **as discontinuous variations or saltation**.
- Mutation is the **sudden stable transmissible discontinuous variation which appear in an organism due to permanent changes in their genotype**.
- De Vries **observed 834 mutation in 54343 plants** of *Oenothera lamarckiana*.
- Mutation is of **two types** – **induced mutation and spontaneous mutation**.
- Change in genotype occurred due to **chromosomal mutation** (due to structural changes and changes in number) and **gene mutation**.

Chromosomal mutation

- Chromosomal mutation is the **changes that occur in the morphology of chromosome resulting in change in number or sequence of gene without any change in ploidy**.
- Chromosomal mutation due to structural changes are of **four types** – **deletion**, **duplication**, **inversion** and **translocation**.
- **Deletion** or **deficiency** involves the removal of a section of chromosomes.
- Deletion are of **two types** – terminal and interstitial.
- In man deletion in **chromosome 5** results in **cri–du–chat syndrome**.
- In **duplication**, there is **addition of a part of the chromosome**.
- Important **examples** of **duplication** is **bar eye character** in *Drosophila.*
- The change in phenotypic expression when genes are relocated without altering their number is called **position effect.**
- In **translocation** a sequence of a chromosome becomes attached to a non-homologous chromosomes.
- In **reciprocal translocation**, mutual exchange of segments between two nonhomologous chromosomes occurs.
- Translocation in heterozygous condition are reported in *Oenothera, Rheo* and *Tradescantia.*
- In inversion a section of the chromosome is separated and reinserted after a rotation of 180°.
- Inversion can be **pericentric (include centromere) or paracentric** (**beyond centromere**).
- Mutation caused by the variation in chromosome number are of two types – **euploidy** and **aneuploidy**.
- **Euploidy** is the condition in which chromosome number is exact multiple of a genome, eg monoploidy, diploidy, polyploidy etc.
- Gametes usually have one set of chromosome hence **haploid**.
- The condition in which the chromosome sets are present in multiple of n is called **polyploidy**.
- Polyploidy is of **three types** : autopolyploidy, allopolyploidy, autoallopolyploidy.
- **Autopolyploidy** is the increase in the number of the same genome, for eg. AAA.
- **Allopolyploidy** is the increase in number of chromosome set due to coming together of genome of two or more species, for eg. AABB.
- **Autoallopolyploidy** is the increase in chromosome set due to coming together of different genome and

occurrence of one genome in more than diploid state, for eg. AAAABB.

- **Aneuploidy** is the phenomenon where change in chromosome does not involve entire set of chromosome but due to division or addition of chromosomes.
- **Hypoploidy** is aneuploidy in which loss of chromosome occurs.
- **Hyperploidy** is aneuploidy in which increase of chromosome occurs.
- Trisomic and tetrasomic are types of **hyperploidy.**
- Monosomic, nullisomic are types of **hypoploidy**.
- Monosomic is $\mathbf{2}\boldsymbol{n} - \mathbf{1}$, trisomic is $\mathbf{2}\boldsymbol{n} + \mathbf{1}$, nullisomic is $\mathbf{2}\boldsymbol{n} - \mathbf{2}$, tetrasomic is $\mathbf{2}\boldsymbol{n} + \mathbf{2}$, double monosomic is $\mathbf{2}\boldsymbol{n} - \mathbf{1} - \mathbf{1}$, double trisomic is $\mathbf{2n + 1 + 1}$,
- The example of monosomy in human is **Turner syndrome** (44 + XO).
- Trisomy of 21st chromosome results in **Down syndrome**.
- Trisomy of 18th chromosome results in **Edward's syndrome**.
- Trisomy of 13th chromosome results in **Patau's syndrome**.
- 44 + XYY is called **Jacob's or criminal syndrome**.
- **Klinefelter's syndrome** is due to additional X chromosome in normal male (44 + XXY).
- 44 + XXX represents **super female**.
- All types of trisomic can be studied in *Datura*.
- Maximum number of chromosome is known for Adder's tongue fern, *Ophioglossum reticulum* ($2n$ = 1262), and *Aulocantha* ($2n$ = 1600).
- **Mixed aneuploids** are aneuploids with both hypoploidy and hyperploidy, e.g., 2N + 1 A– 1B.

Gene mutation

- The sudden stable change in the structure of gene or cistron due to change in nucleotide type or nucleotide sequence is called **spontaneous mutation**.
- Mutation which involve change in single nucleotide is called **point mutation**.
- Point mutation is the process in which **new alleles of a gene** are produced.
- Mutation from wild to new type is called **forward mutation**.
- Mutation from mutated gene to its wild form is called **reverse or back mutation**.
- Mutation which affects vegetative cells are called **somatic mutation** and those which affect sex cells are called **germinal mutation**.
- Somatic mutation are **not inheritable** while germinal mutation are **inheritable**.
- Recessive mutation show their effect after many generation when they become **homozygous**.
- **Pleiotropic mutation** is the result of single mutation changing more than one character.
- The gene mutation which involve more than one base pairs or entire gene are called **gross mutation**.
- The smallest part of gene that can mutate is called **muton**.
- The smallest muton in a gene is a **single base pair of DNA**.
- **Tautomerism** is the phenomenon of changed pairing qualities of the bases.
- Tautomerism is caused by **chemical mutagens**.
- **Substitution gene mutation** results when one or more nitrogenous pairs are changed with others.
- Substitution (replacement) gene mutation is of **two types** : **transition** and **transversion**.
- In **transition mutation**, a nitrogen base is replaced by another of its type *i.e.*, one purine is replaced by another purine (adenine $\leftrightharpoons$ guanine) while one pyrimidine by another pyrimidine (cytosine $\leftrightharpoons$ thymine or uracil).
- In **transversion**, a purine base is substituted by a pyrimidine base and *vice versa*, e.g., uracil or thymine with adenine and cytosine with guanine.
- **Frameshift mutations** are those mutations in which the reading of the frame of base sequence shifts laterally either in the forward direction **due to addition** of one or more nucleotides or in backward direction **due to deletion** of one or more nucleotides.
- **Two types of frameshift mutations** are **insertion** and **deletion**.
- In **insertion** one or more nucleotides are added in the segment of DNA representing a cistron or gene.
- In **deletion** types of frame shift mutation one or more nucleotides are lost from a segment of DNA representing a cistron or gene.
- A gene or cistron of a protein will be **having N bases or nucleotides three times the number of amino acids in a protein molecules**.
- Genes which undergo mutations easily are called **mutator gene**.
- Genes **which does not undergo mutation** even once in several million gametes are called **stable gene**.

- **Induced mutation** was discovered by **Muller (1927)**.
- Muller received Noble prize for his work in **1946**.
- The experimenting organism used by him was *Drosophila* and mutation was induced by X ray.
- Any physical or chemical agent which is used in artificial induction of mutation is called **mutagens**.
- Physical mutagens are of **three types** – **temperature**, **UV radiations and ionising radiations**.
- Increase in temperature **increases** the frequency of mutations.
- UV radiations are non ionising radiations which induce **hydrolysis of cytosine** and **formation of thymine dimers**.
- Ionising radiation (X rays, cosmic rays etc.) **distort** or **break DNA duplex** and **disturb the replication**.
- **Chemical mutagens** are chemicals inducing mutations, for eg. **nitrous acid**, **acridines**, **5 bromouracil** etc.
- **Nitrous acid** (potent mutagen) deaminates cytosine to uracil, guanine to xanthin and adenine to hypoxanthin. This results in replacement of A-T with H-C, C-G with U-A and C-X.
- **Alkylating agents** bring about methylation and ethylation of nitrogen bases, *e.g.*, methyl guanine, ethyl guanine. The alkylated base may slip out of DNA duplex or cause change of base pair, *e.g.*, C-G to A-T.
- 5-bromouracil (Bu), 5-iodouracil (Iu), 5-chlorouracil (Cu) and 5-fluorouracil (Fu) replace thymine and pair with guanine. 2-aminopurine is incorporated in place of adenine with its tautomer pairing with cytosine.
- **Alkylating agents** have been used in warfare as the poisonous gases known as **mustard gases;** they cause extremely painful death acting on skin, mucosal membranes and lungs.
- Some common alkylating agents causing mutations are:
  - Nitrogen mustard
  - Ethyl Methane Sulfonate (EMS)
  - Methyl Methane Sulfonate (MMS)
  - N-methyl-N'-nitro-nitroso-guanidine (NTG).
- **Acridines** like proflavin, acriflavin, euflavin and acridine orange are intercalated in between base pairs leading to their insertion and deletion so as to cause frame-shift or gibberish mutations.
- Most of the mutagens are also **carcinogens**.
- In some mutations, change in one nucleotide does not result in the change of amino acid. Such mutations are called **same sense mutation or silent mutation**, for eg. AGA = AGG = AGT = AGC.
- **Mis sense mutation** is caused when a nucleotide change in one codon causes the change of one amino acid.
- Early termination of polypeptide chain due to certain mutation is called **non sense mutation**.
- Non sense mutation is caused due to occurrence of any of the **three terminating codon** *viz*, **UAA, UGA, UAG**.

NUCLEAR AND CYTOPLASMIC INHERITANCE

- Inheritance is of two types : **nuclear & cytoplasmic**.
- In nuclear inheritance, **traits are equally contributed from both the parents** towards the inheritance of the offspring.
- In nuclear inheritance **results of reciprocal crosses are same**.
- In cytoplasmic inheritance the **result of reciprocal cross is not same except sex linked cases**.
- In cytoplasmic inheritance transmission of traits takes place through **cytoplasmic particles**.
- Cytoplasmic particle constitute **plasmones**.
- Unit of plasmone is called **plasmagene**.
- Plasma genes are found in **plastids**, **mitochondria, plasmid** and **particles like alpha**, **beta**, **kappa etc**.
- The plasmagenes are **present inside cytoplasm in random fashion**.
- DNA is present in **mitochondria** and **chloroplasts too**.
- In cytoplasmic inheritance offsprings bears the **character of female parent** which contributes the main part of egg cytoplasm.
- In cytoplasmic inheritance there is **no segregation** at the time of meiosis.
- Cytoplasmic inheritance is observed in **plastid inheritance** in *Mirabilis* and **kappa particle** in *Paramecium*.
- Cytoplasmic inheritance of colour in plants was first observed by **Correns** (1908) in *Mirabilis jalapa*.

End of the Chapter

Chapter 54

Genetic Material & Protein Synthesis

GENETIC MATERIAL

- Genetic material is **that substance which not only controls the formation and expression of traits in an organism but can replicate and pass on from a cell to its daughter cell or from one generation to next**.
- Earlier it was considered that **proteins** carry the genetic information.
- DNA and RNA are two types of genetic materials.

DNA (Deoxyribonucleic acid)

DNA as genetic material

- The concept that DNA is the genetic material was supported by the work of **O.T.Avery** and **Coworker (1944)** and **Hershey and Chase (1952)**.
- The strongest evidence that DNA is the genetic material comes from the **studies on the bacterial transformation.**
- *Pneumococcus* experiment proved that **DNA is the genetic material.**
- The transforming principle of *Pneumococcus* as found out by Avery, MacLeod and McCarty was **DNA.**
- The hereditary material present in the bacterium *E. coli* is **double stranded DNA.**
- **Fredrick Griffith,** a British Medical Officer, **described the phenomenon of bacterial transformation**.
- Griffith experimented with the **smooth (S)** and **rough (R) strains** of *Diplococcus pneumoniae*.
- **Smooth (S) strains** of bacteria were **virulent** or **pathogenic** and cause pneumonia.
- **Rough (R) strains** of bacteria were **non-pathogenic** or **avirulent**.
- Both S and R strains are found in several types and are known as **S-I, S-II, S-III** etc. and **R-I, R-II, R-III** etc. respectively.
- **Mutations from smooth to rough strain** occur spontaneously with a frequency of about one cell in 10^7 though the reverse is much less frequent.
- **Transformation** was the **first step in the identification of the genetic material**.
- Transformation is the **process by which a cell takes up the segment of naked DNA from its surroundings and incorporates it in its hereditary material and ultimately expresses the character specified by the incoming DNA**.
- Griffith suggested that the **cause of transformation** was the **capsule of S strain**.
- **Hershey and Chase** (1952) discovered that **DNA is the genetic material of bacteriophage**.
- **Bacteriophage** are the viruses which infect bacteria.
- Hershey and Chase (1952) experimented with **T_2 phage which attacks the bacterium** *E. coli*.
- T_2 bacteriophage contains outer **non-genetic protein shell** and **inner core of DNA**.
- The body of T_2 phage is divided into **head**, **neck**, and **tail**.
- Its **head** is elongated, six sided, bipyramidal and contain non ending DNA molecule.
- The **tail** is a hollow cylinder bearing **24 helical striations** and is formed of proteins only.
- **Six tail fibres** appear from the hexagonal plate at the distal end.
- Experiment of Hershey and Chase **include the process of transduction**.
- **Transduction** is the **process in which a bacterium infecting virus serves as a vector transferring DNA from one bacterium cell to another**.
- The isotopes used by them were **^{35}S** and **^{32}P**.

- Though DNA is the genetic material but **in some viruses** like TMV, polio viruses, influenza virus etc. **RNA acts as genetic material**.

Structure of DNA

- DNA is the **major store of genetic information** as the **hereditary information is carried in DNA**.
- DNA is found in **nucleus and cytoplasm**. The contribution of cytoplasmic DNA in the cell's total DNA is about **1 - 5%**.
- **Extranuclear DNA** is found in **mitochondria** and **chloroplasts**.
- **Rosalind Franklin**, studied the structure of DNA using **X-rays.** It showed that DNA is a **helix**.
- In 1953, **James Watson** and **Francis Crick proposed** the **three-dimensional structure of DNA** based on X-ray diffraction photographs of DNA fibres taken by Rosalind Franklin and M.H.F. Wilkins.
- For discovering the structure of DNA, **Nobel Prize** was awarded to **Watson, Crick** and **Wilkins** in the year **1962**.
- The **Watson and Crick model shows that DNA is** a **double helix** with **sugar-phosphate backbones on the outside** and **paired bases on the inside**.
- The planes of the bases are **perpendicular to the helix axis**. The planes of sugars are nearly at right angles to those of the bases.
- The **diameter of DNA molecule** is **20 Å**.
- The pitch (a **complete turn**) of DNA has a length of about **34 Å**.
- Adjacent bases are separated by **3.4 Å** along the helix axis and related by a rotation of **36 degrees**.
- There are about **10 base pairs** in each turn of DNA double helix.
- The two chains are held together by **hydrogen bonds between pairs of bases which help to stabilizes the interaction**.
- **Hydrogen bonds** join the nitrogen bases of one strand with of the other.
- Adenine - thymine pair has **2 hydrogen bonds** while guanine-cytosine pair has **3 hydrogen bonds**.
- **Adenine always pairs with thymine** in DNA and with **uracil** in RNA. Whereas **cytosine** always pairs with **guanine** in both DNA and RNA.
- Linus Pauling believed that DNA has **three strands**.
- Each DNA strand has a backbone of alternate **deoxyribose** and **phosphoric acid groups**.
- The polynucleotide chains in DNA molecule show **polarity** in direction.
- One end of each chain is called **5′ end** and the other is called **3′ end**.
- The sugar-phosphate-sugar component which are joined by **phosphodiester bond** forms the backbone of DNA duplex.
- The nitrogenous base molecules are attached with the deoxyribose sugar molecules by **glycosidic bonds**.
- The **carbon atoms of the pentose sugar involved in phosphodiester bond formation** in DNA are C_3 and C_5.
- The two strands of DNA (called **DNA duplex**) are **antiparallel** and **complementary** *i.e.* **one in 5′ → 3′ direction and the other 3′ → 5′ direction**.
- DNA is always **double stranded**, and rarely single stranded.
- DNA duplex is **made up of two molecules** out of which the one that directs the synthesis of the RNA *via* complementary base pairing is **called template** or **sense strand** and the other one is called **antisense strand**.
- DNA molecule is composed of **four kinds of nucleotides** (AMP, GMP, CMP, TMP) which differ in relative amount from species to species.
- **Behrem (1938)** found the differentiation of DNA from RNA.
- **W.T.Astbury (1940s)** found through X ray diffraction study of DNA that it is a polynucleotide with nucleotides lying at right angle to the long axis of molecule.
- **Kossel (1910)** discovered the presence of two purine and two pyrimidine in nucleic acid.
- **Feulgen (1912)** found staining reaction for DNA which is now called feulgen reaction.
- **Chemical studies** on the bases of DNA were performed by **Erwin Chargaff** in 1950.
- **Pyrimidine bases of DNA** are represented **by thymine** and **cytosine** and **purine bases by adenine** and **guanine**.
- **Erwin Charagaff (1950)** found that purine and pyrimidine content of DNA are **equal**.
- According to Chargaff the percentage of **adenine** (A) is equal to the percentage of

% of A = % T
% of G = % C

thymine (T) and the percentage of **guanine** (G) is equal to the percentage of **cytosine** (C).

- The **percentage of A + G equals 50% and the percentage of T + C equals 50%. These relationships are called 'Chargaff's rules'**.
- Quantitatively **A = T** and **C = G** or $\frac{A}{T} = \frac{C}{G} = 1$.
- Chargaff rule also states that **A + G = T + C** or **A + C = G + T**.
- While the base ratio may vary from species to species but it is **constant for a given species**.
- Base ratio is **high** in advanced organism and **low** in primitive organism.

Types of DNA

- Under different conditions of isolation, purification and crystallization, several forms of DNA have been recognised. They are **A–, B–, C– D**– and **Z–DNA**.
- A–, B–, C– and D–DNA are **right-handed helices** whereas Z–DNA is **left-handed helix**.
- Base pair turn in A, B, C, D and Z are **11**, **10**, **9**, **8** and **12** respectively.
- Z DNA has **zig zag sugar phosphate back**.
- Z DNA was first reported by **Rich and Coworker (1979)**.
- B DNA is the **commonest DNA** and **are metabolically stable**.
- It is believed that during transcription the **B-DNA changes to A form**.
- B DNA exists under condition of **high humidity** (> 92%) and **concentration of salts**.
- Under **low humidity condition, the B-form may change to A, C or D form**.
- Another form of DNA has been also identified which is designated as **E-DNA**. The base pair in **one pitch is 7.5**.
- DNA may be **circular** or **linear** depending upon the absence or presence of free end.
- **Linear DNA**, having free ends, occurs in eukaryotic nuclei, some prokaryotes like PPLO and some autonomous cell organelles occasionally.
- **Circular DNA**, with no free end occurs in bacteria and randomly in semiautonomous cell organelles (like mitochondria and chloroplast).
- Single stranded DNA was first observed by **Sinsheimer (1958)**, in the spherical bacteriophage, $\phi \times 174$.
- The part of the genome in which repetitive sequence are arranged end to end as long tandem arrays is called **satellite DNA**.
- Satellite DNA was the first type to be identified in the human genome.
- **Repetitive DNA** occurs in telomere, centromere and ends of transposons.
- In *Drosophila*, about **25%** and in human beings about **30%** DNA are repetitive.
- **Palindromic DNA** is a part of DNA in which the base sequences of one strand is opposite to that of the other strand when read from opposite directions. DNA regions that transcribe rRNA are often palindromic. The true significance of palindromic DNA is, however, not clear, although several function have been suggested, like –
  - Short palindromes may **function as recognition sites of DNA for proteins** which also have a two fold rotational symmetry, e.g. lac repressor protein, CRP proteins and many bacterial restriction enzymes.
  - Also gives structural strength to the transcribed RNA by hydrogen bonding in hairpin loops.
  - Long palindromic DNA molecules from some lower eukaryotes have been shown to contain genes coding for ribosomal RNA.
    3′ – C – C – G – G – A – A – T – T – C – C – G – G – 5′
    5′ – G – G – C – C – T – T – A – A – G – G – C – C – 3′.

Functions of DNA

- DNA has two important functions – **heterocatalytic** and **autocatalytic**.
- In **heterocatalytic function,** DNA directs the synthesis of chemical molecules other than itself e.g., synthesis of RNA, proteins etc.
- In **autocatalytic function** DNA directs the synthesis of DNA itself.
- When the DNA is heated above physiological temperature (about 100°C) the two helix unwind and separate by breakdown of hydrogen bonds between the base pairs. This is called **denaturation** or **melting**.
- When the denatured DNA is cooled slowly, the two strands re-unite. This phenomenon is called **annealing**.

- **DNA, The Master Copy–** DNA does not directly control the formation of a polypeptide. Instead, it forms an intermediate template, *m*RNA molecule, which, in turn, directs the synthesis of the polypeptide. The DNA is compared to a master copy that is carefully preserved in the nucleus and used only to prepare working copies in the form of *m*RNA molecules. The latter pass out to the ribosomes in the cytoplasm and guide the actual synthesis of proteins.

Replication of DNA

- **Replication** is the formation of exact replica or carbon copy.
- According to **Delbruck**, there are **three** theoretical possibilities for DNA replication *viz*. **dispersive, conservative** and **semi-conservative**.
- During **dispersive method** the DNA undergoes fragmentation and then replicate and joins to form two molecule of DNA.
- During **conservative method** the original DNA molecule is conserved and its copy is synthesized from the medium.
- According to **semi-conservative** method the two strands of the DNA separate and the complementary strand is synthesized from the medium.
- **Watson and Crick (1953) suggested** that DNA replication is semi-conservative.
- Semi-conservative replication of chromosome was found by **Taylor (1957)** in *Vicia faba* using triradiated thymidine.
- **Messelson and Stahl (1958) proved** that DNA replicates by semi-conservative method.
- They experimented on *E.coli* and use the **heavy isotopes of nitrogen** *i.e.*, N^{15}.
- Messelson and Stahl grew bacterial DNA labelled with ^{15}N in ^{14}N medium and **found that F_1 generation have DNA density intermediate between the two**.
- The **newly synthesized DNA** possess one strand contributed by parent DNA and other newly synthesized.
- The replication of DNA **requires many enzymes and protein factors**.
- As the DNA in virus and bacteria are circular so the replication in them **ends at the same point where it starts** (Cairns 1953).
- The **smallest unit of replication** is called **replicon**.
- Bacterial DNA represents only **one unit of replication**.
- **Eukaryotic DNA** are very large hence they represent several replicon.
- During replication the **four nucleotides of DNA are activated by ATP in the presence of phosphorylase**.
- The **first important step in the replication** is **unwinding of double helix**.
- The unwinding of DNA strand is done by enzyme **helicase**.
- Helicase **breaks the H-bonding** present between nucleotide pairs.
- The specific point from where the initiation of unwinding starts is recognised by **initiation proteins**.
- The existing DNA molecule on which new DNA is synthesized is called as **template DNA**.
- The initiation of DNA synthesis requires a **RNA primer** (a short sequence RNA).
- The enzyme which forms RNA from DNA are called **RNA polymerase**.
- The synthesis of RNA primer is brought about by enzyme **primase**.
- The primer grows in **5′ – 3′** direction.
- In *E.coli* replication starts by the formation of **replication bubble**.
- **Topoisomerase** acts as DNA nicking enzyme.
- Topoisomerase releases the **tension** of DNA strands.
- In prokaryotes, topoisomerase is replaced by **DNA gyrase**.
- **Initiation of replication occurs at 3′ end**.
- **DNA polymerase** is responsible for the template directed condensation of deoxyribonucleotide triphosphatase.
- DNA polymerase was discovered by **Kornberg (1957)**.
- The enzyme DNA polymerase **adds the nucleotide complementary to the DNA template in 5′ – 3′ direction** in the presence of ATP.
- The enzyme synthesizes a new strand in **continuous piece** in 5′ – 3′ direction. This strand is called **leading strand**.
- The second new strand is formed in short segments called **Okazaki fragments** in 5′ – 3′ direction.
- Okazaki fragments are joined by means of **DNA ligase**.

- The strand formed by joining Okazaki fragments is called **lagging strand**.
- DNA ligase was discovered by **H.G. Khorana (1967)**.
- RNA primer is removed by **exonuclease activity** of DNA polymerase I.
- The wrong base entered into DNA helix can be identified and corrected by **repair enzymes**.
- The removal of wrong base is done by **DNA polymerase III**, synthesis of new strand by **DNA polymerase I** and sealing by **DNA ligase**.
- A **Y-shaped replication fork** is **formed during DNA replication**.
- DNA replication is **semi-conservative** and **semi-discontinuous**.
- *In vitro* synthesis of DNA was first performed by **Kornberg (1959)**.

RNA (Ribonucleic acid)

- RNA is a **non-hereditary** nucleic acid except in some viruses (retroviruses).
- RNA is a polymer of **ribonucleotide** and is **made up of pentose ribose sugar, phosphoric acid** and **nitrogenous base (A, U, C, G)**.
- **Franklin Conrat (1957)** establishes that RNA is the genetic material is some viruses.
- RNA is single stranded, but double stranded RNA is present in reovirus and wound tumor virus.

Types of RNA

- The RNA may be mainly of **two types** – genetic RNA and non-genetic RNA.
- **Genetic RNA** are seen in most of the plant viruses and some animal viruses.
- The genetic RNA carries the genetic message and is capable of self replication. It is called **RNA dependent RNA synthesis**.
- On the basis of molecular size and function, **three main forms of non genetic RNA** are – *m*RNA, *t*RNA and *r*RNA.
- *m* RNA constitutes about **3.5%** of cellular RNA; *t* RNA is about **15%** and *r* RNA about **80%**.
- ***m*RNA** or **messenger RNA** are formed on specific part of DNA as a complementary copy of one strand of it in nucleus.
- *m*RNA **forms a template for protein synthesis**.
- The **life span of mRNA** is **short** (2 min. in *E.coli* & 4 hrs. in eukaryotes).
- The length of mRNA is more than the length of the protein synthesized.
- *m*RNA is called **monocistronic** when carries codon for single complete protein molecule.
- **Polycistronic** *m*RNA contains several adjacent DNA cistrons.
- ***t*RNA or transfer RNA** are **also known as soluble (s) RNA, supernatant RNA or adaptor RNA**.
- *t*RNA are **smallest,** bearing 70-80 nucleotides.
- *t*RNA is **single stranded** and **takes the shape of clover leaf**.
- The first person to determine the base sequence of a *t*RNA molecule was **Robert Holley**.
- Holley (1965) reported the sequence of an alanine *t*RNA from yeast and **proposed two-dimensional structure of *t*RNA (clover leaf model).**
- **Three-dimensional structure** of *t*RNA was proposed by **S.H. Kim** in 1973.
- A three-dimensional model of **yeast phenylalanine *t*RNA** resembles an **upside-down letter L**.
- **Four sites** can be recognised on *t*RNA. These are –
  - The site at 3′ end is called **amino acid attachment site**. It has base sequence CCA.
  - **Second site** is called **amino acid recognition site** or **DHU loop**.
  - **Third site** is **codon recognition site** or **anticodon loop**.
  - **Fourth site** is **ribosome recognition site** or **GTPCG loop**.
- *t*RNA helps to **transport amino acids** from the surrounding cytoplasm to the site of protein synthesis.
- The term **ribosomal RNA (rRNA)** has been proposed by **Kurland** in 1960.
- Ribosomal RNA is found in ribosomes of cells and is also called **insoluble RNA**.
- The **main function of *r*RNA** is to **attract and provide large surface for spreading of *m*-RNA** over ribosomes during translocation process of protein synthesis.
- In *E. coli* rRNAs are in three forms, sedimenting at 23S, 16S, and 5S, respectively; these three forms differ in base ratios and sequences.

- In eukaryotic cells, which have larger ribosomes than prokaryotes, there are four types of rRNA; 5S, 7S, 18S, and 28S.
- *r*RNA or ribosomal RNA is **formed from the nucleolar organising region**.
- **Ribosomes** are formed from *r*RNA and proteins.
- *r*RNA is **involved in the translation of message of DNA**.
- *r*RNA forms the **structural work bench** on which a polypeptide is formed, during protein synthesis.

GENETIC CODE

- The genetic representation of codon by which the information in RNA is decoded in a polypeptide chain is called **genetic code**.
- The information is transferred in the form of **triplet of bases** coding for one amino acid.
- **George Gamow (1954)** was first to propose triplet code and **coined the term genetic code**.
- **Triplet nature of genetic code** was proposed by **F.H.C. Crick.**
- Genetic code is the **relationship of amino acid sequence** in a polypeptide and **base sequence of DNA.**
- **Marshell Nirenberg**, **Severo Ochoa**, **Hargobind Khorana**, **Francis Crick**, **Matthaei** deciphered the genetic code.
- Nirenberg gave the **first experimental proof** for triplet code.
- Nirenberg and Matthaei used **artificially synthesized *m* RNA** in a cell free system.
- **Three adjacent nitrogenous bases** constitute a codon and specify one amino acid.
- **61 out of 64** codons **code for only 20 amino acid**.
- Complementary matching input is called **anticodon**.
- There is **no punctuation mark** so that genetic code is read continuously.
- The codon which initiates the protein synthesis is called **initiation codon**. They are **AUG for methionine and GUG for valine**.
- **GUG** when present in **beginning** codes for **methionine** , but when present in **intermediate** position, codes for **valine.**
- The codon which do not code for any amino acid are called **non-sense codon** or **terminator codon**.
- Three codon *viz*. **UAG (amber)**, **UAA (ochre)** and **UGA (opal)** are **non sense codon**.
- For a particular amino acid more than one codon can be used. This is called **degeneracy of codon**.
- The first codon discovered by Nirenberg and Matthaei was **UUU** (phenylalanine).
- **Khorana** first deciphered the triplet codon of cysteine and valine.
- Genetic code is **universal**.
- Genetic codes are **non overlapping** *i.e.*, one letter cannot be used for two different codons.
- A particular codon will always code for same amino acid *i.e.*, code is **non-ambiguous**.
- With an exception **GGA is an ambiguous code**, it codes for glycine and glutamic acid.
- **Wobble hypothesis** was given by **F.H.C. Crick** (1965). According to this third nitrogenous base of a codon is not much significant and codon is specified by first two bases.
- Same tRNA can recognise **more than one codons** differing only at third position.
- In *Paramecium* and some other ciliates termination codons **UAA and UGA code for glutamine**.
- **AGG and AGA** code for arginine but **function as stop signals in human mitochondrion**.
- **UGA**, a termination codon, **corresponds to tryptophan** while **AUA denotes methionine** in human mitochondria.
- The sequence of codon of DNA or *m*RNA **corresponds to the sequence of amino acids in a polypeptide**.
- A specific DNA segment will transcribe a specific *m* RNA chain which will form a specific polypeptide chain, this represents **gene polypeptide parity**.

CENTRAL DOGMA & PROTEIN SYNTHESIS

- **Crick (1958)** proposed the **central dogma** of molecular biology.
- Central dogma is the **unidirectional flow of information** from **DNA to RNA and from RNA to polypeptide**.

$$\text{DNA} \xrightarrow{\text{Transcription}} \text{mRNA} \xrightarrow{\text{Translation}} \text{Polypeptide (Protein)}$$

- **Commoner (1968)** suggested the circular flow of information.
- **H. Temin and Baltimore (1970)** introduced the

concept of reverse central dogma *i.e.*, formation of DNA from RNA.

- **Reverse central dogma** was performed by retroviruses. This is represented as
RNA → DNA → *m* RNA → protein.
- DNA is called the **master copy** and *m* RNA is called the **working copy** of hereditary information.
- **Proteins** are the polypeptide chains formed by the polymerization of amino acids.
- Only twenty amino acids are biologically important in the participation of protein synthesis.
- The processes by which mRNA is made by DNA and protein by *m*RNA are respectively called as **transcription and translation.**
- One gene one polypeptide hypothesis states that a structural gene specifies the synthesis of a **single polypeptide**.

Transcription

- The **process of transferring of information stored in DNA to *m*RNA through the synthesis of RNA over the template of DNA is called transcription**.
- Transcription is the **heterocatalytic function of DNA**.
- Transcription **occurs during interphase**.
- In prokaryotes **single RNA polymerase enzyme** undertakes the formation of all RNA.
- In eukaryotes at least **three RNA polymerase enzyme (I, II, III)** are required.
- **RNA polymerase I** is **found in nucleolus and forms *r*RNA**.
- **RNA polymerase II** is **found in nucleoplasm** and **synthesise *hn*RNA**.
- **Heterogenous nuclear RNA (*hn*RNA)**, the precursor of *m*RNA is synthesized by eukaryotic cells, which undergo shortening by looping out mechanism to remove unwanted nucleotide sequence.
- **RNA polymerase III** is **found in nucleoplasm** and **synthesizes *t*RNA**.
- One strand of DNA gives rise to *m*RNA. This strand is called **master strand** or **sense strand**.
- The DNA strand which do not serve as template for transcription is called **anti-sense strand**.
- The **region where initiation began** is called **promotor end** while **where transcription ends** is called **terminator end**.
- RNA polymerase has **five polypeptides** – σ, α, β, β′ and ω.
- Chains of β, β′, α and ω constitute the **core enzyme**.
- The **function of σ factor** is to **confer the specificity of RNA synthesis at the promotor site**.
- σ or **sigma factor recognises the promotor region** while the remaining **core enzymes takes part in transcription**.
- **Rho factor** which in course of transcription replaces σ factor **helps in elongation and termination of the RNA synthesis**.
- The RNA molecule thus produced in transcription is called **transcript**.
- After initiation base pairing takes place by **ribonucleoside triphosphates**.
- **Base sequence in DNA** decides the base sequence of RNA.
- *m*RNA synthesis on DNA template takes place in **5′ to 3′ direction**.
- The elongation requires the bivalent ion **Mn^{++} or Mg^{++}**.
- Primary transcript (newly formed RNA) is called ***hn*RNA** as it is generally bigger than the functional RNAs.
- Introns and intervening sequences of non essential nature are removed by **nuclease**. This process is called **splicing**.
- **Ribozyme** (RNA enzyme) is a **self splicing intron involved in splicing.**
- **Capping** is the process of adding cap of 7-methylguanosine triphosphate at 5′ end.
- *m*RNA cap is required for **ribosomal recognition**.
- Certain nucleotides are methylated, ethylated, deaminated etc. to produce different chemicals like **inosine, methyl cytosine** etc.
- *In vitro* **synthesis of RNA** was first performed by **Ochoa** (1967).

Translation (Protein synthesis)

- The **process of decoding of the message from *m*RNA to protein with the help of *t*RNA, ribosome** and **enzyme is called translation** (protein synthesis).
- Protein synthesis **occurs over ribosomes**. The ribosomes are formed of **two subunits**.
- The rosette group formed by ribosomes is called **polyribosome**.

- In polyribosome, ribosomes are held together by **strand of *m*RNA**.
- The **4 main steps in protein synthesis** (translation) are : **activation, initiation**, **elongation** and **termination of polypeptide chain**.
- The newly synthesized *m*RNA joins the smaller subunit of ribosome **at 5′ end**.
- *m*RNAs **carry the codon** and *t*RNAs **carry the anticodon** for the same codon.
- The amino acid bound to AMP is called **amino acyl ~ AMP** or **activated amino acid**.
- Activation of amino acid is catalysed by the enzyme **amino acid synthetase** in the presence of ATP.
- In presence of ATP an aminoacid combines with its specific aminoacyl-*t* RNA synthetase to produce aminoacyl adenylate enzyme complex.
- This reacts with *t*RNA to form aminoacyl *t*RNA complex.
- Activated *t*RNA is taken to ribosome *m*RNA complex for **initiation of protein synthesis**.
- Initiation of protein synthesis is accomplished with the help of **initiation factor** which are **3** (IF2, IF3, IF1) **in prokaryotes** and **9 in eukaryotes** (eIF2, eIF3, eIF1, eIF4A, eIF4B, eIF4C, eIF4D, eIF5, eIF6).
- A polypeptide chain forms as *t* RNAs deliver amino acids to the **ribosome**.
- Large ribosomal subunit binds the initiation complex **forming two (A and P) binding site for *t*RNA molecules**.
- The first site is **P site or peptidyl site** which is occupied by $t\text{RNA}^{met}$.
- The second site is **A or amino acyl site** and is positioned over the second codon.
- The enzyme **peptidyl synthetase** catalyse the formation of peptide bond between the carboxylic group of amino acid at **P site** and amino group of amino acid at **A site**.
- Enzyme translocase brings about the movement of *m*RNA by **one codon**.
- After about **30 codons** of *m*RNA get translated, a new ribosome join at 5′ - end of *m*RNA to synthesize another polypeptide.
- As many as **5 - 20 ribosome** may join the same *m*RNA depending upon its length.
- The **termination of protein synthesis occur when a non-sense codon reaches at A site of ribosome**. The chain detaches from the ribosome.
- Two subunits of ribosomes dissociate with the help of **dissociation factor**.
- Termination **requires the activities of three termination factor** R_1, R_2 & R_3.
- A potent inhibitor of protein synthesis that acts as an analogue of aminoacyl-*t*-RNA is **puromycin (*i.e.* inhibit translation in eukaryotes).**
- In eukaryotes **two types of polyribosomes** are found *viz*. **free polyribosome, membrane bound ribosomes**.
- **Free polyribosomes** release their terminated protein for direct function as enzyme in cytoplasm or in the organelles such as chloroplast and mitochondria.
- **Membrane bound ribosome** attached to RER wherein the synthesized proteins are translocated through the lumen of ER.
- After synthesis the proteins may be incorporated in membrane or may be secreted from the cell.
- *Secretory proteins* are synthesized by the ribosomes attached to the endoplasmic reticulum membranes and released into the ER. From here they are transported to various membrane bound compartments, e.g. the Golgi complex and the lysosomes. They are then secreted from the cell by exocytosis.
- **Blobel's** and **Dobberstein** (1975) have **proposed** the **signal hypothesis** for selective translation of *m*RNAs.
- **Signal hypothesis** is the major mechanism whereby proteins that insert into or cross a membrane are synthesized by a membrane bound ribosome.
- The first thirteen to thirty six aminoacids synthesized, termed a **signal peptide** are recognized by signal recognition particle that draws the ribosomes to the membrane surface by interaction with a docking protein. The signal peptide may later be removed from the proteins.
- The hypothesis has been reviewed by Blobel (1978). It is postulated that *m*RNAs translating secretory proteins contain a group of *signal codons* on the 3′ side of the initiation codon AUG. The ER membrane is postulated to have *ribosome receptor proteins* capable of moving in the plane of the membrane.

Free ribosomes translate a polypeptide chain which contains a *signal peptide region.* On emerging from the ribosome the signal peptide interacts with the ribosome receptor proteins forming a *tunnel* in the membrane which coincides with the ribosomal tunnel. An enzyme, *signal peptidase*, cleaves the signal peptide from the growing polypeptide chain. When the chain is completed it is released into the space of the ER. The ribosome detaches from the ER membrane and the ribosome receptor proteins diffuse in the plane of the membrane, closing the tunnel.

- Blobel's research has **helped explain the molecular mechanisms behind several genetic diseases**.

Genetic control of proteins

- The function of gene within an individual is in ultimate sense, to control and influence the phenotype.
- The characteristic of gene to store information and contribute towards its expression in the form of phenotype is studied by **Garrod** (1902). He studied several disorders of human beings which seemed to be inherited and called them as **inborn errors of metabolism.**
- The **evidence** for inborn error of metabolism is given by **Beadle** and **Tatum** (1948) in the hypothesis **"one gene-one enzyme"** which states that "a gene controls a structural or functional trait through controlling the synthesis of a specific protein or enzyme formed by the gene". According to Beadle and Tatum gene is defined as a unit of hereditary material that specifies a single enzyme.
- One gene one enzyme theory was given by Beadle and Tatum (1958), while they were working on pink bread mould or *Neurospora* (Ascomycetes fungus), which is also called *Drosophila* of plant kingdom.
- Wild type *Neurospora* grows in a minimal medium (containing surcose, some mineral salts and biotin).
- The asexual spores, *i.e.* conidia were irradiated with X-rays or UV-rays (mutagenic agent) and these were crossed with wild type.
- After crossing sexual fruiting body is produced having asci and ascospores. Ascospores produced are of 2 types –
  - The ascospores, which are able to grow on minimal medium (like wild type), called **prototrophs**.
  - The ascospores which do not grow on minimal medium, but grow on supplemented medium (containing thiamine), **called auxotrophs**.
- *Neurospora* **was used as material for genetic experiments** because –
  - It is haploid so every gene and every mutation finds expression.
  - Short life cycle.
  - Few chromosomes, $n = 7$.
  - Reproduces both asexually and sexually.
  - It is heterothallic with two genetic strains, A(+) and B(–).
  - Karyogamy and meiosis occur in the same cell.
  - The products are duplicated by mitosis and changed to 8 ascospores.
  - Products of meiosis remain linearly arranged.
- **Shear** and **Dodge** are known as **Father of** *Neurospora* **genetics** as they discovered *Neurospora.*
- Beadle and Tatum explained that thiamine synthesis is completed in different steps and each steps is associated with a specific enzyme, which in turn is associated with a specific gene.
- In auxotrophs (mutated forms), due to mutation in some genes (by X-Rays on UV rays) synthesis of some enzymes is inhibited and hence synthesis of thiamine is stopped.
- Thus auxotrophs are unable to grow on minimal medium.
- One gene one enzyme theory is able to explain some metabolic disorders or inborn errors in human beings like – phenylketonuria and alkalptonuria.

End of the Chapter

Chapter 55

Gene Expression & Regulation

GENE EXPRESSION

- Gene expression is the mechanism at the molecular level by which a gene is **able to express itself** in **the phenotype of an organism**.
- The mechanism of gene expression involves **biochemical genetics**.
- It consists of synthesis of **specific RNAs**, **polypeptides**, **structural proteins**, **proteinaceous biochemicals** or **enzymes which control the structure** or **functioning of specific traits**.
- The **formation of RNAs from gene is called transcription**.
- Out of the two strands of DNA, only one strand is effective in producing mRNA in a given cistron. It is called sense strand.
- **mRNA** carries the information to the ribosomes and translates it into amino acid sequence of a polypeptide with the help of tRNAs.
- The **polypeptide expresses the gene by forming a structural protein**, a **proteinaceous biochemical or enzyme**. This process is called **translation**.
- Gene expression **begins** with transcription and translation and is **followed** by folding, post translational modification and targeting.
- The amount of protein that a cell expresses depends on the tissue, the developmental stage of the organisms and the metabolic or physiologic state of the cell.
  [*For more detail on protein synthesis refer chapter Genetic Material and Protein Synthesis*]
- There is colinearly or similarity in the linear arrangement of codons of a gene and the sequence of amino acids in a polypeptide produced by it.
- All the genes present on a chromosome are **not expressed simultaneously**.

Gene expression in viruses

- Virus is a nucleoprotein entity which lives as intercellular obligate parasite because it is able to utilise the synthetic machinery of host cell for its multiplication.
- Virus is made up of **two parts** – capsid and nucleoid.
- **Capsid** is a protein covering around nucleoid and other parts.
- Virus has a **linear or circular genetic material** (**either DNA or RNA**) and is known as **nucleoid**.
- **TMV** was the first virus to be discovered and composed of entirely of protein and RNA.

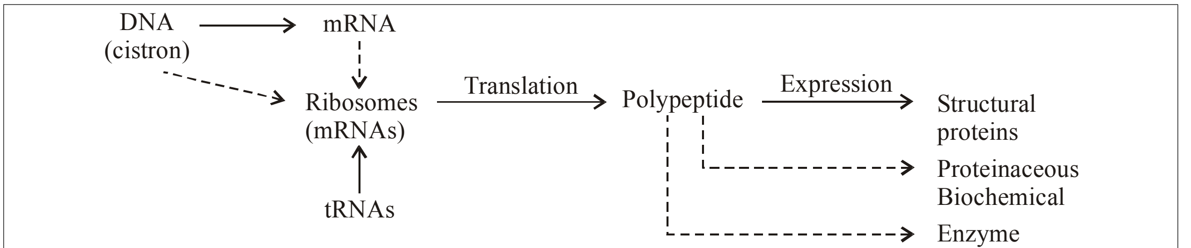


Fig : Mechanism of gene expression

- TMV contain **RNA** as hereditary material.
- Virus undergoes two types of reproductive cycle – **lysogenic** and **lytic** through which it multiplies and thus expreses its genes.
- Virus reproduction is divisible into **infection phase**, **eclipse phase, maturation phase** and **lysis**.
- **Eclipse phase** included replication of viral genome and synthesis of viral proteins required for inactivation of host cell genome & for initiating regulation and control of viral synthesis assembly and release.
- The time period between the infection of viral nucleic acid and the first appearance of new phage progeny is the **eclipse period** which is about 12 min. in T_2-phage.
- **Multiplication of bacteriophage** has been studied in T-even phages of *E.coli* by prominent workers like **Delbruck, Luria** and **Lwoff**.
- The complete virus particle prior of infection are **extracellular virions**.
- **Prophage** or **provirus** is the latent stage of a phage in a lysogenic bacterium in which the viral genome becomes inserted into a specific portion of the host chromosome and is duplicated in each cell generation.
- Viral genome is changed to provirus/prophage state by **integrase enzyme**.
- Phage having the capacity to become prophage is called **temperate phage** and which lack this property is called **virulent phage**.
- The multiplication process of virulent phage is called **lytic cycle**.
- The multiplication process of temperate phage is called **lysogenic cycle**.
- The phenomenon of existence of non-virulent prophage in the host cell is called **lysogeny**.
- The host cell in which lysogeny occurs is called **lysogenic cell**.
- **Lysogen** is a strain of bacteria carrying prophage.
- Lysogenic cycle is shown by l (lambda) phage which also infects *E.coli* bacterium.
- **Lytic bacteriophage** multiply in host bacterium which then undergoes complete lysis (degeneration) to release the resulting daughter phages.
- **Burst size** is the number of virions produced per host cell.
- **Latent period** is the total time taken from the introduction of nucleic acid to rupture of host cell wall. It is about 18 min. for T_2 phage.
- The phenomenon of making DNA over RNA genome through enzyme *reverse transcriptase*, is called **reverse transcription** or **teminism**.
- Virus DNA is **not affected** by nucleases as its cytosine bases are methylated (hydroxy methylated cytosine or HMC).
  [*For more on virus refer chapter* '*Viruses*']

Gene expression in prokaryotes

- Prokaryotes (mostly bacteria) have a genome that consists of **naked folded DNA (circular double stranded) which does not contain any histone protein but has polyamines**, it is called **nucleoid**.
- Prokaryotic/bacterial cell's nucleoid lies freely in the cytoplasm & in contact with a membranous structure called mesosome.
- Nucleus is **absent** in prokaryotic cell.
- Folding of DNA is done with the help of **RNA** and **polyamines**.
- DNA is naked due to **absence of histones** in prokaryotic chromosomes.
- The genome of *E.coli* contains **2000-3000 genes**.
- Sexual reproduction is **absent** in bacteria as they do not produce diploid phase which in turn leads to absence of meiosis phase.
- Bacteria **undergo replication of chromosome and genetic recombination**.
- Genetic recombination includes three processes as – **conjugation**, **transformation** and **transduction**.
- In 1946, **J. Lederberg** and **E.L.Tatum demonstrated sexuality in bacteria** for the **first time**.
- Conjugation was observed under electron microscope by **Anderson (1957)**.
- The unidirectional transfer of DNA from one cell to another through a cytoplasmic bridge is called **conjugation**.
- The process of conjugation is **equivalent to sexual mating in eukaryotes**.
- Bacteria showing conjugation are **dimorphic**.
- Donor or male cell possess **fertility factor** (F^+) and **sex pili** (cilia like structure) while female or recipient is without fertility factor & sex pili.

- **Episome** is the plasmid of fertility factor which is integrated to bacterial chromosome.
- Episome was discovered by **Jacob** & **Wollman**.
- Contact between male donor and female recipient causes development of conjugation tube by means of a pilus of donor.
- **Transformation** is the transfer of gene for virulence from DNA of dead bacteria to living non virulent bacteria.
- It was discovered by **Griffith (1928)** in *Diplococcus pneumoniae*.
- Ability to pick up foreign DNA for a brief period towards the end of active growth is called **competence**.
- **Transduction** is the transfer of genes from one organism to another with the help of virus/vector.
- Transduction was discovered by **Zinder** & **Lederberg** (1952) in case of *Salmonella typhimurium*.
- Transduction is of **two types** – **generalised** (genes are not fixed) & **restricted** (same genes, eg. lac or biogene in case of lambda phage in *Escherichia coli* K–12 because the phage genome attaches between the two).
- **Plasmids** are small double stranded circular extrachromosomal DNA segments found in bacteria. [*For more on bacteria refer chapter* '*Monera*']

Cancer and oncogenes (uncontrolled gene expression)

- **Cancer** is **uncontrolled growth of cells often forming tumors and invading other tissues**.
- Cancer is an example of **growth lacking differentiation and development**.
- Tumor is a **cellular lump**.
- Tumor which remains restricted to the area of formation is called **benign/non-cancerous/non-malignant**.
- **Cancerous/malignant tumors** are abnormal group of cells that may cause death of the individual.
- A malignant tumor of connective tissue is called **sarcoma**.
- **Metastasis** is the secondary growth or invasions.
- **Rous (1910)** found a virus called **Rous sarcoma virus** which causes cancer.
- In human beings cancer is caused by extra activation of certain genes called **proto-oncogenes**.
- A mutated proto-oncogene is called **oncogene**.
- Oncogenes were discovered by **Bishop** and **Varmus**.
- **Mutation in proto-oncogene** shatters the cellular controls over the growth and division rendering the concerned cells carcinogenic.
- Multiple genetic changes occur during the **transformation of a normal cell to cancer cell**. This process is called **oncogenesis**.
- **Oncogenesis** is due to various factors as radiations, heat, tobacco, continuous irritation, chemical mutagens like tar, azo dyes, aromatic amines, urathane, metals like nickel, beryllium, chromium, arsenic.
- Any substances which causes cancer is called **carcinogen**.
- **Carcinolysis** is the destruction of cancer cell.
- Due to **presence of viral oncogenes** in their genome, retroviruses are implicated as a cause of cancer in man.
- **Jumping gene**/transposon can also cause cancer.
- Translocation of fragment **c-abl** from chromosome 9 to chromosome 22 causes **myelogenous leukemia**.
- **Burkitt's lymphoma** is caused by translocation of segment **c-myc** from 8 to 14 chromosomes.
- Tumor suppressor genes normally suppress the tumor.
- Tumor appears only when the appropriate active gene is absent or both the alleles are lost. It means absence of tumor suppressor genes leads to formation of tumors.
- In human beings cancer is caused by ***l* - chromosome translocation**.
- HIV (Human immunodeficiency virus) destroys **immune system of the body** & cause AIDS.

GENE REGULATION

- Different genes in an organism are meant for the synthesis of different proteins.
- There are certain mechanisms that allow only the desired genes to function at a time and restrict the other.
- A variety of mechanisms are now known which regulate gene expression at different levels including transcription processing of mRNA and translation.

- The regulation of gene expression (protein synthesis) in bacteria is called **operon system**.
- Operon model was first given by two French microbiologist **Francis Jacob** and **Jacques Monod** (1961) in *E. coli*, for which they were awarded Nobel Prize in 1965.
- **Operons** are segments of genetic material (DNA) which **function as regulated units or units that can be switched on or switched off**.
- An operon consists of one to several **structural genes, operator gene, regulator gene**, **promoter gene**, a **repressor** and an **inducer or corepressor** (from outside).
- The segment of a DNA molecule determining the amino acid sequence of a protein is known as **structural gene**.
- Structural genes **produce *m*RNA for forming polypeptides/proteins/enzyme** under the operational control of an operator gene.
- **Operator gene** gives passage to RNA polymerase (enzyme) moving from promoter to structural gene. *i.e.,* it controls the activity of structural genes.
- **Regulator gene** controls activity of operator gene by producing repressor molecules.
- The activity of the regulator gene is controlled by a **promoter gene on its left side**.
- **Promoter gene** is an initiation point for transcription and the site for binding of RNA polymerase.
- The mechanism of regulation of protein synthesis utilizing operon model can be illustrated using two examples (lac & tryptophan) in bacteria.
- Operons are of **two types – inducible and repressible**.
- A mutation taking place in a regulator gene may produce a non functional repressor protein with a changed amino acid sequence. Such mutants are called **constitutive mutants**.
- A mutant repressor is not able to bind to the operator gene and so RNA polymerase is not blocked.
- The structural genes that transcribe *m*RNA and enzyme synthesis occur regardless of need and are called as **constitutive enzymes**.
- A mutation in the promoter gene may totally prevent attachment of RNA polymerase and there is no transcription of *m*RNA and no enzyme synthesis occurs.
- An up-promoter mutation results in an increased rate of enzyme synthesis.
- A down promoter mutation decreases the rate of RNA polymerase attachment and reduced enzyme synthesis occurs.
- **Model proposed to explain gene regulation in eukaryotes** are - Frensters (1965) model of gene specific derepressor RNA; models in which non-histone proteins act as derepressors, e.g., those proposed by Paul and coworkers (1971) and Stein *et al*, and Britten and Davidson's operon - operator model (1969).

Inducible operon system

- **Inducible operon system** regulate genetic material which remains switched off normally but becomes operational in the presence of inducer, e.g., **Lac operon system**.
- Inducible operon system occurs in **catabolic pathway**.
- Lac operon of *E.coli* has **3 structural gene** – **Z**, **Y** and **A** which produces 3 enzymes for the degradation of lactose to glucose and galactose.
- **Z** produces β**-galactosidase** for splitting lactose into glucose and galactose.
- **Y** produces β**-galactoside permease** (membrane bound protein) which is required in entry of the lactose/galactose.
- **A** produces β**-galactoside transacetylase** enzyme that transfers an acetyl group from acetyl CoA to β-galactosides.
- The initiation codon of structural gene Z is **TAC** (corresponding to AUG of mRNA) and is located 10 base pairs away from the end of the operator gene.
- The substance whose addition induces the synthesis of enzyme is called **inducer**.
- Inducer is a chemical which **attaches to repressor and changes the shape of operator binding site so that repressor no more remains attached to operator**.
- In the lac operon **allolactose** is the **actual inducer** while **lactose** is the **apparent inducer**.
- Inducers which **induce enzyme synthesis without getting metabolized** are called **gratuitous inducers**, *e.g.* IPTG (Isopropyl thiogalactoside).

- These type of inducers are very **useful for conducting recombinant DNA studies**.
- **Repressor** is a small protein formed by regulator gene which binds to operator gene and block towards structural enzyme and thus checking mRNA synthesis.
- It (repressor) has **two allosteric sites**, one for attaching to operator gene & other for binding the inducer.
- Repressor of lac operon has a molecular weight of 160,000 and four subunits of 40,000 each.
- If **lactose is added**, the repressor is rendered inactive so that it cannot attach on operator gene and synthesis of *m*RNA takes place.
- Transcription is **under negative control when lac repressor is inactivated by inducer**.
- Transcription in lac operon is **under positive control through cyclic AMP receptor protein (CAP)**.
- The catabolite gene activator protein (Cga protein) or cyclic AMP receptor protein (CAP) binds to the Cga site.
- When CAP is attached to the binding site the promoter becomes a stronger one.
- CAP only attaches to the binding site when bound with cAMP.
- When **glucose level is high cAMP does not occur** and so CAP does not bind and hence RNA polymerase do not bind, resulting in low transcription.

Repressible operon system

- **Repressible operon system** is that regulated genetic material which normally remains active but can be switched off when the cell does not require the metabolite or the concentration of an end product crosses a threshold value, *e.g.* **tryptophan or try operon system** & **arginine operon**.
- It occurs in **anabolic pathway**.
- **Tryptophan** is an amino acids which is always needed by the bacterial cell for protein synthesis and hence produced by the sequential action of enzymes.
- **Tryptophan operon** has **5 structural gene** – E, D, C, B, A.
- The gene **E and D encodes for enzyme anthranilate synthetase**, gene **E for glycerol phosphate synthetase** and gene **B for β subunit of tryptophan synthetase** and A **for α subunit of tryptophan synthetase**.
- Operator gene of repressible operon is normally kept switched on as **aporepressor** formed by regulator gene is **unable to block the gene**.
- **Aporepressor** is a **proteinaceous substance** formed by regulator gene of repressible operon system.
- It is able to block operator gene only in the presence of **corepressor**.
- **Corepressor** is a **non-proteinaceous component of repressor** which is also an end product of reaction catalysed by enzymes produced through the activity of structural genes.
- It (corepressor) combines with aporepressor and forms repressor which then block the operator gene to **switch off the operon**.
- The structural genes stop transcription and the phenomenon is known as **feed-back repression**.
- **Corepressor of tryptophan operon** is **amino acid tryptophan**.
- In tryptophan the repressor gene is not adjacent to promoter but located in another part of *E. coli* genome.

	Regulation of enzyme synthesis by induction and repression.
	I. Inducible system
1.	**Inducer absent** : Regulator gene → Active repressor → Binds to and blocks operator gene → No mRNA transcription by structural genes → No enzyme synthesis.
2.	**Inducer present :** Regulator gene → Active repressor → + inducer → Inactive repressor → No blocking of operator gene → mRNA transcription by structural genes → enzyme synthesis.
	II. Repressible system
1.	**Corepressor absent :** Regulator gene → Inactive repressor (aporepressor) → No blocking of operator gene → mRNA transcription by structural genes → Enzyme synthesis.
2.	**Corepressor present :** Regulator gene → Inactive repressor (aporepressor) → + corepressor → Active repressor → Binds to and blocks operator gene → No mRNA transcription by structural genes → No enzyme synthesis.

- **In absence of tryptophan**, the RNA polymerase binds to the operator site and thus structural genes are transcribed.
- The transcription of structural gene leads to the production of enzyme (tryptophan synthetase) that synthesizes tryptophan.
- **When tryptophan becomes available**, the enzymes for synthesizing tryptophan are not needed, co-repressor (tryptophan) - repressor complex blocks transcription.
- One element of tryptophan operon is the leader sequence '*L*' that is immediately 5′ end of trp. E gene.
- This '*L*' sequence controls expression of the operon through a process called **attenuation**.
- Attenuation is the **termination of the transcription permaturily at the leader region**.
- The tryptophan operon is a **negative control**.

Importance of gene regulation

- There are two types of gene action – **constitutive** and **regulated**.
- The **constitutive gene action** occurs in those systems which operate all the times and the cell cannot live without them, e.g., glycolysis. It does not require repression. Therefore, regulator and operator genes are not associated with it.
- In **regulated gene action** all the genes required for a multistep reaction can be switched on or off simultaneously.
- The genes are switched on or off in response to particular chemicals whether required for metabolism or are formed at the end of a metabolic pathway.
- Gene regulation is required for **growth**, **division and differentiation of cells**. It brings about **morphogenesis**.
- During development from a zygote, multicellular organism passes through a number of stages as **cleavage**, **determination**, **growth**, **differentiation** and **development**.
- **Cleavage** is early division of a zygote.
- **Determination** is the commitment of embryo cells to develop into particular part of the organism.
- **Growth** involves cell division, cell enlargement etc.
- The process by which totipotent embryological cells are converted into specialised cells constituting and giving rise to specific tissue is called **differentiation,** eg. RuBP in mesophyll cell and bile in liver cell etc.
- Differentiation is accompanied by morphogenesis and formation of different tissues and organs.
- Totipotent means capable of forming complete organism (Driesch, 1892, 1900) by differentiation.
- Pluripotent means capable of changing but lacking totipotency.
- Development is the whole series of events that occur in the life history.

End of the Chapter

Chapter 56

Human Genetics and its Disorders

- **Human genetics** deal with the inheritance of characters in man.
- **Sir Francis Galton** recommended two methods to determine human genetics traits and their inheritance. These methods are - **pedigree analysis** & **studies of twins.**
- **Pedigree analysis** is a graphical method representing the generation of family with various symbols used for relationships or for particular chemical findings.
- **Genes,** the hereditary unit, contains the hereditary information encoded in their chemical structure for transmission from generation to generation.
- Any changes in the composition of one or more genes on a chromosomes may produce structural, physiological or biochemical abnormalities. Hence these are called **genetic disorders**.
- Genetic disorders are also called **congenital diseases** because these are present and existing from the time of birth.
- Genetic disorders may be **classified on the basis of** –
  - **Chromosomal abnormalities**
  - **Incompatibility of genes**
  - **Single gene disorders**.
- **Chromosomal abnormalities** may **arises due to** –
  - **Non disjunction :** When pair of chromosomes fail to separate.
  - **Translocation :** When a portion of chromosomes breaks & attached to another.
  - **Deletion :** When a piece of chromosomes may detatch & lost from karyotype (chromosomal complement of organisms).
  - **Duplication :** When some genes may appear twice in the same chromosomes.
  - **Inversion :** When chromosomal segment inverted & change or alter the order of sequence of genes.
  - Transverse division of chromosomes instead of longitudinal division (**iso chromosomes**).
- Disorders arises due to chromosomal abnormalities may be **either due to autosomal chromosomal changes** or **sex chromosomal changes**.
- Disorders of incompatibility of genes are of two types – **Rh factor incompatibility** and **ABO incompatibillity**.
- Caused by gene mutation, **single gene disorders** (also called **unifactorial diseases**) **are of three types** –
  - **Recessive autosomal gene disorder** (eg. sickle cell anaemia, alkaptonuria, albinism, Tay sachs disease etc.)
  - **Defective dominant autosomal gene disorder** (eg. Huntington's chorea, achondroplasia etc.)
  - **Recessive sex linked gene disorder** (eg. haemophilia, colourblindness, muscular dystrophy etc.)

CHROMOSOMAL DISORDERS

Autosomal chromosomal changes

- Due to changes in number autosomal disorders are of two types – euploidy and aneuploidy.
- **Euploidy** is the numerical increase of chromosomes from normal $2n$ to multiples of complete haploid set *i.e.*, 3X (triploid), 4X (tetraploid), 5X (pentaploid), 6X (hexaploid). This is **more common in plants**, **rare in animals**, **and does not occur in humans**.

- **Aneuploidy** relates to variation in chromosome number with respect to one or only a few chromosomes. The entire set is not involved in aneuploidy. Thus, the person afflicted with this will have one or few chromosomes more or less than the diploid number.
- Aneuploids are of **three types** –
  - **Monosomic** ($2n - 1$)
  - **Nullisomic** ($2n - 2$) when entire pair of homologous chromosome from a diploid set is missing
  - **Polysomic** when one or more chromosome reduplicates.
- Polysomics can be of **4 types** –
  - **Trisomic** ($2n + 1$) : having 3 chromosomes (= copies) in one set instead of 2. This is due to non-disjunction of homologous pair.
  - **Double trisomic** ($2n + 1 + 1$) : 2 extra chromosomes
  - **Tetrasomics** ($2n + 2$) : one chromosome in quadriplicate.
  - **Pentasomics** ($2n + 3$) : one chromosome in pentaplicate.
- **Disorders of autosomal chromosomal abnormalities** are - Down's syndrome, Edward's syndrome, Patau's syndrome.

Down syndrome

- **Down's syndrome** occur due to **trisomy of 21st chromosomes** with rounded face, flaccid muscle, protruding tongue, folded eyelids short and broad neck, feeble minded, low 1Q (20 - 50), severe neurological disorders, prone to respiratory diseases etc.
- This syndrome is also known as **Mongoloid syndrome**.
- Survivers of Down's syndrome have higher chances of catching Leukemia and Alzheimer's disease.

Edward's syndrome

- Individual suffering from **Edwards' syndrome** due to **trisomy of 18th chromosomes** is characterized by mental retardation, micrognathia short sternum etc.

Patau's syndrome

- **Trisomy of 13th chromosomes** results in **Patau's syndrome**.
- It is **characterised by hare lip** (a form of congenital defect, sometimes hereditary, marked abnormal clefts between the upper lip and the base of nose), **cleft palate** (results from the incomplete closure of palate or roof of the mouth during early embryonic life), **polydactyly** etc.
- Death usually occurs soon after birth or may survive upto 3 months.

Sex chromosomal changes

- The X and Y chromosome of humans differ in their shape, size and banding patterns. X contains more DNA than Y, also has more genes than Y. The genetic capabilities of X are relatively higher than Y.
- Y is very much condensed & contains few functional genes that determine male traits. They are called **holandric genes**.
- Recessive alleles present on X have no equivalent/ comparable gene on Y. It is because of this reason that **recessive allelic genes of X easily express themselves phenotypically**.
- In females of all placentals including humans one of the X chromosomes becomes inert by a process called *Lyonisation*. This inert chromosome was first discovered by Barr on the nuclear membrane as an intensely stained body and is appropriately designated as **barr body**.
- In genetically normal human female one barr body is present. The male do not have it.
- **Aneuploidy in sex chromosome** results in increase in the number of X (in some cases Y as well) called **trisomy**.
- Trisomy **arises by non-disjunction of homologous chromosomes** during egg cell formation.
- Non-disjunction is **more common in sex chromosomes** than the autosome.
- **Deletion** of large **part of the small arm of one of the 5th chromosomes** results in **Cat cry syndrome** (discovered by Lejeune in 1963). These syndrome is associated with malformation of the larynx.
- Child affected with cat cry syndrome during infancy has a characteristic high pitched cry of kitten.
- **Philadelphia chromosome** is one of 22 autosomes that has lost most of the distal part of its longer arm.
- This chromosome is present in those individual which are suffering from **chronic myeloid leukemia**.
- It is **characterised by** an excess of granular

leucocytes in the blood which in turn reduces the number of RBC resulting in severe anaemia.

- **Hypertrichosis** means excessive hair on ear pinna. Genes responsible for this are located on Y chromosomes only which are also known as **holandric genes**. This genes are not expressed in females. Y-linked holandric genes are transmitted directly from father to son.
- **Genetic disorder due to sex chromosomal numerical changes** are – Klinefelter's syndrome, Turner's syndrome, super males and super females.

Klinefelter's syndrome

- Klinefelter's syndrome is one of the **most common cause of hypogonadism in the male**.
- Klinefelter's' syndrome (XXY) is **caused by presence of extra X-chromosome due to union of nondisjunct XX egg** and **a normal X and abnormal XY sperms**.
- These are **genetically sterile male individual** with undeveloped testes, azospermia (less and deformed sperm), gynaecomastia (enlarged breast), mental retardation, occurrence of barr body etc.

Turner's syndrome

- Turners' syndrome (most common type of female genetic disease) **having XO genotype** is **caused by the absence of X chromosomes in female**.
- These are **sterile females with** poorly developed ovaries and underdeveloped breasts. They have webbed neck and broad chest.

Supermales

- Supermales (Y chromosome disorder) having XYY genotype shows over production of testosterone, unusual height, mental retardation, over aggressiveness and criminal bent of mind.

Superfemales

- Superfemales, having XXX genotype, **arises due to presence of extranumerary chromosomes.**
- These females are mentally retarded with congenital abnormalities like underdeveloped external genitalia, uterus and vagina.

INCOMPATIBILITY OF GENES

Rh factor incompatibility

- Rh factor was first of all reported in RBCs of *Macaca rhesus* **(rhesus monkey)** by **Landsteiner** and **Wiener** in 1940.
- Rh factor is **dominant character in heredity**.
- The disease **erythroblastosis foetalis** in human embryo is caused due to disadjustment of Rh factor.
- Erythroblastosis foetalis can **occur when father is Rh positive** and **mother is Rh negative**.
- An Rh negative woman can be sensitized when she bears an Rh^+ child, and future Rh^+ children may have erythroblastosis foetails (also called **haemolytic disease of the newborn**, **HDN)**.
- In developing foetus, erythroblastosis foetalis is caused by **haemolysis**.
- Injection of anti-Rh (**Rhogam)** into an Rh negative woman after the birth of each Rh positive baby can prevent sensitization of the woman by binding Rh positive blood cells from the baby.
- The **commonest cause of haemolytic disease of newborn** is **maternal alloimmunisation** (immunity arising from the mothers body itself).
- **No abnormality arises** when mother is Rh (+)ve and father is Rh(–)ve.
- Erythroblastosis foetalis occurs due to **transplanted transmission of maternally formed antibody against the foetus erythrocytes**, usually secondary to an incompatibility between the mothers Rh blood group and that of her offsprings.

ABO incompatibility

- ABO incompatibility may lead to haemolytic disease of new born, characterised with **anaemia and jaundice**.
- ABO incompatibility is **less severe** as compared to Rh-incompatibility disorder. It **occurs even in the first baby**.

SINGLE GENE DISORDERS

Recessive autosomal gene disorder

- **Type of recessive autosomal gene disorders** are – phenylketonuria, albinism, alkaptonuria etc.
- Phenylketonuria, albinism and alkaptonuria etc are **caused by the absence of specific enzymes**.

Phenylketonuria

- Phenylketonuria **occurs due to absence of** *phenylalanie hydroxylase* enzyme in liver which is essential for the conversion of phenylalanine to tyrosine.
- It is **characterised by** severe mental retardation, hypopigmentation of skin and hair, eczema (itchy

skin), mousy odour of skin, hair and urine due to **increased phenylalanine in blood and urine**.

Alkaptonuria

- Alkaptonuria is also called **black urine disease**.
- Alkaptonuria occurs **due to absence of liver enzyme**, *homogensate/alkapton oxidase* which is essential for the metabolism of homogentisic acid (formed from phenylalanine and tyrosine).
- It is **characterised by** the **increased excretion of alkapton** and its accumulation in body produces arthritis and other **damages**.

Albinism

- Albinism **arises due to** absence of enzyme **tyrosinase** which catalyses the formation of dihydroxy-phenylalanine (DOPA) which form dark brown pigment.
- During this eye disorders may occur due to **damage from bright light**.

Tay Sach's disease

- Tay Sach's disease appears after birth **due to deficiency of enzyme β-D-N-acetyl hexosaminidase**.
- It is **characterised with abnormal fat metabolism** leading to damage to brain and spinal cord resulting in mental retardation and paralysis.

Thalassemia

- Thalassemia is a group of genetic disorders which **results from defective synthesis of subunits of haemoglobin** (α and β-globin chains of haemoglobin).
- In **α-thalassemia**, out of four genes on **11th chromosomes,** absence of 2 genes leads to microcytic and hypochromic erythrocytes without significant anaemia. Death occurs in case of deficiency of all the genes.
- **β-thalassemia** is **characterised by** presence of two defective β-gene on **16th chromosomes**.

Sickle cell anaemia

- Sickle cell anaemia is **due to inheritance of a defective allele coding for β-globin**. It results in the transformation of Hb-A into Hb-S in which **glutamic acid is replaced by valine at sixth position in each of two β-chains of haemoglobin**.
- Sickle cell anaemia is a **blood disease** (affective black Africans) where the red blood cells become **sickle shaped** as compared to normal one.
- The sickle cells are **rigid** and **exhibit a higher viscosity to flow** causing them to lodge in capillaries.
- The major characteristics of this disease are **anaemia and a tendency of the red blood cells to change shape** at low oxygen concentration.
- Due to insoluble in deoxygenated state sickle cell haemoglobin precipitate in the **red blood cells** and giving their characteristic **bizzare shape**.
- These cells are **useless**, so they have to broken down and tend to jam in capillaries and small blood vessels and prevent normal blood flow.
- The absent or reduced blood flow results in **ischemic damage** to many different organs in affected individuals.
- Sickle cell anaemia is an **excellent example of single mutation**.

Galactosemia

- Galactosemia in man is inherited as an autosomal recessive, and the **affected person is unable to convert galactose to glucose**.
- The disease is **due to the deficiency** of the enzyme *galactose phosphate uridyl transferase* (GPT).
- Untreated infants develop hepatomegaly, jaundice and hypotonia and the symptoms can be relieved if galactose is removed from the diet.
- **The gene involved in the galactosemia is located on the short arm of chromosome 9**. Affected individuals, who are homozygous for the allele, exhibit enlargement of liver and spleen and some mental retardation.

Defective dominant autosomal gene disorders

- **Disorders due to dominant defective autosomal genes** are – Huntington's chorea, achondroplasia, polydactyly, bradydactyly, dwarfism.
- **Huntington's chorea** (late acting dominant disorder) is caused by a dominant gene mutation on **short arm of 4th chromosome**.
- It is **characterised by** abnormal speech and respiration, irregular arrhythmic movements of limbs etc. **due to atropy of brain parts**.
- This disease **does not appear** till the age of 25 to 35.
- **Achondroplasia** is a **hereditary disorder of cartilage formation leading to dwarfism**.
- **Polydactyly** and **bradydactyly** is a disease of more **than five digits in fingers and toes** and a **small sized fingers respectively**.
- **Marfan syndrome** is due to dominant mutation

resulting in the production of abnormal form of connective tissues and characteristic extreme looseness of joints. The long bones of body grow longer, fingers are very long called '**spider fingers**' or **arachnodactyly**; weakness develops in the connective tissue and lenses in eyes become displaced. The diagnosis is made on clinical grounds, with involvement in at least two body systems.

- The **molecular basis of Marfan syndrome** is **mutation of a structural gene** (related to fibrillin protein) **on chromosome 15**.
- **Cystic fibrosis** is most common diseases in North America, rare in Asia including India. The body **produces abnormal glycoprotein which interferes with salt metabolism**. The sweat in body becomes rich in sodium chloride; the mucous secreted by body becomes abnormally viscid which blocks passages in the lungs, liver and pancreas. Due to defective liver functioning the fat digestion will not be normal. One of the **principal organ affected by cystic fibrosis is pancreas** which develops fibrous growth.
- The **gene**, responsible for this defect (cystic fibrosis), has been **localized to chromosome 7** and it codes for a chloride transport factor (CFTR) and multiple alleles.
- **Gaucher's disease** is a genetic disease associated with **abnormal fat metabolism**. It is **caused by** the **absence of the enzyme** *glucocerebrosidase* required for proper processing of lipids.

Recessive sex linked gene disorders

- **Disorders occurs due to recessive sex linked genes** are – haemophilia, red-green colourblindness, muscular dystrophy etc.

Haemophilia

- Haemophilia is **also known as bleeder disease** (John Otto, 1803).
- It is an **popular example of sex linked inheritence in human beings**.
- It **occurs due to deficiency of plasma thromoboplastin** (haemophilia, Christmas disease) or **antihaemophilia globulin** (haemophilia A) during which the exposed blood does not clot.
- Haemophilia **appears only in human male** which can be transferred to their grandson through his carrier daughter **(criss-cross inheritance)**. Homozygous condition is **lethal**.

Red green colourblindness

- Red green colourblindness is **more common in male** than females (20 : 1) due to presence of only one X chromosome.
- The sufferer are **not able to distinguish between red and green colour.**
- Red green colour blindness is also called **Daltonism** or **proton defect**.
- Colourblindness is of **three types : protanopia** (red colour blindness), **deuteranopia** (green colour blindness) & **tritanopia** (blue colour blindness.)
- Colourblindness show **criss-cross inheritance** as in haemophila.

Muscular dystrophy

- Muscular dystrophy **occurs due to non-synthesis of protein, dystrophin** which is required for transfer of nerve impulse to calcium storing regions of the muscle.
- Muscular dystrophy is of **two types** – **Duchenne's pseudohypertrophy** and **Becker's/benign pseudohypertrophic dystrophy** (less severe).
- It is **characterised by deterioration of muscles at an early age** with progressive weakness of girdle muscles, inability to walk after age of 12, cardiomyopathy and mental impairment.

G-6-PD deficiency syndrome

- G-6-PD deficiency syndrome **occurs due to deficiency** of *glucose 6-phosphate dehydrogenase* (essential for carrying out hexose monophosphate shunt).
- In the absence of G-6PD, **haemoglobin crystallizes** and **erythrocyte membrane ruptures** during oxidant stress.

Congenital night blindness

- **Congenital night blindness** causes reduced development of visual pigment (rhodopsin) that interferes with the function of retinal rods and hence night blindness. (Also **occurs due to vitamin A deficiency**).
- It is **caused by** a recessive gene carried by X-chromosomes.

End of the Chapter

Chapter 57

Organisms & Environment

- **Ecology** (GK *oikos* - home, *logos* - study) is defined as **the study of inter-relationships between living organisms and their environment**.
- The **term ecology** was **coined by Ernst Haeckel**.
- The two **main branches** of ecology are– **autoecology** and **synecology**.
- **Autoecology** is the study of **inter-relationship of** the **organisms of a species of biotic or abiotic environment**.
- **Synecology** is the **study of inter-relationship of different groups of the living organisms**, such as populations, biotic communities and ecosystems and their environment which are associated together as a unit.
- **Hierarchy** means an arrangement into graded series.
- Ecological hierarchy involves the following categories – organisms, population, species, biotic community, ecosystem, biome, biosphere.
- The hierarchy in the levels of organisation connected with ecological grouping of organisms is called **ecological hierarchy**.
- **Individual organism** is the **basic unit of ecological hierarchy** which is a distinct living entity.
- **Population** is a group of similar individuals in a particular geographical area or space.
- A **biotic community** is any assemblage of populations of different species like plants, animals, bacteria etc. living in a prescribed area or physical habitat and interact with one another.
- **Ecosystem** is defined as the segment of nature consisting of biological community and its physical environment both interacting and exchanging materials.
- **Landscape** is a unit of land with natural boundary having a mosaic of patches. These patches generally represent different ecosystem.
- **Biome** is a major ecological community or complex communities that extends over a large geographical area characterised by a dominant type of vegetation.

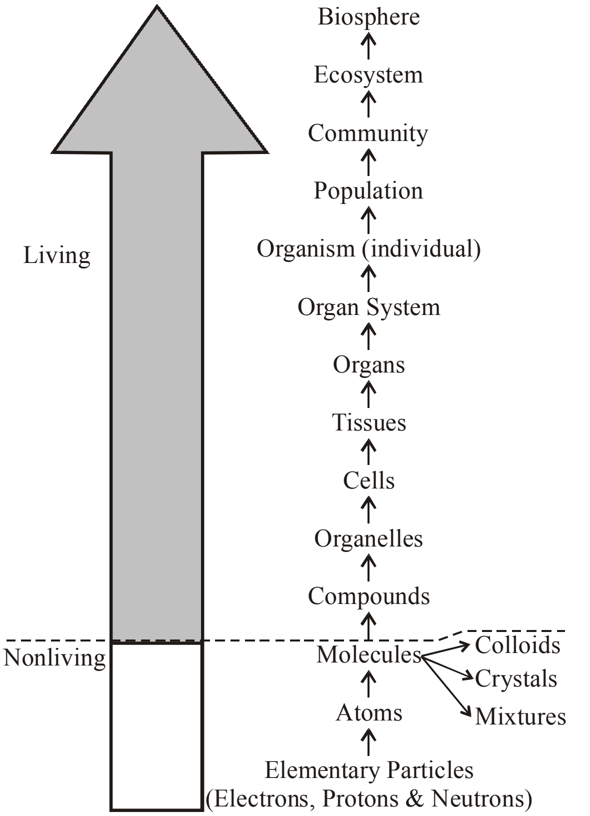


Fig : Ecological hierarchy

- **Biosphere** is the biologically inhabited part of earth along with its physical environment consisting of lower atmosphere, land and water bodies.
- **Environment** is the sum total of all biotic and abiotic factors, substances, and conditions that surround and potentially influence organisms without becoming their constituent parts.
- The **constituents of environment which directly or indirectly influence the form and functioning**

of organisms in any specific way are known as **environmental factors**.

- **Climate** is the characteristic pattern of weather elements in an area over a period of time with regard to temperature, rainfall, pressure, humidity, wind etc.
- Temperature and rainfall are the **two most important factors which determine the climate of an area**.
- **Microclimate** is the local variation of climate that occurs in an area of limited size.
- **Habitat** is the specific locality delimited by a combination of factors, physical features and barriers where a community resides.
- The part of the habitat having a specific property e.g., tree canopy, forest floor etc. is called **microhabitat**.
- **Ecological niche** is a specific part of habitat occupied by individuals of a species which is circumscribed by its range of tolerance, type of food, range of environment, microclimate, shelter etc.
- The place where the organism lives, is called its **habitat** while the conditions and resources for its life activities constitute the **environment**.
- The **environment factors** are **divided into two categories on the basis of their nature** :-
  - **Abiotic or non-living or physical factors**
  - **Biotic or living or biological factors**

ABIOTIC FACTORS

- The abiotic or physical factors affect the structure, behaviour and life history of organisms.
- The **four types of abiotic factors** are **climatic** (light, air, temperature, humidity, precipitation), **edaphic** (soil), **topographic** (earth surface), and **fire**.
- An organism, itself is a component of environment.
- Its growth and development, behaviour & life history, all are influenced by the environment.
- **Atmosphere** is transparent gaseous envelope around the earth which extends upto 1600 km.
- Atmosphere contains **nitrogen** (78.03%), **oxygen** (20.99%), **noble gas argon** (0.94), **carbon dioxide** (0.036%) and **traces of other gases** with **water vapours and dust particles** present in the lower region.
- Atmosphere is **divided into 5 layers - troposphere, stratosphere**, **mesosphere**, **thermosphere** and **exosphere**.
- **Troposphere** extends 8 - 16 km from surface of earth showing decrease of temperature with height from 15°C to –57°C.
- Troposphere contains more than 90 percent of gases in the atmosphere and is the **most important zone of the atmosphere**.
- **Cloud formation, lightning, thundering, thunder storm formation etc. take place** in troposphere.
- **Stratosphere** extend from 8 - 16 to 30 - 50 km. Clouds, dust particles and air masses are absent.
- **Ozone is formed in the stratosphere** from oxygen due to intense solar radiations, $3O_2 \rightarrow 2O_3$. It is called **ozone layer** or **ozonosphere**.
- **Mesosphere** is present between 50 - 100 km height. Temperature decreases from –2°C to –92°C. Gas molecules become charged.
- **Thermosphere** lies between 100 - 500 km height. Temperature rises from –92°C to 1200°C. **Ionised layers occur in this zone** which are collectively called **ionosphere**.
- **Exosphere** is extremely rarefield part of atmosphere between 500 - 1600 km.
- Lower part of atmosphere (called **air**), **moves and forms wind due to uneven heating and rotation of earth which has a direct mechanical effect and an indirect physiological effect**.
- A number of organisms live in water bottom is **called benthic habitat** while **above bottom is the pelagic habitat**.
- **Light intensity, light direction and light quality control a number of processes** of organisms as - **photosynthesis**, **growth**, **movements**, **photoperiodism**, etc.
- The **different zones of light in aquatic habitat** are –
  - **Littoral zone** : Shallow coastal region, producers occur throughout.
  - **Limnetic zone** : Open water zone, oxygen and light decreases with depth.
  - **Photic zone** : Light can penetrate.
  - **Aphotic zone** : Light does not penetrate.
  - **Benthic zone** : Bottom zone.
- Light has many effects on animals also, by affecting their several types of activities like pigmentation, reproduction, development, growth, locomotion, migration etc.
- **Daily responses of animals to light conditions** are known as **circadian rhythm** whereas **annual responses are known as circannual rhythms**.
- **Temperature** or the degree of hotness/coldness of

a place influences the climatic conditions, soil conditions, activities of organisms and growth responses of plants because it influences the rate of all physiological process.

- **Difference in temperature of water** at different depths result in **thermal stratification in deep water bodies**.
- During summer, temperature is higher in the surface water, which is separated from the deeper water mass by a **thermocline** (a zone of gradual change in temperature).
- A thermocline often creates two different layers *i.e.*, **epilimnion** (upper layer of water) and the **hypolimnion** (lower layer of water) in a single body of water.
- Variations in temperature affects animals which are broadly classified into two groups as - homeothermic and poikilothermic.
- **Homeothermic or warm blooded or endotherms** are those animals (e.g., birds and mammals) which are able to maintain their body temperature at a constant level irrespective of the environmental temperature.
- **Poikilothermic or cold blooded or ectotherms** are those animals (e.g., reptiles, fishes, amphibians) in which the body temperature fluctuates with changes in the environmental temperature.
- **Water** is an important component of protoplasm being **used as a general solvent, a reactant, a metabolic by-product** and **an essential material for maintaining turgidity**.
- Water is a **resource**, a **condition** and a **habitat in itself**.
- 71% of earth is covered by water in the form of oceans, ice caps, glaciers, lakes, etc. 97.5% of all water is found in oceans.
- It is a source of cloud formation, precipitation as rain or snow, atmospheric humidity and dew formation.
- A large number of organism have evolved in water. They are known as aquatic organisms. **The aquatic habitat may be freshwater, marine or estuary.**
- Water cycle has 2 components **– global (long)** and **local (short)**
- **Local or short cycle** consists of –
  - Evaporation of water from an area
  - Condensation of water vapour
  - Precipitation over the same area
- **Global or long cycle** involves movement of water vapours in the from of clouds, rainfall over a large area and movement of water from one area to another.
- **Soil** is the upper weathered part of earth's surface having mineral particles (45%), water (25%), air (25%), living organisms and humus (5%) which can substain terrestrial plant life.
- **Transportation of soil** occurs by different agents and is referred accordingly as – **colluvial** (through gravity), **alluvial** (running water), **eolian** (wind), **glacial** (by glacier).
- The **different soils groups** are –
  - **Red soil –** Most famous. They are **acidic laterite soils** which are deficient in lime, magnesium, phosphorus and potassium but rich in organic matter, iron and aluminium, support tea coffee rubber, cardamon areca-nut and paddy.
  - **Black soil –** Also called **black cotton soils/ regurs** with dark brown or black colour from organic matter, clay/hydrated iron and aluminium silicates and undifferentiated B - horizon.

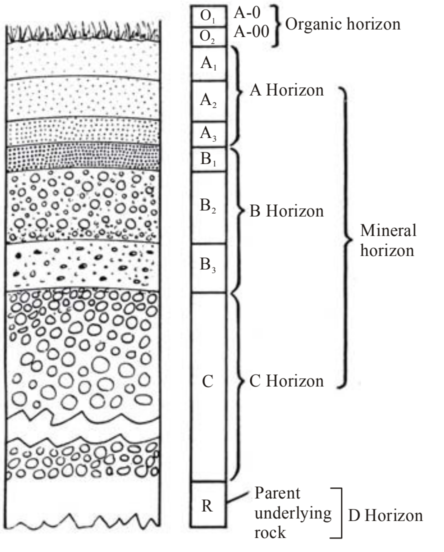


Fig. A generalized forest soil profile showing various zones.

Soil profile : A-0-freshly fallen litter (partly decomposed). A-00 - organic matter (fermentation level and humus level). A$_1$- organic debris + mineral. A$_2$-light colour due to leaching. A$_3$-may be present or absent. B-Horizon- iron and aluminium compounds. B$_1$-transitional layer. B$_2$-dark coloured, maximum amount of leached material. B$_3$-large chunk of parent rock material + leached material. C-thick, large masses of weathered mineral material. D-Unweathered parent rock material.

- **Alluvial soils –** Most productive of Indian soils, **contributes to the largest share of agricultural wealth of the country**. Generally **deficient in N_2 and humus**.
- **Terai/Babar soils –** Mostly colluvial, drained ones highly productive.

- **Depending upon the various integrations of soil particles** [gravel (2.00 mm & more), coarse sand (2.00 mm to 0.2 mm), fine sand (0.20 mm to 0.02 mm), silt (0.02 mm to 0.002 mm), clay (below 0.002 mm)], **soil can be grouped into various types** – **sandy soil, clay soil, loam soil, clay loam soil, sand loam soil and silt loam soil**.
- **Sandy soils** mainly consist of sand particles. These are **loose, dry and poor in nutrients**. The water holding capacity of such soil is poor.
- **Clay soils** chiefly consist of clay particles that are of colloidal dimensions and **have high plasticity and possess high water holding capacity**.
- Clay particles have very small interspaces between them so that neither water nor air can circulate freely and on getting water become water-logged so they are **not suitable for plant growth**.
- **Loam soils** have sand, silt and clay particles in more or less equal proportions and are the **most suitable for plant growth**.

Some important terms related to soil

Weathering	– Breaking of rocks into finer particles
Humification	– Formation of humus. Essential for starting biological activity and nutritional cycle.
Pedogenesis	– The weathered mineral matter is changed to soil
Illuviation	– Deposition in lower layer
Elluviation	– Washing down or leaching
Humus	– It is partially decomposed and partially synthesised dark amorphous organic matter. Humus is formed from detritus or litter (amimal refuse, plant derbis) through degradation into raw humus (individual components recognisable) and leaf mould (amorphous and colloidal). Humus helps in weathering of rocks, forms soil crumbs for increased aeration and hydration, has growth promoting chemicals and releases nutrients slowly.

- **Sand loams** are those soils in which sand particles predominate.
- **Clay loam soils** have a predominance of clay particles and are **suitable for plant growth**.
- **Silt loam soils** have predominance of silt and on getting water, silt loam becomes water-logged with poor air circulation and are **not suitable for plant growth**.
- On the basis of water retained by soil, water has been classified as **gravitational water, capillary water** and **hygroscopic water**.
- **Gravitational water** is **the free water** which due to the action of gravity moves downwards into the soil until it reaches the water-table. **This water is of little direct value to the plants**.
- **Capillary water** fills the spaces between non-colloidal soil particles and forms films around them.
- This water is **held by the capillary forces** around and between the particles and is **of greatest importance to plant**.
- **Hygroscopic water** is the water that occurs in the form of thin film on the soil particles. This water is **not available to the plants**.
- **Field capacity** is the maximum amount of water that the soil can hold after the gravitational water has drained away.
- When the percentage of moisture that is left in the soil at the time at which the plants will not recover from wilting is **termed as permanent wilting point or wilting coefficient**.
- **Topographic factors** (physical geography) change different climatic conditions which in turn affect the vegetation.
- The **important topographic factors** are **altitude** (height above level), **directions of mountains**, **steepness of slope etc**.
- **Fire** is an important ecological factor in temperate forest and grassland regions, as well as in tropical areas having dry seasons. It brings about burning of vegetations.
- Fires are generally classified as –
  - **Ground fires** - These **fires are flameless** develop in such conditions where organic matter accumulated for longer periods.
  - **Surface fires** - It sweeps over the ground surface

rapidly and their flames consume the litter, living herbaceous vegetation and shrubs.
- **Crown fires** - These are **most destructive**, burning the forest canopy, surface debris and bringing about vegetative destruction at large scale.

- Fire has been **used by humans for a number of purposes** –
  - **Clearing - vegetation** for construction of residential and industrial estates.
  - **Creation of farmlands and orchards**.
  - **Growing pastures**.
  - **Scaring away wild animals**.
  - **Enhance hunting**.
  - **Increase in visibility**.
  - **Enmity**.
- The **effects of fire** are –
  - Destruction of plant cover.
  - Destruction of litter mass.
  - Loss of nutrients through volatilisation, e.g., nitrogen, chlorine, sulphur and part of phosphorus.
  - Destruction of habitat resulting in disappearance of many plants and animals.
  - Disruption of nutrient cycling.
  - The burning of vegetation exposes the soil to direct pounding by rain drops, solar radiations and wind.
  - It takes a lot of time for replantation of burnt down forests.

BIOTIC FACTORS

- Biotic community is an association of a number of interrelated populations belonging to different species, in a common environment which can survive in nature.
- **Biotic factors** include all organic factors that mostly influence growth and reproduction, e.g., plants, animals, microbes, interaction of animals.
- These biotic interactions are of **two types** – **positive interactions** (when both the organisms or one organism is benefitted) and **negative interactions**, when both the organisms or one organism is harmed) [*for interaction between species refer chapter Population, Biotic community and Succession*]
- **Man** is always **most important biotic factor**. He changes the environment by his activities regularly, eg., by excessive cutting of trees, fire, domestication of plants and animals, by causing different types of pollution etc.
- **Homeostasis** is the term generally applied to the tendency for biological systems to resist change and to remain in a state of equilibrium.
- A factor that limits growth, development, reproduction or activity of an organism by its deficiency or excess is called the **limiting factors** and its impact on the optimum functioning of the organisms are called **limiting functions**.
- According to **Liebig's law of Minimum** (Liebig, 1840), the growth and reproduction of plants and hence productivity of soil is limited by an essential nutrient that becomes deficient or critically minimum in relation to its requirement.
- According to **law of limiting factors** (Blackman, 1905) when a process is conditioned as to its rapidity by a number of separate factors, the rate of the process is limited by the pace of the slowest factor.
- According to **Law of tolerance** the abundance and distribution of organisms is controlled by any of the ecological factor below its critical minimum and above its critical maximum. Critical minimum and critical maximum values of an environmental factor influencing organisms are called **limits of tolerance**.
- **Acclimatization** is the physiological changes in an organism in response to a change in a particular environmental factor.
- Plants and animals undergo special characteristic changes in order to live and adjust under prevailing environmental conditions which is called **adaptation**.
- **According to the various modes of adaptation**, plants are grouped as **xerophytes**, **hydrophytes**, **halophytes**, **heliophytes** and **sciophytes**.
- **Xerophytic plants grow in dry habitats** where rate of respiration is very high. They are of **4 types** – **ephemerals, annuals or drought evaders, succulents** and **non-succulents**.
- Plants growing in aquatic habitat are called **hydrophytes**. They may be **submerged**, **suspended**, **free floating**, **rooted with floating leaves and emergent**.
- Hydrophytes have mucilage, poorly developed roots, presence of aerenchyma, poorly developed xylem and leaves showing heterophylly in some.
- **Halophytes** are **plants growing in saline habitat** like coastal areas, mangroves, tidal marshes etc.
- **Heliophytes** are **plants growing in bright light** having small thick leaves, shorter and thicker internodes, sunken stomata and thick cuticle.

Table : Plant adaptations

	Types of adaptation	Special characters	Examples
1.	**Heliophytes**	Root system is extensive, leaves pale green in colour with hairy growth, palisade parenchyma well developed. More flowering and fruiting.	....
2.	**Sciophytes**	Leaves large, bright coloured, palisade parenchyma less developed, more vegetative growth than flowering.	....
3.	**Xerophytes**	Plants of dry habitats	....
	(i) Ephemerals	Plants live only in rainy season	*Euphorbia*
	(ii) Annuals	Plants live for a few months after rain	*Echinops, Solanum surattense*
	(iii) Succulents/drought resistants	Fleshy organ for storage of water and mucilage; phylloclades (photosynthetic and green stem), cladodes (1-2 internode long stem show crassulacian acid metabolism) are present.	*Opuntia, Asparagus, Euphoria* (fleshy stem), *Aloe, Agave* (fleshy leaves)
	(iv) Non - succulents	True xerophytes, smaller shoot system, extensive root system, small, leathery leaves, possess prickles and spines.	*Nerium, Casuarina, Capparis, Acacia*
4.	**Hydrophytes**		....
	(i) Submerged	Not rooted, remain completely under water	*Ceratophyllum*
	(ii) Free floating	Not rooted in mud, float freely on the surface of water	*Eichhornia* , *Lemna*, *Wolffia* *Azolla*, *Salvinia*
	(iii) Rooted hydrophytes with floating leaves	Root fixed in mud but leaves are floating on water surface.	*Trapa*, *Nelumbo*, *Marsilea*, *Nyphaea*
	(iv) Rooted submerged	Rooted in mud and remain in water.	*Hydrilla*, *Vallisneria*, *Isoetes*, *Potamogeton*
	(v) Rooted emergent	Root fixed in soil, stem exposed to air.	*Ranunculus*, *Typha*, *Cyperus*, *Sagittaria*
5	**Halophytes**	Grow in saline habitat, have high osmotic pressure, show some xerophytic characteristics like succulents leaves, stem, etc. Show mangrove vegetations in marshy areas, possess pneumatophores (breathing roots), vivipary (germination of seeds on parent plant)	*Artiplex*, *Spartina*, *Tamarix* *Avicennia*, *Aegiatilis*, *Rhizophora*

- **Sciophytes** are **plants growing in partial shade** showing soft, slender stem, large and thin leaves, thin cuticle and surface stomata.
- Certain plants are adapted to grow in oligotropic soils (poor in nutrients), e.g., tropical rain forests have plants showing mycorrhizal roots.
- Animals adapt themselves for **protection from predators**, **feeding habit, camouflage, mating, adjust to environmental stress conditions**.
- Physiological and behavioural adaptation to environmental variations and stress conditions occur in the form of **migration, hibernation, aestivation, camouflage, mimicry, echolocation, water scarcity and prevention of freezing**.
- **Migration** is a two way movement of an animal group to other places for food, climate and other reasons.
- **Camouflage** is the **ability to blend with the surroundings** to remain **unnoticed for protection**, e.g., insects, reptiles.
- **Mimicry** is **the resemblance of one species with another** in order to **obtain advantage against predation**.

- Mimicry may be **batesian** (defenseless, e.g., viceroy butterfly mimics unpalatable toxic monarch butterfly) and **mullerian** (resemblance to two animal both unpalatable/ferocious to their mutual benefit, e.g., monarch butterfly and queen butterfly).
- **Hibernation** is the winter sleep of some animals to survive against food scarcity and cold weather in which several physiological changes occur like lowering of body temperature and slowing of pulse rate.
- **Aestivation** is the state of inactivity occurring in some animals during prolonged period of drought or heat, e.g., lungfish.
- **Echolocation** (production of echoes) is the process used by bats to **know their path while flying at night**.
- Some animals adapt **cold hardiness** by developing extra solute in the body fluids and special ice nucleating proteins in the extra cellular spaces, eg., ice fish.
- Animals facing **water scarcity** develop thick coat to minimize evaporation, make minimum consumption of water or may not produce urine,e.g., camel, kangaroo.

End of the Chapter

Chapter 58

Population, Biotic Community & Succession

- **Biotic community** is a grouping of different but interacting population of different species which live harmonious in a given locality, eg. pond, forest community etc.
- Each member of biotic community is called **species**.
- It is represented by **population**.

POPULATION

- **Population** is a group of individuals of the same species within a community occupying a particular space, has various characteristics which are unique possession of the group.
- **Population ecology** is the study of all aspects of a population and the various factors affecting it in its growth, density, size, multiplication, natality, mortality, competition etc.
- **Population density** is the number of individuals of a species per unit area or space at a given time.
- The inherent ability of a population to increase is termed **natality**. In broader sense **natality** is the production of new individuals of any organisms per unit of population per unit time through hatching, birth, germination or vegetative propagation.
- **Mortality** is the rate of death of individuals per unit time *i.e.*, number of individuals dying in a given period of time.
- **Population dispersal** is the movement of individuals or their reproductive products into and out of population area.
- Population dispersal **takes place in three forms** : **emigration** (one way outward movement), **immigration** (one way inward movement) and **migration** (periodic departure and return).
- The number of individuals added per unit population per unit time due to higher rate of births and immigrations over the rate of deaths and emigration is called **population growth**.
- Population have characteristic patterns of increase called **population growth forms** which are differentiated into two types **- J- shaped growth form** and **S-shaped growth form**.
- The **J-shaped** curve is a biopotential curve when environmental resistance is zero; it is **produced because larger populations increase more rapidly than smaller ones**.
- The **J-shaped curve** shows three stages: **lag phase**, **exponential phase** and **crash phase**.
- In **lag phase** there is a slow rise in population as the initial size of the population is very small.
- During **exponential phase**, the population size rises rapidly.
- A point is reached when population declines suddenly due to mass scale deaths. It is called **crash phase**.
- The J type of growth pattern can be **easily observed in algal blooms**, **some insects, annual plants and the lemmings of Tundra**.
- The **S-shaped curve (sigmoid curve)** is generated when a population approaches the environment's carrying capacity.
- The S-shaped curve shows three phases –
  - **Early phase** (**Lag phase**): Little or no growth takes place due to small size of population and lack of adaptation;
  - **Middle phase** (**Log phase or exponential phase**): There is geometrical increase in population size owing to abundance of food and other favourable conditions.
  - **Stationary phase** (**Zero growth or Plateau rate**): Birth and death rates are equal, the population stabilizes around the carrying capacity of the environment.

Table : Differences between J-shaped and S-shaped growth forms of population.

	J-shaped population growth form	S-shaped population growth form
1.	It occurs in erruptive type of population	It is found in stable type of population
2.	An equilibrium is never reach in population size	An equilibrium is reached when the size of population approaches the carrying capacity of the area.
3.	Exponential phase is very rapid	Exponential phase is comparatively less rapid
4.	A phase of deceleration never occurs	A phase of deceleration occurs before equilibrium is reached.
5.	Environmental resistance does not operate to slow down exponential phase	Environmental resistance begins to operate in slow down exponential phase.
6.	Population grows well beyond the carrying capacity of the area	Population seldom grows beyond the carrying capacity of the area.
7.	A crash phase occurs at the end of J-shaped growth.	A crash phase does not occur.

- S-shaped growth curve is **seen more frequently as** in **yeast cells grown in laboratory and human population**.
- The **carrying capacity** of habitat/locality/ environment is the **maximum number of individuals of a population that can be supported in a given time**.
- The number or percentage of the individuals in a population in different age groups is called **age distribution**.
- In ecology **three different type of age groups** have been recognized, these are – **pre-reproductive**, **reproductive** and **post-reproductive**.
- The **age distribution** in a population may be **graphically represented in the form of an age pyramid** showing the number of individuals in different age groups.
- Age pyramids are of **three types**. These are –
  - **Triangular** - The number of pre-reproductive individuals is very large.
  - **Bell-shaped** – The number of pre-reproductive and reproductive individuals is almost equal.
  - **Urn shaped** – The number of reproductive age group is higher than individuals of pre-reproductive age group.
- **Biotic potential** (r) of a population is the potential ability or inherent power of a population to increase in the number when the age disribution in the population is stable and all environmental conditions are optimum.
- The sum of environmental factors that limits the population size and keeps check on the realization of full biotic potential is called **environmental resistance**.
- Environmental resistance **rises with the size in population size**.

BIOTIC COMMUNITY

- Members of biotic community depends upon one another for food, reproduction, dispersal and productions, the phenomenon is called **species inter-dependence / interaction**.
- **Three types of interactions** occurs amongst different members of a biotic community - **neutral**, (no one is harmed neither benefitted), **positive** (beneficial) and **negative** (antagonistic).
- The relationship between two living individuals of different species in which one is benefitted while the other is neither harmed nor benefitted is **commensalism**.
- **Examples of commensalisms** are –
  - The colonial hydrozoan *Hydractina* attaches itself to whelk shells inhabited by hermit crab.
  - The woody stem of lianas is closely associated with supporting tree.
  - Orchids, bromeliads, *Usnea, Alectoria* (**epiphytes**) grow on another plant for shelter only but are nutritionally independent. The large plant is neither benefitted nor harmed by the growth of epiphytes.
  - Some plants grow on the surface of animals (**epizoans**). *Basicladia* grows on the back of fresh water turtle.

- The pilot fish (*Remora*) always accompanies shark.
- Sucker fish (*Echeneis*) attaches itself to under surface of shark.

- Some animals are called **ectocommensals** or **epizoite**. They are associated with other animal for anchorage and protection. Examples are, *Kerona* on *Hydra*, annelids on cray fish, barnacles which attach themselves to the backs of whales.
- Commensalism may also be **internal** such as *Escherichia coli* found in human colon.
- **Mutualism** is the interaction in which growth and survival of both populations is benefitted and neither can survive under natural conditions without the other.
- Mutualism is also termed as **symbiosis** and is generally **obligatory**.
- **Examples of mutualisms** are –
  - The sea anemone *Calliactis* attaches itself to a shell used by hermit crab.
  - Herbivorous ruminants contain a vast number of cellulose digesting bacteria and ciliates.
  - Formation of root nodule of leguminous plants by *Rhizobium*, a bacterium.
  - *Anabaena* (a nitrogen fixing blue green alga) is associated with water fern *Azolla.*
  - **Mycorrhiza** is a mutualistic interaction in which a fungus (e.g. *Boletus*) and a root (e.g. *Pinus*) are involved.
  - **Termites** harbour cellulose digesting **flagellates** in their alimentary canal.
  - Swollen thorn of acacias give shelter to ants.
  - The body of lichen is made up of a matrix formed by a fungus, within the cells of which an alga is embedded.
  - Some unicellular photosynthetic plants, known as **zoochlorellae**, live symbiotically in the outer tissue of certain sponges and coelenterates. *Chlorella vulgaris* lives within the gastrodermal cells of *Hydra.*
- **Proto-cooperation** is **non-obligatory mutually beneficial relationship in which both the populations benefit**, e.g., crocodile bird rids crocodile of leeches sticking inside its mouth.
- **Amensalism** is an **interaction between two living organisms in which one population is inhibited (not allowed to grow) and the other is not affected**. E.g., penicillin does not allow *Staphylococcus* bacterium to grow and *Trichoderma* inhabits the growth of fungus *Aspergillus* and *Convolvulus arvensis* inhibits the germination and growth of wheat.
- Amensalism is of **two types** –
  - **Antibiosis –** Some micro-organisms secrete certain chemical substances which kill or inhibit other micro-organisms. These substances are called antibiotics and phenomenon is called antibiosis.
  - **Allelopathy –** Some higher plants also secrete certain chemical substances which inhibit the growth of other plants. This phenomenon is called allelopathy, eg, roots of carrot grass or

Table : Interaction of species.

	Interaction	**Effect on Species I**	**Effect on Species II**	**Result**
I.	Neutral Interactions	Zero	Zero	Neither benefitted nor harmed
II.	Negative Interactions			
	1. Competition	(–)	(–)	Mutual inhibition
	2. Predation	(+)	(–)	One is benefitted, other is harmed.
	3. Parasitism	(+)	(–)	Parasite benefitted, host harmed
	4. Amensalim	(–)	Zero	One harmed, other uneffected
III.	Positive Interactions			
	5. Scavenging	(+)	Zero	Useful to scavenger, no effect on other
	6. Commensalism	(+)	Zero	Commensal benefitted, no effect on other
	7. Protocooperation	(+)	(+)	Both benefitted but association not obligatory
	8. Mutualism	(+)	(+)	Both benefitted, association obligatory.

The different types of parasites

Ectoparasite	:	live on the body of the host (e.g., sucking lice)
Endoparasite	:	live inside the host body (e.g., *Ascaris*, malarial parasite)
Partial/temporary parasite	:	spend only a part of their life cycle on the host (e.g., leech, female mosquito)
Permanent parasite	:	spend their entire life as parasite (e.g., *Ascaris*, lice)
Holoparasite	:	completely dependent on their host for all requirement (e.g., *Rafflesia*)
Hemiparasite / semiparasite	:	obtain a part of their nourishment from host and the rest is prepared by them own (e.g., *Viscum, Loranthus*)
Stem parasite	:	live on the host stem to obtain food (e.g., *Cuscuta, Loranthus*)
Root parasite	:	parasitic on host root (e.g., *Rafflesia*)
Pathogenic parasite	:	parasite causes diseases in the host (e.g., *Corynebacterium diptheriae* causes diptheria)
Non-pathogenic parasite	:	parasite do not harm the host (e.g., *Entamoeba coli*)
Hyperparasite	:	parasite that lives on another parasite (e.g., *Nosema notabilis* is the hyperparasite on myxosporidian)

congress grass (*Parthenium argentatum*) which is most troublesome terrestrial weed in India secrete trans – cinnamic acid which checks the growth of other plants.

- **Competition** is the relationship in which **each population adversely affects the other in the struggle** for resources in short supply.
- Competition is of **two types** as - **intraspecific** (between individuals of same species) and **interspecific** (between individuals of different species).
- **Predation** is an **interaction between members in which one population adversely affects the other by direct attack** (capture, kill and eat) but is nevertheless dependent on the other. The former is called **predators** and the latter is called **prey**.
- The carnivorous animals eat the other animals and the herbivorous animals eat the plants and so are predators.
- **Parasitism** is the relationsip between two living organisms in which **one organism resides on the body of the other living organism (host) and derives nourishment from its tissues**. It is always an one side relationship for the parasite which is always benefitted from the host.

Biotic community organization

- The number of species of plants, animals and other organisms that occur in a biotic community is called **species composition**.
- Species composition (type of species) differs from one ecosystem to another depending upon geography, topography and climate.
- Maximum species composition occurs in tropical rain forests and coral reef and minimum occurs in deserts and arctic regions.
- The total number of species and their relative abundance in a biotic community is **species diversity**.
- **Keystone species** is a species which has significantly large influence on the community structure and characteristics.
- Removal and decrease in the number of key stone species causes serious disruption in the community.
- **Critical link species** are species which play an imporant role in **supporting network species** by functioning **as pollinators, nutrient - circulators or absorbers**.
- **Ecotone** is defined as the place or area, where **two major communities meet & blend together**. It consists of species of both the communities.
- The tendency of ecotone to contain a greater number of species and a higher population density is called **edge effect**.
- The species which are found most abundantly in ecotone boundary are known as **edge species**.

Analysis of plant community

- **Communities are analysed for** –
  - Knowing the constituent species.
  - Relative abundance, cover and importance of species.
  - Study of variations within and between communities.
  - Recording of various types of communities.
  - Naming and classifying communities.
- Community characteristics are of **two types**– **analytical characters** and **synthetic characters**.

- **Analytical characters** are structural characteristics which can be directly observed or measured.
- Analytical characteristics, if measurable, are called **quantitative characters**, eg frequency, abundance, diversity, biomass, leaf size.
- Non–measurable analytical characters which can be observed are known as **qualitative characters**. eg, species composition stratification, periodicity, growth forms, dispersion, life forms.
- **Synthetic characters** are generalisations or abstractions which are derived from analytical characters, eg, constancy, fidelity, pattern, dominance, physiognomy.

BIOTIC OR ECOLOGICAL SUCCESSION

- **Biotic** or **ecological succession** (Hult, 1885) is the natural development of a series of biotic communities at the same site, one after the other till a climaxot community develops which does not evolve further because it is in perfect harmony with the environment of the area.
- A biotic community is influenced by **biotic factors**, **physico-chemical factors** and **geographical factors**.
- The **first biotic community** which develops in a base area is called **pioneer community**.
- **Climax community** is the stable, self perpetuating and final biotic community that **develops at the end of biotic succession** and is in perfect harmony with the physical environment.
- Climax community is also termed as **climatic climax community**.
- Climax community has **maximum diversity** and **niche specialization**.
- The various biotic communities that develop during biotic succession or the intermediate communities between the pioneer and climax communities are termed as **seral** or **transitional communties**.
- The entire sequence of development stages of biotic succession from pioneer to a climax community is known as **sere**.

> **Pioneer community** (the first biotic community on base area) → **seral community** (the various biotic community that develop during successsion → **climax community** (the stable, self perpetuating and final biotic community)

- **Changes that occur during biotic succession** are –
  - Small short lived plants to large long-lived plants.
  - Unstable biotic community to stable biotic community.
  - Little diversity to high degree of diversity.
  - Greater niche specialization.
  - Increase in biomass.
  - Increase in soil differentiation.
  - Increase in human content of soil.
  - Aquatic or dry conditions to mesic conditions.
  - Simple food chains to complex food webs.
- Ecological succession is of **two types** – **primary** and **secondary succession**.
- **Primary succession** is a biotic succession which occurs on a **previously bare or unoccupied area**, e.g., new exposed rock area, sand dunes, igneous rocks, deltas etc.
- **Secondary succession** is a biotic succession that occurs in an area from **which a community has been removed and where nutrients and conditions for existence are present**, e.g., cut over forest, abandoned crop land, ploughed field.
- Successions are variously designated as - **xerosere/lithosere** (succession on bare rock), **hydrosere** (succession in water), **psammosere** (succession on sand).
- Structure of hydrosere is depicted in the following flowchart :

Climax forest community (mesophytic)
e.g., *Temperate mixed, Tropical rain, Tropical deciduous.*
↑
Woodland stage
e.g., *Salix, Poplus, Almus, Cornus.*
↑
Sedge meadow stage
e.g., *Juncus, Cyperus, Eleocharis, Carex.*
↑
Reed swamp stage
e.g., *Sagittaria, Phragmites, Typha, Scirpus.*
↑
Floating stage
e.g., *Nymphaea, Trapa, Azolla, Lemna, Wolffia, Pistia.*
↑
Submerged stage
e.g., *Elodea, Hydrilla, Vallisneria, Utricularia, Potamogeton.*
↑
Pioneer stage
e.g., *Diatoms, Bacteria, Cyanobacteria, Green algae.*

- The **structure of lithosere or xerosere** is shown by the following flow chart.

Climax forest community (mesophytic)

↑

Shrub stage
e.g., *Rhus, Phytocarpus*

↑

Herbaceous stage
e.g., *Eleusine, Aristida.*

↑

Moss stage
e.g., *Polytrichum, Torula, Grimmia.*

↑

Foliose lichen stage
e.g., *Parmellia, Dermatocarpon*

↑

Crustose lichen stage (pioneer stage)
e.g., *Rhizocarpus, Rinodina, Lacanora.*

Importance of biotic succession

- Sequence of biotic succession is usually fixed. Ecologists can immediately recognize the seral stage of a biotic community found in an area.
- It tells us how a biotic seral stage like grasses and herbs of a pasture can be maintained by net allowing the biotic succession to proceed further through interference like grazing and fire.
- Information gained through biotic succession is used in having controlled growth of one or more species by preventing their superiors to invade the area, eg., maintainance of teak forest.
- Dams are protected by preventing situation and biotic succession to occur.
- It gives information about the techniques to be used during reforestation and afforestation.

Some other types of succession

- **Autogenic succession** - After the succession has begun, in most of the cases, it is the community itself which, as a result of its reactions with the environment, modifies its own environment and, thus causing its own replacement by new communities. This course of succession is known as autogenic succession.
- **Allogenic succession** - In some cases replacement of one community by another is largely due to forces other than the effects of communities on the environment. This is called allogenic succession and it may occur in a highly disturbed or eroded area or in ponds where nutrients and pollutants enter from outside and modify the environment and in turn the communities.
- **Autotrophic succession** - It is characterized by early and continued dominance of autotrophic organisms like green plants. It begins in a predominantly inorganic environment and the energy flow is maintained indefinitely. There is a gradual increase in the organic matter content supported by energy flow.
- **Heterotrophic succession** - It is characterized by early dominance of heterotrophs, such as bacteria, actinomycetes, fungi and animals. It begins in a predominantly organic environment and there is a progressive decline in the energy content.
- **Induced succession** - Activities such as overgrazing, frequent scraping, shifting cultivation or industrial pollution may cause deterioration of an ecosystem. Agricultural practices are retrogression of a stable state to a young state by man's deliberate action.
- **Retrogressive succession** - It means a return to simpler and less dense or even impoverished form of community from an advanced or climax community. In most cases, the causes are allogenic, *i.e.,* forces from outside the ecosystem become severe and demanding. *For example*, most of our natural forest stands are degrading into shrubs, savanna or impoverished desert-like stands by the severely grazing animals brought from surrounding villages. Excessive removal of wood, leaf and twig litter also leads to retrogressive succession.
- **Cyclic succession** - It is of local occurrence within a large community. Here cyclic refers to repeated occurrence of certain stages of succession whenever there is an open condition created within a large community.

End of the Chapter

Chapter 59

Ecosystem

- Any unit which includes all the organisms interacting with the physical environment so that a flow of energy leads to clearly defined trophic structure, biotic diversity and material cycle within the system is known as an **ecosystem**.
- The term **ecosystem** or **biocenosis** was coined by **Sir Arthur Tansley** in 1935.
- Ecosystems can be recognized as **self regulating and self sustaining units of landscape** that may be **terrestrial** or **aquatic**.
- **Forests, grasslands, and deserts** are **examples of terrestrial ecosystems**. The **aquatic ecosystems** can be either **freshwater** (ponds, lakes, streams), or **salt-water** (marine esturaries) types.
- Ecosystem may be **natural** (forest, sea), if developed under natural condition or **artificial** (garden, agriculture) if created by man.

Components of ecosystem

- An ecosystem has **two basic components** : **abiotic** (non-living) and **biotic** (living organisms).
- **Abiotic components** include **inorganic substances or minerals** (standing state or standing quality), **organic substances** and **different climatic conditions** like temperature, pH, light, etc.
- **Biotic components** include **producers**, **consumers and decomposers**.
- **Producers** are autotropic, generally chlorophyll-bearing organisms, which **produce their own food** (high energy organic compounds) by fixing light energy in the presence of simple inorganic abiotic substances, eg. green plants, yellow green algae, brown red algae, algal protist.
- **Consumer or phagotrophs** are heterotrophic (the food is produced by other living organisms), organisms, which generally ingest their food.
- Consumers are of **three types - primary consumers, secondary consumer** and **tertiary consumers** according to the nature of their feeding habit.
- **Primary consumers** are **herbivores** that directly feed on producers *i.e.*, green plant, e.g., rabbit, deer, sheep etc.
- **Secondary consumers or primary carnivores** are the **carnivorous animals** that feed on the herbivores, e.g., fox, snake, owl, peacock.
- **Tertiary consumer or secondary carnivores** are the **animals that feed on the secondary consumers**, e.g., lion, tiger etc.
- **Decomposers or saprotrophs** are other heterotrophic organisms, consisting mostly of **bacteria and fungi which live on dead organic matter or detritus**. (They decompose the organic remains by secreting extracellular digestive enzymes).

Structure and function of ecosystem

- **Important structural features of any ecosystem** are – species composition, trophic structures, startification, standing state and stunding crops.
- The structure of ecosystem can also be depicted through **food relationships of producers and consumers**.
- **Trophic structure** of ecosystem is a **type of producer - consumer arrangement, in which each food level** is called **trophic level**.
- The **producers occupy the first trophic level**, **herbivores the second**, and the **carnivores constitute** the **third trophic level**.
- Stratification is the occurrence or vertical zonation in the ecosystem and indicates the presence of favourable environmental conditions.
- Stratification **helps in accommodation of large number and types of plants in the same area**. It **also provides a number of microhabitats and**

niches for various types of animals

- Stratification is **absent or poor** where environmental conditions are unfavourable. *For example*, desert ecosystems have very few trees and shrubs.
- The **amounts of nutrients**, *for example*, nitrogen, phosphorus and calcium **present in the soil at any given time**, is known as the **standing state**.
- The standing states of nutrients differ from one ecosystem to another, or with seasons even in the same ecosystem.
- **Standing crop** is the **amount of living biomass present in an ecosytem**. It indicates the productivity and luxuriance of growth.
- The **important functional aspects of ecosystems** are **productivity**, **decomposition**, **energy flow**, **nutrient cycling** (*described later*), and **stability**.

Productivity

- The productivity of ecosystem **refers to the rate of biomass production**, *i.e.* the amount of organic matter accumulated per unit area per unit time.
- Productivity is of **two kinds - primary** and **secondary**.
- **Primary productivity** refers to the rate at which sunlight is captured by producers for the synthesis of energy-rich organic compounds through photosynthesis.
- The **rate of total production of organic material** is known as **gross primary productivity**.
- The balance energy or biomass remaining after meeting the cost of respiration of producers is called **net primary productivity**.
- Net productivity = Gross productivity – Respiration and other losses.
- At the trophic level of consumers the rate at which food energy is assimilated is called **secondary productivity**.

Decomposition

- **Decomposition** involves breakdown of complex organic matter by decomposers to inorganic raw materials like carbon dioxide, water and various nutrients.
- The **process of decomposition occurs in three steps – fragmentation of detritus**, **leaching action** and **catabolism**.
- **Factors affecting decomposition** are – chemical nature of detritus, soil pH, temperature, moisture and aeration.
- Decomposition process **gives rise to two products** – **humus** and **inorganic nutrients** (= minerals).

Energy flow

- The energy flow and storage in an ecosystem follows the basic laws of thermodynamics.
- In an ecosystem, energy is transferred in the form of food, and this leads to degradation and loss of a major fraction of food energy as heat during the metabolic activities and a very small fraction becomes stored as biomass.
- There is transfer of 10% of energy from one trophic level to another.

Food chain and food web

- All trophic levels in an ecosystem are connected by transfer of food or energy. The transfer of food and its contained energy from one trophic level (e.g. producers) to the next trophic level (e.g. consumers) is called **food chain**.
- **Two types of food chains** can be distinguished in all ecosystems. These are **grazing (predator) food chain** and **detritus food chain**.
- **Grazing food chain** extends from producers through herbivores to carnivores, as
  Grass → Grasshopper → Lizard → Hawk.
- **Detritus food chain** begins with dead organic matter and passes through detritus-feeding organisms in soil to organisms feeding on detritus-feeders.
- The detritus food chain in lake is as -
  Freshly fallen litter (organic matter) → Decomposers or Saprobes, → Detrivores → Game fish (top consumers).
- Different food chains are often interconnected, e.g. a specific herbivore of one food chain may serve as food of carnivores of several other food chains. Such interconnected matrix of food chains is called **food web**.

Example of different food chains

1. Food chain in aquatic ecosystem

Producers
↓
Primary consumers or herbivores (zooplanktons as dinoflagellates and copepods)
↓
Secondary consumers or primary carnivore (aquatic insects, crustaceans and aquatic animals)
↓
Tertiary consumer or secondary carnivore (small fish)
↓
Tertiary carnivore (large fish squids)

2. Food chain in terrestrial ecosystem

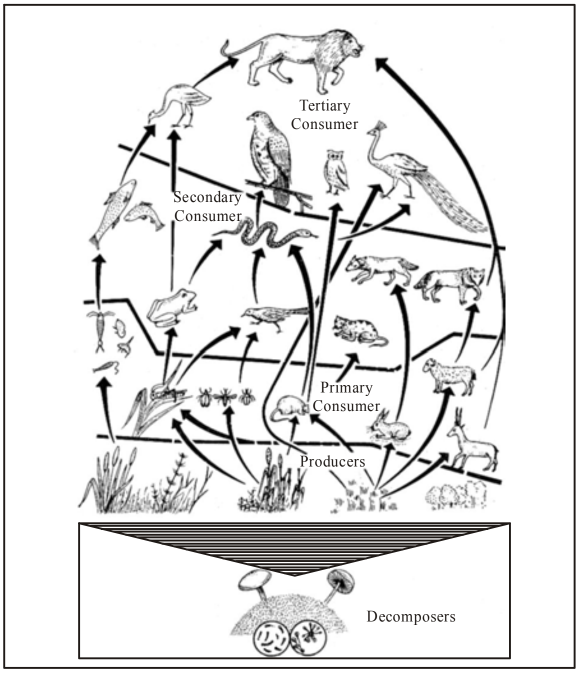
A. In cropland
Producers crop plants
↓
Grasshoppers and rodents
↓
Snakes and lizards
↓
Hawk

B. Grass land
Producers (Grasses)
↓
Grazers (deer, cattle)
↓
Lion

C. Forests
Trees
↓
Aphids
↓
Spider
↓
Small birds
↓
Hawk

3. Detritus food chain
Detritus
↓
Earth worm
↙ ↘
Frog → Snake → Peacock
Sparrow → Falcon

Food web



Ecological pyramids

- The **graphical representation of trophic structure of ecosystem** constitutes **ecological pyramids or food pyramids** where producers occupy base of the pyramid and top consumers occupy apex of the pyramid.
- The **concept of ecological pyramids was developed** by **Elton** (1927).
- The ecological pyramids are of **three types** – **pyramids of number**, **pyramids of biomass**, and **pyramid of energy**.
- **Pyramid of numbers** is graphical representation of numerical strength of various populations in different trophic levels per unit area of an ecosystem with producers forming base, intermediate levels forming intermediate tiers and apex formed by top carnivores.
- Number of individuals is generally maximum at the producer level in pyramid of number.
- **Pyramid of biomass** is graphic representation of amount of biomass per unit area sequence-wise in rising trophic levels with producers at the base and top carnivores at the apex.
- Biomass is maximum in producers. It is the amount of living matter measured in terms of dry weights.
- **Pyramid of energy** is graphic representation of energy per unit area sequence-wise in various rising trophic levels with producers at the base and top carnivores at the apex.
- Maximum energy is found at producer level.
- **Pyramid of number and biomass may be upright or inverted**, depending upon type of ecosystem but **pyramid of energy is always upright because** energy of the production is always more than primary consumers and so on, *i.e.*, energy goes on decreasing.
- All the ecosystem are **interconnected by flow of energy** and **transfer of materials** with the neighbouring ecosystem or distant ecosystem.
- Only **1 - 4% of the total solar energy is utilized by plants** for photosynthesis and **rest of the solar energy is reflected back**, absorbed by ground, water and atmosphere.
- Sugar cane is the **most efficient user of the solar energy**, *i.e.*, 10 - 12%.
- **Energy flow is unidirectional**, *i.e.*, from producers to secondary consumers and not back.

- **Energy goes on decreasing with each and every trophic level**, *i.e.*, energy of the producers > primary consumers > secondary consumers > tertiary consumers.
- **Lindemann gave the law of 10% for energy flow** (10% energy transfer law), *i.e.*, only 10% of total energy received by one trophic level is transferred to next trophic level.

Ecological efficiencies

- The ratio between the energy assimilated over the energy available between two trophic levels is called **ecological efficiency**.
- Ecological efficiencies may be expressed as **photosynthetic efficiency**, **net production efficiency**, **assimilation efficiency** and **trophic level efficiency**.
- **Photosynthetic efficiency** is the percentage of incident solar radiations trapped by producers to perform photosynthesis and produce gross primary productivity.
  Photosynthetic efficiency =
  $$\frac{\text{Energy in gross primary productivity}}{\text{Energy in incident solar radiations}} \times 100$$
- Photosynthetic efficiency is **1 - 5%**. It can **also be expressed in relation to PAR when it is 2 - 10%**.
- **Net production efficiency** is percentage of net primary productivity in relation to gross primary productivity. Tree species with large amount of non-photosynthetic biomass have lesser net production efficiency than small sized producers.
  Net production efficiency =
  $$\frac{\text{Net primary productivity}}{\text{Gross primary productivity}} \times 100$$
- **Assimilation efficiency** is the percentage of food energy assimilated for body building to total food ingested.
  Assimilation efficiency =
  $$\frac{\text{Food energy assmilated}}{\text{Food energy ingested}} \times 100$$
- **Ecological efficiency/trophic level efficiency** is the percentage of energy converted into biomass by a higher trophic level over the energy of food resources available at the lower trophic level.
  Ecological efficiency =
  $$\frac{\text{Energy converted into biomass at trophic level}}{\text{Energy present in biomass at lower trophic level}} \times 100$$

Biogeochemical cycles or Nutrient cycles or Material cycles

- **Nutrient cycles** involves storage and transfer of nutrients through various components of the ecosystem so that the nutrients are repeatedly used.
- The term **biochemical cycling** is **used for exchanges/ circulation of biogenetic nutrients between living and nonliving components of biosphere**.
- **Biogenetic nutrients/biogeochemicals** are essential elements required by organisms for their body building and metabolism which are provided by earth and return to earth after their death and decay.
- There are **two types of nutrient cycles** – **gaseous** and **sedimentary**.
- The **gaseous type** of nutrient cycle is generally located in the atmosphere or the hydrosphere, eg, carbon, oxygen, water, nitrogen, hydrogen.
- In the **sedimentary type**, the reservoir exists in the earth's crust, eg, phosphorus, calcium, magnesium.
- The cyclic representation of carbon assimilation by green plants (photosynthesis) which then passes into bodies of animals (plants are eaten) and finally during respiration of plants and animals and decompositions by microbes, the carbon dioxide is returned back to the atmosphere is **carbon cycle**.
- **Oxygen cycle** is the cycling of oxygen between the biotic and abiotic components of the environment.
- In the process of respiration oxygen is taken in by living organisms and released into the atmosphere, combined with carbon, in the form of carbon dioxide.
- Carbon dioxide enters the carbon cycle or is taken up by plants for photosynthesis and during photosynthesis oxygen is evolved by the chemical splitting of water and returned to the atmosphere.
- In the upper atmosphere, ozone is formed from oxygen and dissociates to release oxygen.
- The **cycling of phosphorus** between biotic and abiotic components of the environments represents **phosphorus cycle**.
- Inorganic phosphates (PO_4^{3-}, HPO_4^{2-}, or H_2PO_4) are absorbed by plants from the soil and bodies of water and eventually pass into animals through food chains.
- Within living organisms **phosphates are built up into nucleic acids and other organic molecules**. When plants and animals die, phosphates are released and returned to the abiotic environment through the action of bacteria.

- Phosphates in aquatic environments eventually become incorporated into and form part of rocks, through a gradual process of erosion, these phosphates are returned to the soil, seas, rivers, and lake.
- Phosphorus-containing rocks are mined for the manufacture of fertilizers, which provide an additional supply of inorganic phosphate to the abiotic environment.
- Cycling of sulphur between biotic and abiotic components is **sulphur cycle**.
- Sulphate (SO_4^{2-}), derived from the weathering and oxidation of rocks, is taken up by plants and incorporated into sulphur-containing proteins, passed along food chains to animals. Decomposition of dead organic matter and faeces by anaerobic sulphate-reducing bacteria returns sulphur to the abiotic environment in the form of hydrogen sulphide (H_2S) which can be converted back to sulphate or to elemental sulphur by the action of different groups of photosynthetic and sulphide-oxidizing bacteria.
- Though nitrogen is essential to all forms of life, the huge amount present in the atmosphere is not directly available to most organisms.
- It can, however, be assimilated by some specialized bacteria and is thus made available to other organisms indirectly.
- **Nitrogen fixation** is a chemical process in which atmospheric nitrogen is assimilated into organic compounds in living organisms and hence into the nitrogen cycle.
- **Micro-organisms involved in nitrogen cycle** are– *Rhizobium* (symbiotic), *Azotobacter, Clostridium* (non - symbiotic bacteria), *Nitrosomonas, Nitrococcus* (nitrifying bacteria), *Bacillus*, *Micrococcus* (denitrifying bacteria).

Raunkiaer's classification of Plants

Raunkiaer (1934) has distinguished plants into five forms on the basis of size, shape, branching, crown, life span and perennation. These are –
(i) **Therophytes.** Annual plants which perennate in the form of seeds.
(ii) **Cryptophytes.** Perennial plants with underground storage parts : (a) **Geophytes.** Subterranean perennating structures (root, root tuber, bulb, stem tuber, rhizome, corm), (b) **Helophytes** (Marshy plants). Perennating structure are embedded in mud. (c) **Hydrophytes.** Aquatic plants.
(iii) **Hemicryptophytes.** Perennating structures occur at ground level. Aerial shoots die on the onset of winter, e.g., rosette plants.
(iv) **Chemaephytes.** Small plants of cold areas where perennating buds or shoot apices lie at or above the ground level.
(v) **Phanerophytes.** Perennial herbs, shrubs and trees, epiphytes, succulents, lianas, etc. where perennating buds occur at 10 cm or more height above ground level.

Biomes

- **Biomes** are major ecosystems delimited by particular geographical area or climate.
- Biomes are often **classified in seven categories** : tropical rain forests, savannahs, deserts, temperate grassland, temperate deciduous forests, taiga and tundra.
- **The major forest biomes in India are** – tropical rain forest biome, tropical deciduous forest biome, temperate broadleaf forest biome and temperate needle leaf (coniferous) forest biome (taiga).

Table : Major biomes of the world

	Biome type	Annual temp/weather	Annual rainfall	Important features
1.	Tropical rain forest	23 - 27°C	200 - 350 cm	Multi storied vegetation (5 distinct layer of vegetation). Shows maximum biodiversity -lianas, epiphytes, trees show root buttress. Trees include ebony, mahagony, cinnamon, fig, rubber etc. Palms, plantains, bamboo occur here and there. Fauna consists of deer, goat, antelope, elephant, snakes, lizards, parakeet etc.

contd....

2.	Savannahs	Warm climate	90 - 150 cm	Tropical open grass land with shrubs and trees. This biome supports buffalo, tiger, zebra, mites, grasshopper, ants, beetles.
3.	Deserts	Hot (Thar, Sahara) cold (Gobi)	25 cm	Succulent plants, deep rooted trees and shrubs, show allelopathy (secrete some chemicals substances that inhibit the growth of other plants), show poor biodiversity.
4.	Temperate grassland	Hot summer, cold winter	25 - 75 cm	Mostly leguminous herbs, scattered bushes, occasional trees, extensive root system. eg. Prairies of USA, pampus of South America, Steppes of Eurasia, tussocks of New Zealand, veldts of South Africa, Downs of Australia. Fauna - Deer, elk, bison, wolf, sheep, rabbit, mice, burrowing owl etc.
5.	Temperate deciduous (broadleaf) forest	6 – 20ºC / Warm summer, cold winters	100 - 250 cm	Dominant trees are oak, birch, maple, beech, elm, magnolia, poplar, chestnut etc. shrubs, herbs, ferns, mosses, lichens, grasses, vines etc. are seen. Fauna consists of deer, fox, rabbit, hare, snakes, lizards, salamanders, owls, sparrows etc.
6.	Taiga (northern coniferous forest)	6 – 15°C / Pleasant summer, chilled winter	50 - 170 cm	Gymnosperm with cone shaped canopy, have needle shaped leaves. Pine, Deodar, cypress, Spurce etc. Larch, Juniper, Fir, Hemlock and Yew also occur at places. Lichens, mosses, fern, herbs are abundant. Fauna includes wolf, deer, rabbit, hare, elk, squirrels, porcupine etc.
7.	Tundra	Long cold winters, short summers	Less than 25 cm	Encircles the top of the world. Scattered patches of grasses, sedges, lichens, low diversity, low productivity. Amphibians and reptiles are absent, common animals are lemming, snow grouse, snow owl, arctic fox, polar bear, reindeer, arctic hare.

End of the Chapter

Chapter 60

Natural Resources and Their Conservation

- **Natural resources**, also called **earth resources**, are those living and non-living resources of the earth (including atmosphere, hydrosphere and lithosphere) which have the potentiality to be used by human being to fullfill their requirements of food, shelter, and clothing etc.
- Of the different types of inexhaustible, renewable exhaustible and non - renewable exhaustible natural resources, the **most important resources** are - e**nergy**, **water** (fresh water and marine), **land**, **soil**, **mineral** and **organisms**.

Natural resources

classified on the basis of

Chemical nature

- **Inorganic** Includes water, air, minerals, fuels, metalliferous stones etc.
- **Organic** Includes plants animals, microbes, fossil fuels
- **Mixture of organic and inorganic** Includes soil

Abundance and availability

Inexhaustible
* Occur in unlimited quantities
* Not likely, to get exhausted by man's use
* Eg., air, clay, sand, solar energy, wind power etc.

Exhaustible
* Occur in limited quantities
* If used indiscriminately are likely to get exhausted
* Eg., mammals, fossils fuels, forests etc.

Two types

Renewable
* Replenished, recycled or reproduced
* Must not be used beyond its renewability
* Eg., forest (timber, rangeland), wild life (food), agricultural systems (food & fibre), underground water, soil fertility (inorganic nutrients).

Non-renewable
* Likely to get exhausted with use because of its lack of recycling
* Eg., fossil fuel (coal, petroleum, natural gas), minerals, biological species.

Presence or absence in different countries

- **National** Minerals, land
- **Multinational** Rivers, lakes, migratory animals & birds
- **International** Sunlight, air.

Flow chart : Classification of natural resources

ENERGY RESOURCES

- All the natural resources that provide us with energy in one form or the other are included in the energy resources.
- **Animal power** is renewable conventional energy resource got from draught animals.
- Draught animals [= draft animal used for its physical (*i.e* muscular) power] are **used in transport,**

drawing water and agriculture, e.g., bullocks, buffaloes, camels, horses.

- **Fuel wood** is a renewable conventional resource used for cooking and heating in villages, remote areas, urban poor, wayside dhabas.
- In India, annual consumption of firewood is around 300 million m^3 with natural availability being only 60 million m^3. The rest is got from excessive tree felling leading to deforestation.
- **Organic wastes** constitute a renewable resource that mostly **include animal & human waste**.
- **Animals wastes** include cattle dung, droppings of sheep and goat, poultry litter, slaughter house wastes fishery wastes.
- **Humans wastes** include night soil, urine, food wastes, domestic residue.
- Organic wastes can be **more profitably be used in generation of biogas**.

Table : Different categories of energy resources

Renewable	– Which are regenerated by natural process, eg., biomass energy, solar energy, hydropower, wind power, tidal, geothermal.
Non-renewable	– Which do not get regenerated or recycled eg., fossil & nuclear fuel.
Conventional energy	– In common use (animal power, fuel power, fossil fuel and hydroelectric energy).
Non-conventional	– New or not in common use (solar energy, nuclear energy, wind, geothermal, tidal).
Commercial energy	– Energy which can be transported and traded, eg., electricity, fuel, solar energy.
Non-commercial	– Available locally, not transported and traded
Biomass energy	– Indirect solar energy *i.e.*, trapped in the form of organic matter.
Non-biomass	– Direct solar energy, wind energy, hydropower, geothermal energy.

- **Biogas** contains **50 - 70% methane**, **30 - 40% CO_2, traces of H_2, H_2S and N_2**.
- **Agroindustries** include bagasse, bran, oil cakes, press mud, saw dust.
- **Forest residue** include fallen twigs, leaves, bark, stumps and roots.
- **Crop residues** include crop stubble, straw, weeds, cotton and jute, sticks, husk, corn cobs, fodder waste. Dried dung cakes are **used for heating and cooking**.
- **Energy plantation** is growing of firewood trees on nonforest and nonagricultural lands.
- **Energy cropping** is growing crops which yield fuel. Alcohol can be obtained from potato, sugarcane, maize and tapioca. Yield of alcohol is 50% of sugar/starch concentration.
- **Gasoline** with 10 - 20% ethanol can be **used in conventional internal combustion engines** without much alternation and the mixture is called **gasohol.**
- **Fossils fuels** are non-renewable conventional energy resources found inside earth's crust where they have been **formed through heat and compression on forests and other organic matter buried underneath** due to earthquakes, landslides, lava, etc.
- Fossil fuels can be **solid** (coal, lignite), **liquid** (petroleum) or **gaseous** (natural gas). The oldest coal deposit are anthracite (80% carbon, 300 million years back). Others are lignite (50 - 65% carbon) and bitumen (less than 40% carbon).
- Fossil fuels provide for 70% of total energy needs of the world and 87.4% of all commercial energy.
- **Hydroelectric power** is cheap, conventional and almost inexhaustible source of energy where falling water (now flowing also) runs turbines to generate power.
- This power requires dam/reservoir building which destroys forests, wildlife and displaces several villages.
- There is increased salt content of water, higher incidence of water-borne disease besides developing water pressure which may cause earthquakes.
- **Nuclear energy** is non-conventional, non-renewable resource. Nuclear fission (now fusion also) of selected radio-active materials (like uranium-235) yields large amount of heat energy.
- The **common fuel used in atomic reactors** is

uranium. Fast breeder reactor can use thorium.

- Some **nuclear reactors of India** are **at Kota**, **Tarapur**, **Narora** & **Kalpakkam**.
- **Solar energy** is inexhaustible non-conventional resource.
- Its use is yet to pick up because of requirement of back up system to store and generate electricity during night and during cloudy days.
- There are **three methods of harnessing solar energy - direct heating** (e.g., solar cookers), **thermal power plants** (steam generation of heating salt water), and **photovoltaic conversion**.
- **Photovoltaic cells** are very **small semiconductors** of silicon, gallium, arsinide or cadmium telluride which have electron surplus and electron deficient regions.
- **Wind energy** is an inexhaustible resource which was **used in very old times in grinding grains, lifting water and propelling ships**.
- The instrument that converts wind energy into electric energy is called **wind mill**.
- **Geothermal energy** is a non-conventional source of energy where heat present in hot interior rocks or hot water coming out of them is used for generating electricity.
- **Tidal energy** is a non-conventional inexhaustible source of energy. Tides moving in narrow areas are allowed to run dual flow turbines.
- **Low heat turbines** connected to a sloping ramp are **used to convert wave energy into electricity**.

WATER RESOURCES

- Water is the **main constituent of hydrosphere**. It is **a renewable resource**.
- 3/4 surface of Earth is covered by ocean which contains 97.5% Earth's water in strongly saline condition. The rest contains the following – fresh water (2.5%); frozen water (1.97%), ground water (0.5% of fresh water); rivers; & lakes (0.02%); soil (0.01%); and water vapour (0.001%).
- Water resources are broadly categorised as **fresh water** and **marine or ocean water**.

Fresh water resources

- **Fresh water** is a major **renewable inorganic resource** which is an essential component of all living beings, a habitat for several organisms, determinant of vegetation and climate, floods and droughts, required for drinking, bathing, washing, cooling, construction work, disposal of sewage and industrial effluents, irrigation, etc.
- An average modern human being requires 350 - 700 litres of fresh water per day.
- Fresh water occurs in **ponds**, **lakes**, **streams**, **river** & **underground pools**.
- At most of the other places more water is withdrawn from surface and subsurface reservoirs than their recharging. As a result many wetlands have dried up and ground water is becoming scanty at many places.
- Excessive irrigation in arid/semiarid areas **increases soil salinity**.
- Over withdrawal of ground water in coastal regions results in movement of saline water from sea in underground aquifers, resulting in spoilage of water quality.
- Deforestation, especially in the hilly areas has reduced water absorption, storage in catchment areas, greater incidence of soil erosion and floods during rainy season.
- Water is seldom available in the pure form because it is a general solvent of atmospheric gases and several solid substances which, therefore, get dissolved into it.
- Rapid evaporation of water, as in semi-arid areas, brings salts to the surface and, therefore, gives rise to soil salinity.
- **Hardness of water** gives rise to soil salinity.
- Hardness of water is **due to the presence of salts**. Salts present in water shorten the life of cooking utensils, water heaters, boilers, steam turbines, etc. A salt content of upto 3.5 gm/litre of water is safe for irrigation. Beyond this concentration the water becomes harmful to crops.

Conservation & management of fresh water resources

- **A number of measures are required for optimum utilisation** and **conservation of fresh water resources**.
- Assured irrigation is available to only 40% area as compared to over 90% in advanced countries.
- There is a lot of wastage of agriculture water because only 50% of water supplied to soil is useful, the rest goes waste. Bricklining of irrigation channels and sprinkling technique of irrigation are recommended to save water.

- Industry wastage should be reduced and waste water can be recycled.
- Domestic water supply wastage should be reduced. Waste water should be treated and used in irrigation and other purposes.
- Rainwater harvesting, surface storage and recharging of ground water should be carried out.
- **Afforestation helps in preventing soil erosion**, **reduces surface run off**, **retains water** and **protects water sheds** for continued water supply.
- Dams and reservoirs can be constructed to control floods and ensure round the year supply of water besides generation of electricity.
- Through desalination, sea water and saline underground water can be converted into fresh useful water.
- Canals are made to carry water in arid and semiarid area.
- Desiltation, dredging of water bodies should be undertaken regularly to prevent decrease in capacity for storage.

Marine or Ocean resources

- **Oceans** occupy 71% of earth, constitute 97.5% of total water, manufacture 85% of total biomass, function as heat bank, source of common salt, cloud formation, biogeochemical cycles, tidal power, offshore petroleum fields, a source of navigation and dumping ground with rivers.
- Oceans contain **algal resources**, **animal resources** and **minerals**.
- Oceans contain a large variety of algae from minute microscopic unicells to large kelps reaching a length of 100 - 150 m (e.g., *Macrocystis*). All types of algae occur in sea, *viz*. green, brown, red, blue-green, etc.
- A number of **marine algae** have been **used as human food**.
- Animals are even now given fresh or processed sea weeds, e.g., green algae - *Ulva* and *Caulerpa*, brown algae - *Laminaria*, *Alaria*, *Macrocystis* and *Sargassum*, red algae like *Porphyra* or Laver, *Rhodymenia* or sheep weed, *Chondrus* or Irish moss.
- Marine algae are also **used in preparation of manure alongwith fish shells and animal droppings**.
- **Important gels are obtained from marine algae**, eg., carageenin (red alga *Chondrus*), funori (red alga *Gloiopeltis*), algin (brown algae *Fucus, Laminaria*, *Sargassum*), agar (red algae *Gelidium*, *Gracilaria*).
- Marine fish are a **good source of food** besides providing fish glue, fish metal, fish protein and vitamins. Depending upon the place of catching there are two categories– **demersal** (at or near bottom) and **pelagic** (at or near surface).
- The **edible molluscs** are mussels, clams and oysters. Pearl oyster, a source of pearls, is also reared to obtain pearls.
- The **edible crustaceans** are crabs, lobsters and prawns.
- **Economically important mammals** are dolphins, porpoises and whales which provide meat, skin, ivory, oils, frozen glands, etc.
- Food fish is the term used for all types of edible aquatic animals because the major proportion is that of fish. India catches 3.9 million tonnes of food fish from sea out of the total of 73 million tonnes world wide.
- **Common salts is extracted from sea water** by concentration in salt pans in coastal areas. In old days some minerals were obtained from sea weeds, eg., iodine (*Fucus, Laminaria*), bromine (*Rhodomela*). Oceans also contain mineral concentrates, e.g., manganese nodules, phosphate nodules.

LAND RESOURCES

- **Land** is the solid exposed crust of earth that supports plants, animals and human beings and is the **source of minerals**.
- Land is **largely covered with natural forests, grasslands**, **wetlands** and **man made urban & rural settlements along with agriculture**.

Forests

- **Forests** are the vast natural resources **dominated by trees** and **provide** for **mankind with fuel, fodder, timber, paper, raw material, water yield** and **animal produc**t.
- **Wood land** is closer to human habitat with open canopy (overhanging shelters) and managed by human beings.
- **Forestry** deals with establishment, protection, management and exploitation of forests.
- **Silviculture** is the branch of forestry that deals with the establishment and cultivation of forest plants like teak, sal, kel, sheesham etc.

- **3 major functions** can be **associated with forests are** –
  - **Productive functions** : Provide a number of articles of economic use, e.g., wood, fruit, alkaloids, essential oil, latex etc.
  - **Protective functions** : Provide protection from excessive cold, heat, drought, noise, conserve water and soil.
  - **Regulative function** : Regulate biogeochemical cycles, checks flood and drought etc.
- **Deforestation** is the falling down or removal of forest trees.
- The **major causes of deforestation** are – jhuming (shifting cultivation); construction of hydroelectric projects; forest fires; construction of roads and railways and canals; over grazing of cattles in forest areas; requirement of wood.
- **Impact of deforestation are** – shrinking fuel food; decrease in availability of timber; soil erosion; flash floods during rainy season; siltation; causes drought; loss of biodiversity and germplasm; amount of rainfall decreases; increases atmospheric CO_2 content and causes global warming; uprooting and loss of livelihood of tribals.
- **Reforestation or afforestation** is planting of more trees.
- **Conservation of forests aims** at management of forests in such a way so as to maintain them at optimum form and derive optimum sustainable benefit for present as well as future generations. **Two major strategies** are adopted – **protection or conservation forestry**, and **production or commercial forestry**.
- **Protection or conservation forestry** engages protection of degraded forests to allow recoupment of their flora and fauna. Well stocked forests are managed scientifically for producing timber and other forest products without causing any negative environmental impact on forests.
- **Commercial forestry** is of **three types - social forestry**, **agroforestry** and **production plantation**.
- **Social forestry** is the raising quick growing multipurpose plants in common village lands for fodder, fire wood, and small timber. This programme was **started in 1976**.
- **Urban forestry** is the plantation of fruit, flower and shade bearing plants in urban areas to reduce pollution.
- **Agroforestry** is the plantation of multipurpose trres/shrubs along with crops for stabilizing soil, need of fodder, fruit and timber of the community.
- Agroforestry includes **taungya system**, **shifting cultivation or jhum** (or **slash and burn**) system.
- In **taungya system**, agricultural crops are grown in between rows of planted trees like sal and teak.
- **Jhum or shifting cultivation** allows regrowth of forests after clearing and cultivation in an area for a few year.
- **Conservation of forests** is done by –
  - Sustained yield **block cutting**. Cutting is allowed only in non-vulnerable forests at a rate which is equal to their regeneration capacity.
  - **Van mahotsava** : A special function of tree plantation.
  - Prevention of scraping and litter removal.
  - Advanced silviculture.
  - Control of weeds.
  - Pesticides.
  - Fire fighting equipment.
  - Census.
  - Supervision and surveying.
  - Economy in extraction and use of timber.
  - Water shed protection.
  - Alternate source of fuel for villagers.
  - Controlled grazing.
  - **Chipko movement** : A movement initially meant for protecting trees but now meant for preservation of environment including habitat and wildlife, it was started in 1973 in Gopeshwar in Chamoli district by **Sunderlal Bahuguna**. (A similar movement called **appiko movement** started in 1983 in Karnataka).
- For **conservation of forests**, **different type of laws have been implanted**.
- The **basic objectives of Forest act, 1927** are – (i) establishment and management of three types of forests - village forests, reserved forests and protected forests. (ii) protection of nongovernment forests and forests land against over - exploitation and denudation. (iii) control of movement of forest products. (iv) control of grazing.
- **Reserve forests** are forests grown over ecological fragile areas near water regimes and no cutting down of trees is allowed.

Table : Importance of forests

	Economic use	Examples/obtained from
1.	Timber	*Shorea robusta, Tectona grandis*
2.	Saw dust	*Tectona grandis*
3.	Fuel wood	80% of forest wood (most trees)
4.	Bamboo	*Bambusa*, *Dendrocalamus.*
5.	Paper	*Pinus*, *Abies*, *Picea*, *Eucalyptus.*
6.	Rayon	Regenerated cellulose fibre
7.	Food	*Juglans regia* (walnut), *Prunus amygdalis* (almond), *Cocos nucifera* (coconut)
8.	Canes	*Calamus sp.*
9.	Essential oils	For incense and perfume, e.g., *Cymbopogon* species (palmarosa, citronella, lemon grass, ginger grass), *Vetiveria zizanioides* (khas) and *Santalum album* (sandal wood).
10.	Tannins	Bark of *Acacia*, *Juglans*, leaves and branches of *Uncaria*, wood and fruits of *Caesalpinia*.
11.	Gums	*Acacia nilotica*, *Boswellia serrata* (salai), *Anogeissus latifolia* (dhaora), *Sterculia urens* (kuteera).
12.	Resins	*Pinus* (pine resin) and *Shorea robusta* (damar). Pine resin yields turpentine and rosin (colophany).
13.	Dyes	Cutch (Heart wood of *Acacia catechu*), henna (leaves of *Lawsonia inermis*) and haematoxylin (heart wood of *Haematoxyon campechianum*, *H. brasiletto*).
14.	Spices	Nutmeg (seed and aril of *Myristica fragrans*), bari elaichi (=Bengal Cardamom, dried fruits of *Ammomum aromaticum*), chhoti elaichi (dried fruits of *Elettaria cardamomum*), cinnamon (dalchini, inner bark of *Cinnamomum zeylanicum*), clove (laung, unopened dried floral buds of *Syzygium aromaticum*).
15.	Camphor	It is distilled from wood of Cinamomum *camphora*.
16.	Drugs	Quinine from *Cinchona,* reserpine (blood pressure and schizophrenia) from *Rauwolfia serpentina*, senna (purgative) from *Cassia angustifolia*, belladona atropine and truth drug from *Atropa belladona*, triphala consists of dried fruits of *Emblica officinalis* (Amla), *Terminalia bellerica* (bahera) and *Terminalia chebula* (harar).
17.	Kendu	Leaves of *Diospyros exsculpta* for wrapping bidis.
18.	Soap substitute	Ritha (*Sapindus mukorossi*) and shikakai (soap pod, *Acacia rugata*).
19.	Rudraksha	Seeds of *Elaeocarpus sphaericus*.
20.	Animal product	Lac (*Kerria lacca*), honey and wax (*Apis dorsata, A. indica. A. florea*, *A. mellifera*), tassar silk (*Antheraea paphia*), muga silk (*Antheraea assamensis*).
21.	Employment	A large number of professionals and nonprofessionals are engaged in afforestation, gathering of forest products, management of forests and wildlife. Revenue generated by forests runs into several thousand crores of rupees.

- **Forest (conservation) act, 1980, amended 1988** : The **basic objectives of this acts are** – no forest land can be deserved and diverted to nonforest purpose without the approval of central government. A diversion when permitted would be accompanied by compensatory afforestation, in some cases twice the forested area lost. Six regional officers have been set up to monitor enforcement of act - Bangalore, Bhopal, Bhubhneshwar, Lucknow, Shillong and Chandigarh.
- **National forest policy (1988)** aims at increasing forest cover of the country both in plains and hills so that the optimum of 33% forest cover is achieved in plains and 67% in hills.
- **Other aims of national forest policy** are – (i) maintenance of environmental stability through

preservation and restoration of ecological balance. (ii) check of soil erosion and denudation of catchment areas. (iii) checking on spread of sand dunes. (iv) increase in forest tree cover through massive afforestation and social forestry programmes. (v) steps to create massive peoples movement for afforestation, management and protection of forests. Already about 14.25 million hectares of degraded forests are being restored, managed and protected by 63,000 Joint Forest Management Committees.

- The moral basis of human responsibility towards environment is called **environmental ethics**.

Grassland

- **Grassland or rangelands** are the land areas dominated by grasses and herbs and **provide forage to cattle and support wildlife**.
- **Major causes of degradation of grassland** are –
  - **Agriculture**. Grasslands are large plain tracts with good humified fertile soil cover. They have been converted into agricultural lands at many places, e.g., North American praires.
  - **Overgrazing**. With the conversion of parts of fertile grasslands into agricultural land the remaining less fertile grasslands are used for grazing of animals. As a result grazing pressure increases. In arid and semiarid areas of India, the grazing cattle population is 2 – 10 times the capacity of grasslands, trampling and compaction.
  - **Scraping**. At many places, grassland is scraped to collect grass for feeding the cattle and storage as dry hay. The scraped soil is exposed and degrades quickly.
  - **Fires**. Occasional fires are common in grasslands. Fires burn down the grass and expose the soil for growth of other plants and erosion.
  - **Soil erosion**. Whenever plant cover is removed by overgrazing, scraping and fire, the soil is exposed to run off water and dry wind. They cause removal of top soil.
  - **Desertification**. Conversion of fertile forest, grass covered or agricultural land into barren sandy or arid areas is called **desertification**. It occurs when denuded areas dry up due to prolonged drought and dry soil is exposed to wind erosion. Very fine soil particles are picked up by the wind and carried as dust. The coarser particles left behind are of the size of sand. Therefore, wind erosion makes the soil sandy. The sandy soil is unstable as sand shifts due to surface creep caused by wind. This produces sand dunes. The sandy and dusty wind deposits its dust and sand over adjacent fertile areas and converts the same into desert. Therefore, desert once formed spreads over its boundaries.
- **Grassland management can be done** by the following –
  - Grazing should be limited to only that number of animals which can be comfortably supported by a piece of grassland.
  - Grasslands should be closed to grazing when new plant growth is to take place, like rainy season.
  - A grassland should be divided into blocks with each block be allowed to be grazed on rotational basis, this allows other blocks to recover.
  - Reducing loss of soil and water from the grassland by contour bunding.
  - Occasional controlled burning of dried mulch to promote release of nutrients and prevent growth of trees and shrubs.
  - Removal of tree seedlings, bushes, shrubs and weeds which tend to reduce productivity of grasslands .
  - Occasional seedling with high yielding leguminous herbs for maintaining soil fertility.

Wetland

- **Wetlands** are low lying flat, marshy, swampy or peat lands which may get inundated upto depth of six meters.
- Wetlands may be **natural or artifical**, **temporary or permanent**, **fresh water**, **brackish** or **saltish with static or flowing water**.
- Conservation of wetlands **can be done by -**
  - Preparation of inventory of all wetlands.
  - Identification of wetlands of critical importance for immediate conservation.
  - Checking dumping of wastage in wetlands.
  - Bordering the wetlands with growth of trees and shrubs so as to prevent excessive flow of silt and nutrients.

Table : Difference between fresh water and marine wetlands.

	Fresh water wetlands	Marine wetlands
1.	They occur in land.	They occur in coastal areas.
2.	The wetlands develop in depressions where rain water or flood water can collect.	The wetlands develop at the mouths of rivers or shallow areas along the sea coasts.
3.	Salt content is low.	Salt content is high.
4.	Help in charging groundwater.	They have no such role.
5.	They are abode of several resident birds and halting grounds for migratory birds.	Marine wetlands have no such function.
6.	Are of 3 types - marshes, swamps, riverine.	Are of 2 types - estuaries, mangroves.

SOIL RESOURCES

- **Soil** is the upper weathered humus containing part of earth's surface that supports plant life on earth.
- The study of soil is called **pedology**.
- Soil consists of the **inorganic materials** derived from rocks; the **organic material** derived from dead organism; the **air & water** occupying the pores between the soil particles which are loosely packed; **small organisms** like bacteria, fungi, nematodes etc.
- The **removal of the top fertile layer of soil** by agents like water, wind, etc. is called **soil erosion**.
- **Natural or geological erosion** is extremely slow removal of top soil due to rain water or wind.
- **Human induced erosion** is caused by removal of plant cover through overgrazing, litter collection, tree felling and leaving the soil unprotected during agricultural operations.
- **Sheet erosion** is the removal of extremely thin layer or sheet from soil surface.
- **Rill erosion** is the development of finger like or groove like narrow depressions or rills due to running water.
- Deeper, wider channels developed by cutting power of running water, 15 - 30 m deep gullies, are called **ravines**.
- **Wind erosion** is caused by carrying of very fine soil particles as dust, saltation and surface creep of larger particles.
- **Soil conservation** refers to **various soil and crop management practices** that can minimize erosion & reduce nutrient depletion of agricultural soils.
- **Soils erosion can be prevented or controlled by** –
  - **Crop rotation** : The practice of sowing different crops, usually legume and nonlegume, in successive seasons on the same piece of land for maintaining soil fertility.
  - **Mixed cropping** : Growing two or more crops stimultaneously on the same land.
  - Covering of harvested field with plant litter of polyethene (LDPE or low density polyethylene) in order to decrease runoff, prevent growth of weeds and retention of water (called **mulching**).
  - **Strip cropping** : Sowing of perennial crops alternating with annuals, or annuals with different seasons of sowing and water.
  - **Contour Bunding** : Raising small bunds on edges of fields to prevent loss of top soil through water or wind.
  - Growth of several alternate rows of trees and shrubs at right angles to prevalent direction of wind for reducing its speed and preventing carrying of soil particles.
  - **Afforestation and Reforestation** : Plantation of forests.
  - **Grazing** is allowed in certain seasons and only for limited number of animals.
  - **Contour ploughing** – Ploughing is carried out at **right angles to the slope**.
  - Depending upon the climate and availability of moisture, soil is seeded with drought resistant grasses and leguminous herbs.
- **Reduction of soil fertility** is caused by water logging, pH change, salination, leaching of minerals, overgrazing and nonculture.
- **Restoration of soil fertility** can be done by green manuring, rotation of crop, irrigation, maintenance of soil pH and stoppage of overgrazing.
- Presence of excess salt (sodium potassium and magnesium) is called **soil salinity**.

MINERAL RESOURCES

- **Minerals** are largely **non-renewable inorganic** resources that are presently mined from lithosphere.
- Minerals are raw materials for industry in manufacture of appliances, tools, implements and materials required for every sector of human society.
- Minerals are of **two types - metallic** (e.g., iron, copper, aluminium, gold) and **non-metallic** (e.g., asbestos, feldspar, phosphates, sand, salt).
- Their (minerals) average abundance is called **clarke** (e.g., 8% for aluminium, 0.001% for lead). Wherever minerals occur in quantities many times larger than their clarke, **an ore body is present from where the mineral is extracted**.
- **Mineral conservation** may be done by –
  – Reuse of an article several time
  – Recycling of metals through reprocessing
  – Scarce metals can be substituted by more abundant metal; and
  – Use and throw tendency should be checked.

Table : Important minerals and their uses.

Mineral	Selected uses
Metal elements	
Auminium	Sructural material, packaging
Chromium	Chrome plate, steel alloys
Copper	Alloy material in gold jewellery, silverware, brass and bronze, electric wiring, pipes, cooking vessels
Gold	Jewellery, dentistry, alloys
Iron	Primary component of steel
Lead	Pipes, battery electrodes, pigments
Manganese	Alloy steels, disinfectants
Nickel	Coins, alloys, metal plating
Platinum	Jewellery, equipments, industrial catalyst
Potassium	Fertilizer, glass, photography
Silver	Jewellery, vessels, photography, alloy
Uranium	Nuclear bomb, electricity, tinting glass
Tin	Cans/containers, alloys
Zinc	Brass, electrodes, medicine
Non-metal elements	
Phosphorus	Medicine, fertilisers, detergents
Sulphur	Insecticide, rubber types, medicine
Liquid metal element	
Mercury	Thermometer, dental inlays, electric switches

ORGANISM RESOURCES

- **Plan**t constitute a **renewable organic resource** which, being producers, form the basis of biotic existence and man-made environment. They provide us food, sugar, fibres, drinks, condiments, medicines, timber, pulp for paper, rubber, gums, resins, tannins, alcohol and organic acids.
- Plants **maintain balance of CO_2/O_2, provide shelter to numerous animals**, **moderate the climate**, **increase periodicity of rainfall** and **prevent soil erosion**.
- **Cultigens** are plants whose ancestry has become obscure and which cannot survive in nature without human help, e.g., cabbage, maize etc.
- *Eichhornia crassipes* have became a serious weed used in India.
- A few **animal resources are domesticated** and **exploited** for–
  – **Food** : Fowls and ducks (eggs, meat), goat, sheep, rabbit, pig (meat), cow, buffalo, reindeer, sheep (milk and meat), honey bee (honey), fish, oyster, prawn, mussel (meat). Animal protein is most suitable for human beings, **pets** : Dogs, cats, pigeons, **wool** : Sheep, Angora rabbit, Kashmiri goat, **silk** (silkworm), **lac** (lac insect), **musk** (musk deer), **ivory** (elephant), **cantharidine** (blister beetle).
  – **Leather goods** from hides, **draught animals**, **pollinators and disseminators**, **aboratory animals**, **source of hormones**.
- **Micro-organism resources are exploited for various reasons as –**
  – *Saccharomyces cerevisiae, S. elliposidens, Rhizopus oryzae* and *Mucor javanicus* in preparation of wines, whisky, rum, beer, cider, brandy etc.
  – Yoghurt from milk by *Streptococcus thermophilus*, buttermilk by *Streptococcus cremoris, S.lactis* and *Leuconostoc dextranicum*.
  – Food yeast - Rich in protein, vitamins and minerals.
  – Different organic acids like acetic acid, citric acid, lactic acid, and fumaric acid, antibios, vitamins are obtained from micro-organisims.
  – *Pseudomonas* and *Clostridium* help in retting of stem and leaf fibres.
  – Bacteria help in nitrogen fixation; nitrification; ammonification; curing of tea, tobacco, coffee etc.

End of the Chapter

Chapter 61

Biodiversity

- **Biodiversity** (synonym for 'life on earth') or **biological diversity** (GK *bios*-life, *diversity*-forms) is the occurrence of different types of ecosystem, different species of organisms with their biotypes and genes adapted to different climates, environments along with their interactions and processes.
- Biodiversity **includes three interrelated hierarchial levels**. These are – **genetic diversity**; **species diversity**; and **community** or **ecosystem diversity**.
- **Genetic diversity** means variation of genes within the species; the differences could be in alleles (different variants of same genes), in entire genes (the traits determining particular characteristics) or in chromosomal structures.
- The genetic diversity enables a population to adapt to its environment and to respond to natural selection.
- **The amount of genetic variation is the basis of speciation** (evolution of new species). **It plays an important role in the maintenance of diversity at species and community levels**.
- Genetic diversity is the basis of formation of new species. The greater is the genetic diversity of a species, the higher is its efficiency to adapt. The greater the diversity the wider is the geographical distribution.
- Lower genetic diversity within a species or variety may be useful for uniformity in yield as a well as higher yield.
- The variety in the number and richness of the species of a region is known as **species diversity**.
- The number of species per unit area is called **species richness** and the number of individuals of different species represents **species evenness**.
- Actually species diversity is the product of species richness and species evenness.
- Diversity at the level of community and ecosystem has three perspectives *i.e.* **alpha(α) diversity, beta diversity** and **gamma diversity**.
- **α-diversity**, also known as within-community diversity, means diversity of organisms sharing the same community/ habitat.
- α-diversity is **dependent upon species richness and evenness**.
- Such diversity shows a lot of competition, adjustment and inter-relationships among the members of the same community.
- **Beta diversity** or between community diversity means the rate of replacement of species along a gradient of habitats or communities due to presence of different microhabitat, niches and difference in environmental condition.
- **Gamma diversity** is the diversity of the habitats over the total landscape or geographical areas.
- The **important factors causing loss of biodiversity** are – **habitat loss, habitat fragmentation, disturbance, over-exploitation, pollution, exotic species, intensive agriculture** & **forestry**.
- Expanding population and development require more industrial areas, extension of present towns and cities, more area for agriculture, new roads, canals, dams, etc. All these activities will result in **destruction of natural habitats (or habitat loss)**.
- Destruction of habitat is **the primary cause of extinction of species**. Grasslands were converted into agricultural lands during colonisation of America. New Zealand abounded in wetlands.
- In tropical areas human settlements required cutting down of trees and burning of the remaining forests. Destruction of the habitat kills most of the organisms.

- Some organisms especially animals leave the habitat but being alien in other habitats, they usually die out there.
- **Habitat fragmentation** is the breaking of a large habitat into smaller patches due to development of agriculture, water body and other changes.
- The phenomenon of reduction in species diversity in small patches is called **insularization**. Initially, there may be increase in number of species in patches but ultimately it decreases. This type of decrease is called **relaxation**.
- Fragmentation **reduces the core area and increases the edge area**.
- Species occupying the deep or interior portion of the forests would be badly affected due to disruption of their inter-relationships.
- Most of them are relatively rare species (Gaston, 1994) which tend to disappear as their habitat area shrinks due to fragmentation.
- Forest patches having croplands, orchards, plantation and urban settlements on their outskirts are **examples of fragmented habitats**.
- Fragmentation of habitats (e.g., forest land surrounded by crop-lands, orchards, plantation, urban areas) results in disruption of complex interactions amongst species, destruction of species in the cleared regions, annihilation of species restricted to deeper undisturbed parts of forests and decreased biodiversity in the habitat fragments.
- **Disturbance** is alternation made in the habitat, environment and the community of an area. Disturbance is both **natural** and **anthropogenic**.
- **Natural disturbance** is caused by natural calamities like drought, excessive rain, landslides, floods, tree falls, disease, defoliation by insects and dry weather fires.
- **Anthropogenic or man-made disturbance** is actually very high in intensity, rate and spatial extent, *e.g.*, tree felling, collection of litter, fire for clearing forests.
- While some natural disturbances are beneficial for biodiversity (Intermediate Disturbance Hypothesis, Connel, 1978), large scale disturbance is harmful to diversity. Corn and Bury (1989) found that timber harvesting along the banks of streams reduced their diversity.
- **Overexploitation** of any particular species reduces the size of its population so that it becomes vulnerable to extinctions, eg., hunting of animals, collection of medicinal plants.
- Biological systems should not be exploited beyond the degree of their renewability. Exploitation beyond this level results in degradation and extinction of the resource.
- Excessive tree felling in the forest, overgrazing, uprooting of orchids and medicinal plants, hunting of animals, etc. have resulted in degradation of habitats and extinction of many species, *e.g.,* Cheetah from India, Dodo from Mauritius. Both orchids and medicinal plants have become threatened plants.
- **Pollution** are harmful alterations made in our surroundings by human activities like industrial effluents, industrial emissions, automobile emissions, pesticides, fertilizers, sewage, etc.
- Pollution load of our requirement is rapidly rising so that it has already proved harmful to many ecological systems.
- Acid rain (caused by excessive sulphur and nitrogen oxide emissions) has destroyed more than 50% of natural forests and several fresh water lakes in many western countries.
- Oil spills in sea destroy plankton, algae, marine animals and smearing of sea birds resulting in their immobility and death. SO_2 pollution of air kills lichen population of the area. Pesticides often enter food chains and undergo biomagnification. It caused decline in population of fish eating birds and falcons.
- Lead and other heavy metals entering water bodies as effluents and wastes cause mortality in animals. Cattle regularly drinking such polluted waters may get killed.
- Ducks, cranes and swans often die after taking in spent shotgun pellets that fall in their aquatic habitat.
- Nutrient enrichment of water bodies occurs by run off from fields and sewage disposal. This causes dense growth of plants. The phenomenon is called **eutrophication**.
- Eutrophication **leads to depletion of oxygen**, death of animals, accumulation of organic matter and fouling of water.
- Any new species entering in a geographical region are known as **exotic (alien) species**.
- Exotic species may **cause disappearance of native**

species through changed biotic interactions. Like,

- Water hyacinth (*Eichhornia crassipers*) was introduced in Indian waters to reduce pollution. It has clogged water bodies including wetlands at many places resulting in death of several aquatic plants and animals.
- *Lantana camara* (a straggling shrub) has becomes a serious weeds which has replaced many species in forests of U.P. and M.P.
- *Eupatorium odoratum* has reduced the population of *Tectona grandis* in North-East.
- *Parthenium hysterophorus* has pushed out several herbs and shrubs from open places in the plains.
- **Nile Perch,** a large predator fish was introduced in Lake Victoria of South Africa. It began to threaten the entire fresh water ecosystem by feeding on small herbivorous and detrivorous chichlid fish species which were endemic to the aquatic system. Chichlid species not only became extinct but finding no food for itself, Nile Perch also died out.

- Exotic species on becoming invasive **constitute the second most potent factor** (first being habitat destruction) **for extinction of species**.
- With the pressure of increasing human population, **agriculture became both intensive and extensive**.
- **Extension of agriculture** resulted in diminishing of wetlands, grasslands and forests.
- **Intensive agriculture** is based on a few crops and their few high yielding varieties and as a result there is reduction in the genetic diversity. The remaining varieties are disappearing fast. Similarly, crops with smaller yields and returns are being edged out of cultivation. It has decreased biodiversity.
- **Forestry** is the tendency to grow economically important trees in pure strands, *e.g.,* sal, teak. It drives away or annihilates other species found in forests.
- Today **forestry means growth of exploitable forest plants**. There is, therefore, a tendency to grow only these plants in almost pure strands.
- Other economically less important plants are being ignored resulting in their extermination and hence loss of biodiversity.
- Spread of agriculture at the cost of wetlands, grasslands and forests and destruction of habitats results in extinction of species.
- **Natural disturbance and degradation** are caused by spontaneous jungle fire, pest infestation, defoliation by insects etc.
- **Man made disturbance** include felling of trees, use of fire for clearing forest areas, collection of litters and overexploitation of economically important products.
- **Extinction** is the disappearance or elimination of a species from earth. It is different from disappearance of a local population which is called **extirpation**.
- Complete extinction of a species **results in complete loss of genetic information contained in it**.
- **Extinction of species** is a natural process when older species disappear and new ones evolve to take their place over the long period of time.
- A species becomes **prone to extinction** due to two categories of attributes – **drastic environmental changes** and **population characteristics**.
- **Population traits which makes a species susceptible to extinction** are –
  - Large body size, *e.g.*, elephant, rhinoceros, Bengal tiger, lion
  - Small population size
  - Low reproductive potential, *e.g.*, blue whale, giant panda.
  - Higher status of trophic level, *e.g.*, bald eagle, bengal tiger.
  - Narrow range distribution or small geographical range, e.g., woodland caribou.
  - Lack of genetic variability
  - Inability to switch over to alternate foods.
- There are **three types of extinction process** – natural, mass extinction and anthropogenic extinction.
- With the change in environmental conditions, some species disappear and others, which are more adapted to changed conditions, take their place. This loss of species, which occurred in the geological past at a very slow rate, is called **natural** or **background extinction**.
- **Mass extinction** is a catastrophic, widespread– often global–event in which major groups of species are wiped out over a relatively short period when compared to normal (background) extinctions of natural causes (in at least one case due to an asteroid impacting the earth), in the earth's history. During these mass extinctions, certain groups of organisms disappeared while others survived apparently

unscathed. And after each mass extinction, species numbers rebounded as whole new groups of organisms evolved and colonized the planet.

- **Anthropogenic extinction** is a man-made extinction where an increasing number of species are disappearing from the face of the earth due to human activities. This extinction causes a very severe depletion of biodiversity, especially because it is occurring within a short period of time.
- IUCN is **International Union of Conservation of Nature and Natural Resources** which is now called World Conservation Union (WCU). It has its **headquarters at Morges, Switzerland**.
- The species particularly susceptible to extinction are : large body size (Bengal tiger, lion and elephant); and small population size and low reproductive rate (blue whale and giant panda).
- The known and described number of species of all organisms on the earth is between 1.7 and 1.8 million, which is fewer than the 15% of the actual number.
- Wildlife Institute of India has divided the country into **ten biogeographical regions** – Trans Himalayas, Himalayas, Desert, Semi-arid, Western Ghats, Deccan Peninsula, Gangetic Plain, North East, Coasts, Islands.
- Among the biogeographical regions of India, **Deccan peninsula** has the **most extensive coverage** of the Indian landmass (42%).
- The most **biodiversity-rich zones** are – **Western Ghats** and **North east**, account for 4 and 5.2 percent of the geographical area, respectively.
- Trans-Himalayas is cold desert with sparse vegetation. It has a rich community of goat and wild sheep besides snow leopard.
- North-East and Western Ghats have wild relatives of number of cultivated plants like banana, citrus, mango, pepper, etc.
- Most of the endemics restricted to a particular area of a region occur in – North-East, North-West, Western Ghats, Andaman Nicobar islands. Western Ghats possess a very large number of endemic amphibian species.
- In temperate region the climate is severe with short growing period for plants, in tropical rain forest the conditions are favourable for growth through out the year.
- Degree of biodiversity shows two **master gradients – altitudinal** and **latitudinal**.
- Biodiversity is **minimum in the arctic region**, **moderate in temperate area** and **maximum in tropical regions**. For example, the number of species of vascular plants is 118-236/0.1 ha in tropical forests, 21–48/0.1 ha in temperate zone and 0.0–10.0 ha in arctic area.
- The second master gradient of biodiversity is observed when one ascends a mountain. Biodiversity is maximum at the base. It decreases with the increase in altitude.
- Rise in altitude also decrease mean temperature, a fall of 6.5ºC for every 1000 m increase in altitude. Lower temperature and greater seasonal variability reduces diversity.
- Biodiversity is the source of food, medicines, pharmaceutical drugs, fibres, rubber and timber. The diversity of organisms also provides many ecological services which are responsible for maintaining ecosystem health.
- **Conservation of biodiversity** is protection uplift and scientific management of biodiversity so as to maintain it at its optimum level and derive sustainable benefits for the present as well as future strategies.
- There are **two basic strategies of biodiversity conservation** – ***in situ* (on site)** and ***ex situ* (off site)**.
- All efforts should be made to preserve the species that are endangered through out the range. The threatened species should be given preference over others in the conservation programme.
  [For more details on wild life conservation refer chapter Wild Life & Conservation]
- **Megadiversity centres** are regions of world which are extremely rich in species, especially the endemic ones. **Mittermeir and Werner** (**1990**) have recognized **12 megadiversity centres**– India, Malaysia, Indonesia, China, Zaire, Madagaskar, Australia, Ecuador, Peru, Brazil, Columbia and Mexico. India with only 2.4% of land area accounts for nearly 8% species of the world.
- The **concept of 'Hot Spots'** of biodiversity was **developed by Norman Myers** to designate priority areas for *in situ* conservation.
- The **criteria for determining hot spots** are: number of endemic species and degree of threat, that is measured in terms of habitat loss.

- There are **twenty-five hot spots** identified worldwide.
- There are **two hot spots in India**; they are (i) **Western Ghats,** and (ii) **Eastern Himalaya**; these areas are rich in flowering plants, reptiles, amphibians, swallow-tailed butterflies and some mammals, which show a high degree of endemism.
- **Western ghats** occur along the western coast of India extending for almost 1600 km through Maharashtra, Karnataka, Tamil Nadu and Kerala to Srilanka. Rainfall is good.
- Forests lying at low elevation upto 500 m are evergreen while those at moderate elevation (500-1500 m) are semi evergreen. 1600 species of plants are endemic to this area. Southern Western Ghats are known as Malabar.
- It has high biodiversity as well as high degree of threat perception to biodiversity. IUCN has recognised **three threatened areas** – **Agastyamalai hills, Silent valley** and **Periyar National Park** (new Amambulam Reserve).
- **Eastern himalayas** is **meeting place of three biogeographical regions**– **Indian**, **Malayan** and **Chinese**. It extends to Bhutan and through north-cast to Myanmar and is called Indo-Burma hot spot.

Table : Uses of Biodiversity

Used as	Sources	Used as	Sources
Food	Carbohydrate rich crop-wheat, corns, rice.	**Cultural benefits**	Sacred plants – *Ocimum sanctum* (tulsi), *Ficus religiosa* (Peepal), *Prosopis cineraria* (Khejri), Sacred birds, snakes are sometimes worshipped.
Source of fats and oils	Soyabean, coconut, cotton seed, peanut, sunflower, sesamum, safflower, rapeseed, mustard and oil palm. Oil is also obtained from wild gourd, bitter colocynth, jojoba.	**Ecosystem services**	Forests and oceans – control climate & gaseous temperature, nutrient cycling,conservation of water, formation and conservation of soil.
Fibres	Cotton, flax, jute, hemp, rosella, agave, abaca, and coir.	**New varieties** (obtained from crossing with wild varieties)	Disease free rice plants are obtained by crossing rice plants with *Oryza nivara* (wild) Potato resistant to late blight (*Solanum demissum*), potato mosaic virus, leaf roll virus (*Solanum acaule*), nematodes (*S. spegazzeni*) are also obtained.
Drugs/medicines	*Vinca rosea* yields alkaloids used for treatment of leukemia, *Papaver somniferum*-morphine for pain, *Cinchona*- quinine (for malaria), *Taxus brevifolia* taxol for treating cancer. *Rauwolfia serpentina*-reserpine for blood pressure and schizophrenia.		
Asthetic value	Ecotourism, Birdwatching, wild life pet keeping.		

End of the Chapter

Chapter 62

Pollution & Global Environmental Changes

- An undesirable change (may be physical , chemical or biological) in air , water or soil due to excessive accumulation of pollutant is called as **pollution**.
- The pollution by volcanic eruption, UV radiation, soil erosion, dust storm, forest fire etc. are called as **natural pollution**.
- The pollution caused by human beings (industrial, water removal etc.) are called as **anthropogenic pollution**.
- A **pollutant** is any substance, chemical or other factor that changes the natural balance of environment.
- The increase in toxicity by reaction among the pollutant is known as **synergism**.
- Pollution is **different from contamination** which occurs in the presence of harmful organisms or their products causing disease or discomfort.
- **On the basis of emission of pollution**, it can be **point source** (from single point), **line source** (which passes along a belt), **area source** (in mining area) and **diffuse source** (over a large area).
- There are **5 types of pollution : air**, **water**, **land**, **noise** and **radioactive pollution**.

Pollutants
on the basis of

- **Existence**
  - **Quantitative** those component which become pollutant when its concentration reaches beyond a threshold value, eg. CO, CO_2, NO_2 concentration in the air
  - **Qualitative** do not occur naturally in nature, but passed through human activities, eg. DDT and other pesticides
- **Natural disposal**
  - **Biodegradable** quickly degraded by natural means, eg. sewage
  - **Non-biodegradable** either do not degrade or degrade very slowly in nature, eg. mostly inorganic compounds (like salts of heavy metals, radioactive materials etc.), DDT, long chain of phenolic chemical etc.
- **Persistence**
  - **Primary pollutants** persists in form in which they are added to the environment, eg. plastic ware, DDT
  - **Secondary pollutant** formed by interaction among primary pollutant, more toxic than primary pollutant, eg. peroxyacyl nitrates (PAN) and ozone

AIR POLLUTION

- Air pollution is the occurrence or addition of foreign particles, gases or pollutants in the air which have an adverse effect on human beings, animals, vegetation etc.
- The **various causes of air pollution** are –
  – Combustion of natural gas, petroleum, coal and wood in industries, automobiles, aircrafts, railways, thermal plants, agricultural burning, kitchens, etc. (soot,

flyash, CO_2, C, nitrogen oxides, sulphur oxides).
- Metallurgical processing (mineral dust, fumes containing fluorides, sulphides and metallic pollutants like lead, chromium, nickel, beryllium, arsenic, vanadium, cadmium, zinc, mercury).
- Chemical industries including pesticides, fertilizers, weedicides, fungicides.
- Cosmetics.
- Processing industries like cotton textiles, wheat flour mills, asbestos.
- Welding, stone crushing, gem grinding.

- The air pollutants have been classified into two categories as **primary air pollutants or primary emissions** and the **secondary air pollutants**.
- **Primary emissions or pollutants** include those substances which are **emitted directly from some identifiable sources**. These include – sulphur compounds; carbon compounds [includes oxides of carbon (CO, CO_2) and hydrocarbons]; nitrogen compounds (includes NO_2 and NH_3); halogen compounds [includes hydrogen fluoride (HF) and hydrochloric acid (HCl)]; particles of different size and different substances are found suspended in air.
- The oxides of sulphur, carbon, nitrogen, hydrocarbons, photochemical oxidants and fluorides are the **common gaseous pollutants**.
- **Carbon monoxide** (accounts for **50% of atmospheric pollution**) is the **most poisonous gas** and is released from motor vehicles and industries.
- Carbon monoxide is harmful to man as it **competes with O_2 for haemoglobin and form carboxyhaemoglobin**.
- When a man inhales air containing normal concentration of O_2 and also carbon monoxide, he suffers from suffocation because haemoglobin combines with CO instead of O_2 and the product formed cannot dissociate.
- CO poisoning can lead to giddiness, laziness, exhaustion, reduced vision, nervous and cardiovascular disorder and even death.
- The CO_2 increase in the air may cause rise in atmospheric temperature which may melt the polar ice, causing rise in ocean level and consequent flooding of towns.
- **Nitrogen oxide** form about **10% of pollutants**.
- Oxides of nitrogen **causes eye irritation, respiratory troubles, lung oedema, blood congestion and dilation of arteries**. Nitrogen monoxides like CO, lowers the oxygen carrying capacity of the blood.
- **Oxides of sulphur (sulphur dioxide** and **sulphur trioxide)** form about **18% of total air pollutants**.
- They may cause respiratory diseases (asthma, bronchitis, emphysema) and eczema in man. The exhausts from Mathura Refinery are a threat to the Taj at Agra.
- **Burning of fossil fuels** is the **main cause of sulphur dioxide pollution.**
- SO_2 and its transformation products in atmosphere on plant cell causes membrane damage, plasmolysis, chlorophyll destruction, metabolic inhibition, growth and yield reduction.
- SO_2 causes **chlorosis, necrosis of vegetation metabolic inhibition** and **growth reduction**.
- The compounds of SO_2 have **mutagenic effects**.
- **Acid rain** is **mainly due to pollution of sulphur dioxide** (combined with water forming sulphuric acid).
- Acid rain **(term coined by Robert August in 1872)** is rainfall and other forms of precipitation with a pH of less than 5. (pH of normal rain is 5.6–6.5).
- There are **two types of acid deposition** : wet deposition and dry deposition. **Wet deposition is acidic water** received through rain, fog and snow while **dry deposition is wind blown acidic gases** and **particles in the atmosphere**.

Approx. half of the natural forest have been destroyed by acid rain in Europe and N-E United States.

- **Problems and impacts of acid rain** are –
  - Soil acidity – affect land flora and fauna.
  - Acidification of lakes and streams – affect aquatic life, crop productivity, human.
  - Corrodes buildings, monuments and statues made of lime stones, bridges, fences, railings etc.

In Greece and Italy, invaluable stone statues have been partially dissolved and the Tajmahal in India is affected by the acid rain.

- The **nitrogen oxides by producing peroxy acylnitrates, photochemical smog** affects human health and plant vegetation.
- **Flourides** causes **leaf chlorosis**, **necrosis of margins, tips** and **abscission of leaves, fruits** etc.

- Hydrogen flourides causes **flourosis**.
- **Phosgene** and **methyl isocyanate** were **responsible for the Bhopal gas tragedy** that took place in **1984 in India**.
- **Lead** is a pollutant from automobile exhausts which affects health adversely and causes mental illness.
- Lead is believed to be **responsible for the fall of the Roman Empire**.
- **Hydrocarbons** or **volatile organic compounds** are **formed naturally by incomplete combustion of fuel in automobiles**.
- **Marsh gas or methane** is produced during decomposition of organic matter, paddy fields and due to incomplete combustion in automobiles and industries.
- Many hydrocarbons are carcinogenic. They **also cause irritation of eyes and bronchial constriction**.
- **Garden pea** is **SO_2 pollution indicator**.
- **Lichens** are grown as **pollution indicator**.
- **Maize** indicates **flouride pollution**.
- **Particulate matter** (PM) are air borne matters which results not only from direct emission of particles but also from emissions of some gases that condense as particles directly or undergo transformation to form particles.
- PM consists of soot, flyash, dusts of various types, fur, hair, spores, pollen grains etc.
- Fine particles of ash present in fuel gas are called **fly ash**. It is expelled from thermal power plants.
- Fly ash **block the stomata and also reduces the absorption of light energy by plants**.
- Fly ash is **absent in automobile exhausts**.
- Particulate matter from processing industries, eg. cotton dust, iron mill dust, mine dust, flour mill dust, gem grinding **causes pneumoconiosis, byssinosis, emphysema, siderosis** and **other pulmonary problems** (iron deposition in tissues).
- Particulate matter can be **settleable** and **suspended**.
- **Suspended PM** can be **further differentiated** as **aerosol** (less than 1 mm), **dust** (solid, more than 1 mm) and **mist** (liquid, more than 1 mm).
- Smoke causes about **10 – 15%** of atmospheric pollution.
- Most of the components of smoke are similar to those present in automobile exhausts like sulphur dioxide, sulphites, **3-4-benzpyrene** (causing lung cancer) and oxides of nitrogen.
- Soot, lead particles from exhaust, asbestos, flyash, volcanic emission, pesticides, H_2SO_4, mist, metallic dust, cotton, cement dust etc. **when inhaled by man cause respiratory diseases** such as tuberculosis, cancer and byssinosis (due to cotton dust).
- Different bacterial cells, spores, fungal spores, pollen grains can create bronchial disorders, allergy and many other diseases in animals and plants.
- **Secondary air pollutants** are usually produced photochemically from primary pollutants and are called **photochemical oxidants**.
- Photochemical oxidants includes **peroxyacyl nitrate (PAN)**, **ozone** and **aldehydes**.These are formed by the reaction of nitrogen oxide with the hydrocarbons present in the air.
- Secondary pollutants are **photochemical smog** and **acid rain**.
- The fog deposited with smoke and chemical fumes forms a dark and thick covering, the **smog**.
- Smog is very common in almost all the industrial areas and the cities situated in the basin experience it more because there the smog is trapped for many days by the stagnant air.
- **Smog** is of **two types - classical (London) smog** and **photochemical (Los Angeles) smog**.
- **Classical smog**, occurs at low temperature, contains sulphur gases (hydrogen sulphide, sulphur dioxide), smoke & dust particles.
- It is formed by condensation of water vapours with H_2S & SO_2 over dust & smoke particles. In them **secondary pollutants are absent**.
- It occurred in London during December 1952 when it affected 50% of population & killed over 4000 persons.
- **Photochemical or Los angeles smog**, having oxidizing environment, **contains secondary pollutants**.
- It is formed at high temperature due to still air, emission of nitrogen oxides & carbohydrates from automobile exhausts & solar energy.
- The **principal photochemical products** are **olefins**, **aldehydes**, **ozone** (*described later*), **PAN** (peroxyacyl nitrate), **PBzN** and **photochemical smog**.
- **PAN** is **produced due to reaction between oxides of nitrogen and hydrocarbons under effect of ultra violet radiation of sunlight**, when O_3 is also formed.
- There are three techniques for control of gaseous **pollutants – combustion**, **absorption** and **adsorption method**.

- In **combustion process**, oxidisable gaseous pollutants are completely burnt at a high temperature.
- In **absorption technique**, gaseous pollutants are absorbed in suitable absorbent materials.
- **Adsorption technique** is applied to control toxic gases, vapours and inflammable compounds that could not be efficiently removed or transferred by the aforesaid technique.
- According to sizes of air pollutants range and types of chemicals, different suitable devices are effective. Some **new devices** are **most widely used as settling chambers**, **cyclone collector**, **bag filters**, **wet collectors**, **electrostatic precipitators** (ESP, **most effective device**), **gas scrubbers**, **catalytic combustion**, **incineration** etc.

WATER POLLUTION

- **Water pollution** is the deterioration of the quality of water due to addition of foreign substances, factors (heat) and deprivation that makes it health hazard, unfit for human use and aquatic organisms.
- **Water pollutants** may be of **three types** – **biological** (viruses, bacteria, protozoa etc); **chemical** (organic wastes, organic biocides, inorganic chemicals); and **physical** (hot water, oil spills etc).
- Water pollution has two major sources – **natural** and **anthropogenic**.
- **Natural sources of water pollution** includes clay and slit from soil erosion, leaching of minerals, falling of organic matter from the banks.
- **Anthropogenic or man-made sources of water pollution** are domestic waste, sewage, soaps and detergents, run-off from agricultural fields having fertilizers and pesticides, industrial wastes, heat, waste from animal sheds and slaughter houses, oil pollution, etc.
- **Sources of water pollution are –**
  - Industrial discharge of chemical wastes and byproducts
  - Discharge of poorly-treated or untreated sewage
  - Surface runoff containing pesticides
  - Slash and burn farming practice, which is often an element within shifting cultivation agricultural systems
  - Surface runoff containing spilled petroleum products
  - Surface runoff from construction sites, farms, or paved and other impervious surfaces, e.g. silt
  - Discharge of contaminated and/or heated water used for industrial processes
  - Acid rain caused by industrial discharge of sulphur dioxide (by burning high-sulphur fossil fuels).
  - Excess nutrients added by runoff containing detergents or fertilizers
  - Underground storage tank leakage, leading to soil contamination, hence aquifer contamination.
- Water pollutants may be **organic** or **inorganic type**.
- **Some organic water pollutants are** –
  - Insecticides and herbicides, a huge range of organohalide and other chemicals
  - Bacteria, from sewage or livestock operations
  - Food processing waste, including pathogens
  - Tree and bush debris from logging operations
  - VOCs (Volatile Organic Compounds, industrial solvents) from improper storage.
- **Some inorganic water pollutants include** –
  - Heavy metals including acid mine drainage
  - Acidity caused by industrial discharges (especially sulphur dioxide from power plants)
  - Chemical waste as industrial byproducts
  - Fertilizers, in runoff from agriculture including nitrates and phosphates
  - Silt in surface runoff from construction sites, logging, slash and burn practices or land clearing sites.
- **Organic matter in water provides nutrition for decomposers** such as bacteria and fungi. They breakdown the organic matter using oxygen and deficiency of oxygen kills fishes and other aquatic animals.
- **BOD** (biological oxygen demand) is the amount of dissolved oxygen required by bacteria in decomposing the organic wastes of water. **Higher the BOD**, **lower would be the dissolved oxygen**.
- When large amount of sewage is dumped into water, the BOD **will increase**.
- Pure drinking water should have BOD of **less than 1 ppm**.
- **Chemical oxygen demand** (COD) test is aimed to determine the amount of oxygen needed to oxidise all pollution materials.

- The **value of COD is much higher** than BOD.
- Many pesticides such as **chlorinated hydrocarbons, organophosphates, organochlorine** compound etc are nonbiodegradable and their residues have long life. They enter the food chain and accumulates mostly in fatty acids.
- **Detergents** are regarded as **major pollutant in surface water.**
- **Phosphorous and nitrates of fertilizers** and **detergents** dissolve in water and **accelerate growth of algae which form mat on the water surface**.
- The **algal growth deoxygenate water** which are responsible for death of fishes and other aquatic animals.
- The increased productivity of lake and pond etc. due to nutrient enrichment is called **eutrophication**.
- Eutrophication causes **reduction in dissolved oxygen**.
- Industrial wastes such as cadmium, arsenic, mercury, lead, zinc etc. when released into water may reach the human body with contaminated food etc., which are very harmful for the health.
- The metals concentrate through the food chain to levels that result in heavy metal poisoning.
- Main sources of **mercury pollution** are combustion of impure coal, smelting of metallic ore, paper and paint industries.
- Concentration of toxic material increases at every trophic level. This is known as **biomagnification**.
- Radioactive waste from atomic power plants are stored in underground tanks. Radioactive materials reaches to crops, livestocks, and man through food chain.
- **Faecal pollution** is indicated by number of *Escherichia coli* in water.
- Warmer water has less oxygen (14 ppm at 0°C, 1 ppm at 20°C), so **thermal pollution** causes deoxygenation of water bodies which decreases the decomposition of organic wastes and kills the aquatic animals.
- **Phosphate pollution** is **caused by sewage and agricultural fertilizers**.
- Polluted water affect the health and economy of man as well as other living organisms. Pollutants make water unfit for domestic and industrial use.
- Taking fishes and other eatable aquatic animals poisoned with methyl mercury causes deformity called **minimata disease**.
- **Itai-itai disease (in Japan)** is **caused due to accumulation of cadmium**, characterized by pain in joints and bones .
- **In blue-baby syndrome excess nitrate** reacts with haemoglobin and forms nonfunctional methaemoglobin in infants. It **impairs oxygen transport**.
- Contamination of drinking water with **arsenic causes black foot disease**. It is characterized by diarrhoea.
- Excess use of fluoride tooth paste may lead to **skeletal fluorosis** or **knock knee disease** in which joints and bones become stiff and hard.
- Polluted water are treated in Effluent Treatment Plant before their release into water bodies. There are three steps in sewage treatment –
  - **Primary treatment** - Physical treatments such as sedimentation, floatation, fragmentation and filteration are involved in primary treatment.
  - **Secondary treatment** - There are two ways in secondary treatment : **anoxic** (it is through the action of anoxic micro - organisms and macromolecules) and **aerobic** (it is by two ways : trickling filter method and activated sludge method).
  - **Tertiary treatment** - Removal of nitrates and phosphates takes place in this step.
- Sewage water treatment is very expensive that is why only first two steps are followed in many countries.
- **Treatment of industrial effluents** involves neutralization of acids and bases, precipitation of metallic compounds, chemical oxidation etc.

SOIL POLLUTION

- Soil pollution, also **called land pollution** is addition or removal of nutrients which reduces the productivity of soil.
- The substances which are responsible for the reduction of soil productivity is called as **soil pollutants**.
- Soil pollutant alters the basic composition of the soil that may kill important soil organisms.
- **Pesticides, fertilizers, chemicals** and **radioactive wastes** etc. are the **main sources of soil pollution**.
- Various metals such as lead, tin, copper, cadmium etc., insecticides such as BHC, DDT, aldrin, melathion, fungicides, weedicides and many fertilizers are responsible for soil pollution.

- Quality of land also deteriorate due to **deforestation**, **desertification**, **water logging**, **flooding**.
- There are **two types** of soil pollution : **positive** and **negative soil pollution**.
- When there is **addition of undesirable substance** in the soil then it is called as **positive pollution**.
- When there is **reduction of soil fertility** due to loss of its top layer, it is called as **negative pollution**.
- Negative pollution is also, sometimes, called **third pollution or landscape pollution** in which fertile land is converted into barren areas by addition of solid wastes like leather good, spoiled food items etc.
- Soil pollution can be **checked by improving the disposal wastes**, **appropriate use of chemical fertilizers** and **use of biological pest control** .
- The **most important measure to check land degradation** is **restoration of forest, crop rotation**, **improved drainage etc**.
- There are **two types of wasteland** : **unculturable** and **culturable**. Rocky area, snow-covered area, steep slopes are unculturable area. Water-logged land, marshy area, forest land etc. are the example of culturable land area.

RADIOACTIVE POLLUTION

- Pollution of air, water and soil with radioactive materials is called as **radioactive pollution**.
- Radioactive pollution may be **natural or man-made**.
- Cosmic rays which reaches the earth, radiation from radioactive material present in rocks, soil etc. are **natural radiation**.
- Atomic explosion, atomic reactors and nuclear fuel, mining and refining of plutonium and thorium etc. are **man-made radiation**.
- Radioactive pollution affects all the organisms including humans. It causes **cancer, mutations and even death** in humans and animals.
- Radioactive wastes from various atomic reactors should be changed into harmless form before disposing off.
- Leakage of radioactive material from nuclear reactors should be prevented. Atomic explosion and use of atomic weapons should be banned.
- Radioactive pollution is **not curable**, hence it must be checked.
- Radioactive substances that are carried to distant places by wind and fall on the ground alongwith rain water is called **nuclear fall out**.
- Wastes from atomic power plants come in the form of spent fuels of uranium and plutonium.
- In India, there are **4 atomic power plants** : **Narora, Tarapur, Kalpakkam,** and **Rawat Bhata**.
- Many radioactive isotopes like C^{14}, I^{125}, P^{32}, O^{18} and their compounds are used in **scientific researches**.
- On the basis of their action on cells, **radiations** are **divided into two categories – non-ionising radiations & ionising radiations**.
- **Non-ionising radiations** include ultra-violet rays (100–300 nm) which are **known to cause sunburn**, **snow blindness**, **inactivation of organic bio-molecules formation of thymine-dimer in DNA**, and **skin cancer**.
- **Ionising radiations** include X-rays, cosmic rays and atomic radiations which **damage the living cells by ionisation (shifting the electrons from one to other bio-molecule)**.
- High altitude plants have **polyploidy** as a protective mechanism against radiations.
- **Actively growing and dividing cells** like those of stratum germinativum, intestinal lining, bone marrow, gonads and embryo (with all cells rapidly growing and dividing) are **more susceptible to ionising radiations**.
- **Less active and non-dividing cells** like osteocytes of bones, muscles fibres and neurons are **not so easily damaged** by radiations.
- **Strontium-90** accumulates in the bones to cause bone cancer and tissue degeneration in a number of organs.
- **Iodine-131** damages WBCs, bone marrow, spleen, lymph nodes, skin cancer, sterility and defective eye sight.
- **Radioactive iodine** may also cause cancer of thyroid glands.
- **Cesium-137** brings about nervous, muscular and genetic changes.
- **Uranium** causes skin cancers and tumors in the miners.

NOISE POLLUTION

- **Unpleasent loud sound** is called as **noise (also called slow killer)** and **disturbing level of noise** is known as **noise pollution**.
- Annoying noise from industries, transport vehicles, agricultural machines, defence equipments, domestic gadgets, music systems, public address systems and demonstrations are **various causes of noise pollution**.

- Noise pollution is measured in **decibels**.
- A **sound more than 115 db is harmful to the ears**.
- Moderate conversation has a noise value of **60 dB**; scooter, buses, trucks, etc. create noise of about **90 dB**; jets of about **150 dB** and rockets of **180 dB**.
- A decibel value above tolerable limit of noise is about **140 dB**.
- **Noise pollution can cause** damage to heart, increase blood cholesterol and even raise blood pressure and is also responsible for stomach disorders (ulcers), reduced hormonal secretions and change in the renal functions.
- Noise also causes anxiety and stress, increased rate of heart beat, headache by dilating blood vessels etc.
- A **constant exposure** to noise of **130 dB** (explosions) may **lead to partial or complete deafening of the ears**.
- A **regular exposure** to sound of **80 dB reduces hearing by 15 dB in 10 years**.
- Noise **become uncomfortable above 100 dB**.
- Noise stimulates the **secretion of adrenaline** which increases irritability, nervousness, neuromuscular tension and feeling of fatigue, so decreasing the working efficiency.
- Noise causes **vasoconstriction** which decreases the blood flow.
- Average street noise level in the metropolitan cities like Mumbai, New Delhi and Calcutta is **above 95 dB**.
- Mumbai considered to be the **third noisest city** in the world. Some areas in Mumbai have recorded as high as 105 dB of noise.
- **Reduction of noise level from the source**, **check of noise transmission, and protection of human beings from noise** are the **three main measures to control noise pollution**.
- **Green muffler scheme** involves the growing green plants along roadsides to reduce noise pollution.

GLOBAL ENVIRONMENTAL CHANGES

- The atmospheric green house gases forms a blanket like covering around the earth. It controls the escape of heat from the earth's surface to outer space and keep it warm and hostile. This phenomenon is known as **green house effect**.
- The capacity of atmosphere to keep the earth warm depends on the amount of green house gases.
- The greenhouse effect is a phenomenon whereby increased carbon dioxide emissions create a condition in the upper atmosphere, causing a trapping of excess heat and leading to increased surface temperatures.
- The **major natural greenhouse gases** are – **carbon dioxide** (60%), **methane** (20%), **nitrous oxide** (6%) and **chlorofluorocarbons** (14%). Also of minor significance are **water vapour** and **ozone**.
- The **major atmospheric constituents (N_2 and O_2) are not greenhouse gases**, because homonuclear diatomic molecules (e.g. N_2, O_2, H_2) neither absorbs nor emit infrared radiation as there is no net change in the dipole moment of these molecules.
- When concentration of green house gases increase in the atmosphere, it retains more and more infrared radiation, resulting in enhanced green house effect.
- Due to enhanced green house effect, there is increase in **global mean temperature or global warming**.
- Carbon dioxide, methane, chlorofluorocarbon and nitrous oxide are radioactive gases which **absorbs long wave infrared radiations**.
- Global warming has many fold effects as –

Table : Important legislations for the protection of environment.

	Name of Act	Function
1.	**The Environment Protection Act, 1986**	Law meant for the protection of air, water, soil and noise.
2.	**The Insecticide Act, 1968**	Power of government to regulate the import, manufacture, sale, distribution and use of insecticides.
3.	**The Water** (prevention and control of pollution) **Act, 1974**	Deals with preservation and quality control of water pollution.
4.	**The Air** (prevention and control of pollution) **Act, 1981**	Deals with preservation and control of air pollution.

– **Effect on weather and climate** - There is increase in average temperature by 1.4-5.8 degree centigrade by the year 2100. Warming of atmosphere increases its moisture containing capacity. All these are responsible for change in precipitation pattern. This climatic change is harmful for human health.
– **Sea level change** - The global warming is responsible for increase in sea level and melting of glaciers and green land ice sheets.
– **Effects on range of species distribution** -

Due to increase in global warming, many species are expected to shift poleward or towards high elevation in mountain regions.

– **Food production** - Increase in temperature causes extensive growth of weeds which ultimately decrease crop production.

- Some **strategies** should be followed to **deal with global warming** –
  – Vegetation cover should be increased for photosynthetic utilization of carbon dioxide.
  – Chlorofluorocarbon should be replaced with some other substitute having little effect on global warming.
  – Reducing the use of nitrogen fertilizers to reduce nitrous oxide emission.
  – Minimizing the use of fossil fuel to reduce the green house gas emission.
- Stratosphere have a thick layer of **ozone** which **protects life on earth from harmful effects of UV radiations**.
- **Ozone** in the Earth's atmosphere is generally **created by ultraviolet light striking oxygen molecules**, which consist of two oxygen atoms (O_2), creating two single oxygen atoms, known as atomic oxygen. The atomic oxygen then combines with a molecule of O_2 to create ozone, O_3.
- Ozone absorbs most of the ultraviolet radiation, so it **shields earth against biologically harmful solar radiations.**
- **Ozone depletion** refers to the phenomenon of reduction in the amount of ozone in the stratosphere. The depletion of O_3 layer by human activities may have serious implications and this has become a subject of much concern over the last few years.
- Ozone layer depletion **has various negative effects on atmosphere**. UV radiation increases more on earth. In humans it causes skin cancer, cataract, reducing the functioning of immune system. UV radiation inhibits photosynthesis in phytoplanktons.
- **Chloroflourocarbons or CFCs** (CCl_2F_2 and CCl_3F; used as coolants in air conditioners and refrigerators, cleaning solvents, aerosol propellants and foam insulation), **nitrogen oxides** (coming from fertilisers) and **hydrocarbons** are **responsible for O_3 depletion**.
- CFC produces active chlorine in the presence of UV radiation. These destroy ozone, converting it into oxygen.
- Nitrogen dioxide is a pungent gas; it produces a brownish haze, causes nose and eye irritations and pulmonary discomfort.

> - **Montreal Protocol :** A landmark international agreement to protect the stratospheric ozone by agreeing to limit the production and use of ozone depleting substances phasing out ozone depleting substances & helping the developing countries to implement use of alternatives to CFCs.
> - **Helsinki Declaration** (May, 1989) : Montreal Protocol was ratified by 82 nations at Helsinki. They pledged to phase out CFCs by 2000.
> - In June 1990, 93 nations amended Montreal Protocol and Helsinki Declaration. They agreed to phase out CFCs and other ODS by the end of 20th century.
> - **Intergovernmental Panel on Climate Changes** (IPCC, 1988) : Prepared a world climatic programme (WCP).
> - **Convention on Climate Change** (CCC) Under UN framework in 1991.
> - **Earth Summit** (United Nations Conference on Environment and Development, 1992). It was held in Rio-de-Janeiro (Brazil) and adopted the recommendations of CCC for reducing greenhouse gases. The recommendations were signed by 154 nations. They pledged to maintain emission of green house gases at 1990 level.
> - **Kyoto Protocol :** International conference held in Kyoto, Japan (during December 1997) obtained commitments from different countries for reducing overall greenhouse gas emissions at a level 5% below 1990 level by 2008-2012.

- Major aerosol pollutant present in jet plane emissions is **fluorocarbon**.
- The **ozone** layer is **destroyed by aerosols**.
- Aerosols are certain chemicals released into the air with force in the form of mist or vapour.
- The thickness of ozone shield is declining gradually. This is called as **ozone hole** (First discovered in 1985 over Antarctica).
- **Dobson** is an **unit of ozone hole amount**.
- UV radiation is non-ionizing type and it is lethal due to inactivation of proteins, pigments and nucleic acids.
- Carotenoid pigments prevent the damage of plant cells from ultraviolet rays.
- The molecular action of ultraviolet rays is mainly reflected through destruction of hydrogen bonds between DNA strands.

End of the Chapter

Chapter 63

Wild Life & Conservation

- **Wild-life** includes animals, plants and micro-organisms in their natural habitat like grassland forest, desert etc.
- **William Hornady** (in 1913) coined the term **wild-life** in his book "**Our Vanishing Wild Life**"
- Wild-life is important because it **balances population**, **maintains food chains, natural cycles, biodiversity, control pollution, prevent soil erosion** and it is the **source of gene bank.**
- Reasons behind the depletion of wild-life are **large scale destruction of habitat, poaching, hunting, change of migratory route, introduction of exotic species** and **exploitation of natural products**, etc.
- Exotic species or species introduced from outside **produce ecological imbalance due to removal of biological control**.
- **Ecological diversity** occurs due to the presence of large number of species in a community or area.
- Because of the presence of high degree of variability in the gene pool and occurrence of a large number of varieties, biotypes and cotypes, **genetic diversity occurs**.
- The species which is found in a particular natural habitat beyond which it is unknown, is called **endemic species**, e.g., *Ficus religiosa.*
- **Exotic species** are those species which are not native to an ecosystem, but often established purposefully or inadvertently by human activity.
- Hunting are of **three types** - **sport hunting** (for recreation), **subsistence hunting** (for safety and food) and **commercial hunting** (for food).
- A species of wild life likely to disappear from the world sooner or later is called **threatened species**.
- For conservation of wild life, the **threatened species** have been classified as **'endangered'**, **'vulnerable'** and **'rare' according to the degree of danger they face for survival**.
- **Rare species** are species with small populations either restricted geographically with localised habitats or with widely scattered individuals. These species are at risk of becoming more rare, but they are not in immediate danger of extinction.
- **Vulnerable species** are species under threat of or have actually declining number, or which have been seriously depleted in the past and have not yet recovered.
- **Endangered** one are species with low population numbers that are in considerable danger of becoming extinct.
- **Critically endangered species** are those that are facing very high risk of extinction in the world and can become extinct any moment in immediate future.
- **Indeterminate species** are in danger of extinction but the reason is unknown.
- **Red data book** are directories and scheme compiled

Table : Some important abbreviations.

UNESCO	–	United Nations Educational, Scientific and Cultural Organization
MAB	–	Man and Biosphere programme (1971)
IUCN	–	International Union for the conservation of Nature and Natural resources (1948), Switzerland
WWF-N	–	World Wide Fund for Nature (1961)
IBP	–	International Biological Programme
ZSI	–	Zoological Survey of India
BSI	–	Botanical Survey of India
BNHS	–	Bombay Natural History Society, Bombay (1883)
IBWL	–	Indian Board for Wild Life (1952)
CITES	–	Convention on International Trade in Endangered Species of wild flora and fauna (1976).

by IUCN providing upto data informations of all endangered animals and plants.

- Red data book has **pink pages for critically endangered species**. As soon as a species recovers it is deleted from the pink page and entered on green page.
- **Threatened species** is liable to become extinct if not allowed to realise full biotic potential by providing protection from exotic species/human exploitation / habitat deterioration/depletion of food.
- The number of critically endangered animals and plants in India is 18 and 44 respectively, eg *Sus salvanius*, *Berberis nilghiriensis*.
- In India endangered animals are *Ailurus fulgens* (Red Panda), *Bentinckia nicobarica*, Blue whale, Asiatic wild Ass etc.
- *Addax* antelope is vulnerable species and its number continue to decline.
- **Great Indian Bustard** *(Ardeotis nigriceps)* is a rare species of birds found in India.
- The number of threatened plants is 474 while that of animals is over 100, e.g., **Newcomb's snail, golden-lion, tamarin** etc.
- The **rhinoceros, sloth bear, tiger, wild ass** are **some endangered animals of India**.
- Vulnerable species are likely to move into the endangered category in near future if the casual factors continue to operate.
- Snow leopard (*Leo uncia*) was listed as indeterminate species.
- **Wildlife Institute of India** is located at Dehradun (U.P.) .
- **Indian Institute of Forest Management is situated** at Bhopal.
- **Hoolock gibbon** is the **only ape in India**.
- The process in which careful exploitation, protection and management of our natural resources is carried out and the process by which these natural resources are protected from destructive influence, misuse and decay are together known as **conservation (Odum 1972.)**
- Various methods by which wild life can be conserved are **enactment of wild life laws**, **species preservation**, **assemblage protection, habitat preservation, mass education** etc.
- **Important steps for conservation of wild life** are : (i) protection of life in natural as well as artificial habitats, (ii) preference for threatened species over others in conservation programme, (iii) maintenance of life-supporting systems (air, water and land), (iv) safeguarding of critical habitats, (v) preservation of the ecosystem rather than a single species, (vi) discouraging the over-exploitation of species of ecosystem, (vii) stopping trade of rare species, (viii) protection of migratory animals by international agreements, (ix) integration of national conservation programmes with international ones, and (x) setting up of national parks and sanctuaries.
- Conservation are categorized into **in-situ** and **ex-situ**.
- *In situ* **conservation** is the protection and management of important components of biological diversity through a network of protected areas.
- **Protected areas** are ecological/biogeographical areas where biological diversity alongwith natural or cultural resources is protected, maintained and managed through legal or other effective measures.
- *In situ* conservation is being undertaken by **national parks**, **wildlife sanctuaries** and **biosphere reserves**. It is being conducted by Ministry of Environment and Forests. Joint Forest Management (JFM) is practised in 10.25 million hectares of degraded forests through 36075 village forest protection committees.
- **National parks** are reserves of land, usually owned by governments, that are protected from most human development and pollution.
- Cultivation, grazing, forestry and habitat manipulation are **not allowed in the national parks**.
- The idea of national park was **first formulated by painter George Catlin**.
- The World's **first national park is Yellow stone national park.**
- The **first National Park in India** was set up in 1935 in the foot hills of Himalayas in Uttar Pradesh and was known as **Hailey National Park**. It is now known as (after the famous wild life lover) **Corbett National Park.**
- National parks are large areas as scenic & national beauty maintained for scientific, educational & recreational area.
- **Dachigam National Park** is **famous for Hangul (Kashmiri stag)**.

- **Indian rhinoceros** is the **most important protected species** in **Kaziranga National Park.**
- **Orang National Park (Assam)** is one of **India's youngest national park** and home of the **World's third largest population of the one horned rhinoceros.** It covers only 78.8 sq. km area.
- **Sanctuaries** are tract of land with or without lake where wild animals or fauna can take shelter without being hunted.
- **Keoladeo Ghana National Park**, popularly known as Bharatpur is India'a **best known bird sanctuary**.
- The **Bharatpur Bird Sanctuary** known as **largest bird sanctuary in Asia**, which is much more famous as a refuge of migratory birds, like barons, ibis, pelicans and painted storks that make it their temporary home during the winter months.
- **Two splendid protected habitats situated in the Himalayan foothills** are the **Corbett National Park** and the **Dudhwa National Park** that provide an unforgettable wildlife experience.
- **Ashoka was the first ruler** in recorded history **to order the establishment of wild life sanctuaries**.
- **Project tiger** was started in **1973**. Its aim is to create reserves in selected areas of India to increase the tiger population.
- **Number of national parks and sanctuaries selected for 'Project Tiger'** as per latest information are **18**.
- The **famous tiger reserves in India** are **Corbett and Dudhwa** in **U.P.**, **Kanha** and **Indravati in M.P.**, **Simplipal in Orissa** etc.
- The **largest tiger reserve** in India is **Nagarjuna sagar**, Hyderabad.
- The **concept of biosphere reserve** was **evolved in 1986 by MAB** (Man and Biosphere) **programme of UNESCO**.
- **Biosphere reserves** are multipurpose protected areas which are **meant for preserving genetic diversity in representative ecosystem by protecting wild population, traditional life style of tribals and domesticated plant and animal genetic resources**.
- A biosphere reserve is basically **divided into the following zones - core zones** (no human activity is allowed), **buffer zone** (limited human activity is allowed), **manipulative zone** (where human activity is allowed but ecology is not permitted to be disturbed) and **restoration zone** (degraded area for restoration to near natural form).

- **3rd October** is known as **World animal day**.
- **29th December** is known as **biological diversity Day.**
- **5th June** is **World environment day.**
- **Wild life week** is **first week of October**.

- **First biosphere reserve** in India was set up in 1986 in **Nilgiri**.
- There are about **243 biosphere reserves in 65 countries of the world**.
- **Salim Ali Centre for Ornithology and Natural History** is **situated at Coimbatore**.
- **Asian lion** is only found in **Gir forest** of Gujarat.
- **Siberian crane** is **most peculiar winter visitor of Ghana bird sanctuary**. In this sanctuary, saurus crane is renowned for its breathtaking courtship dance.
- **Golden Langur** is found in the jungles of Assam state.
- Autobiography of Dr. Salim Ali is **"Father of a Sparrow"**.
- **Fastest animal** of the world is **Cheetah**. Its speed is 79 to 115 km per hour.
- **Largest living bird** is **African Ostrich**.
- **Fastest flying bird** is the **swift**. Flying speed is 171 km per hour.
- Bird that flies at maximum height is **Bar-headed Due** that can fly at a height of 20,000 meters.
- **"The old man of the jungle"** is **used for Orangutan**.
- Animal with **maximum height** is **Giraffe**.
- There have been about 83 national parks and 21 sanctuaries with a total area of about 1, 41, 298 sq.Km.
- Few **protected Indian wild life are** – Himalayan newt (*Tylototriton verrucous*), Gharial (*Gavialis gangeticus*), Leathery turtle (*Dermochelys coriacea*), Python (*Python molurus*), Great Indian bustard (*Choriotis nigriceps*), Great Indian hornbill (*Buceros bicornis*), Large falcons (*Falco peregrinus*), Siberian white crane (*Grus leucogeranus*), Black buck (*Antelope cervicapra*), Chital (*Axis axis*), Gangetic dolphin (*Platanista gangetica*), Golden langur (*Presbytis geci*).
- **Gahirmatha marine sanctuary** in Orissa is the **conservation breeding site for turtles**.

- Some country symbols based on animals are **India -** Tiger, **Australia** - Kangaroo, **China -** Giant panda, **USA -** Bald eagle, **Russia-**White bear etc.
- The **first recorded bird** that is now no more was **Dodo** of Mauritius.
- The number of **vertebrate species** facing extinction is **1000**.
- **Famous snake garden** of India is situated in **Madras.**
- **Flamingoes** are **protected in Chilka lake, Orissa**.
- *Ex situ* **conservation** is the conservation outside their (organism) habitats by perpetuating sample populations in genetic resources centres, zoos, botanical gardens etc.
- *Ex situ* conservation **includes offsite collection and gene banks**.
- **Offsite collection** are live collections of wild and domesticated species in **botanical gardens, zoos, arboreta** etc.
- **Gene banks** are institutes that **maintain stocks of viable seed** (seed banks), **live growing plants** (orchards), **tissue culture** and **frozen germplasm with the whole range of genetic variability**.
- Seeds are of **two types** – **orthodox** and **recalcitrant**.
- **Orthodox seeds** can tolerate reduction in moisture content (upto 5%), anaerobic conditions and low temperature of –10° to –20°C or even lower for prolonged periods, *e.g.,* cereals, legumes.
- **Recalcitrant seeds** are those seeds which get killed on reduction of moisture and exposure to low temperature, *eg.,* tea, cocoa, jackfruit, coconut. They can be stored for shorter duration after treatment with fungi in rooms having humid air and normal oxygen.
- Plants with recalcitrant seeds are grown in **orchards** where all possible strains and varieties are maintained, e.g., litchi, oil palm, rubber tree, etc.
- **Tissue culture** is carried out through callus formation, embryoids, pollen grain culture and shoot tip culture for those plants which are either seedless, have recalcitrant seeds, variable seed progeny or where clone is to be maintained.
- This method is **useful in maintaining a large number of genotypes in small area**, **rapid multiplication of even endangered species** and **for hybrid rescue**.
- **Shoot tip culture maintains virus free plants**. It is **used for international exchange of germplasm in vegetatively multiplied cultivars**, *e.g.,* **banana**, potato.
- **Cryopreservation** is preservation at –196ºC (liquid nitrogen) and which can maintain tissue culture, embryos, animal cells/tissues, spermatozoa indefinitely. The cryopreserved material is revived through special technique when required.
- Major *ex situ* conservation of biodiversity is being managed by **National Bureau of Plant, Animal and Fish Genetic Resources.** There is an International Crop research Institute for Semi-Arid Tropics (ICRISAT) in Hyderabad for conserving germplasm of groundnut, pigeon pea, chick pea, pearl millet and sorghum.

Table : Important protected wildlife and associated protected areas.

	Protected animal	Protected area/areas
1.	*Panthera leo* **(Lion)**	**Gir National Park, Junagarh (Gujarat).**
2.	*P. tigris* **(Tiger)**	18 National parks/sanctuaries under **"Tiger Project"** e.g. **Corbett National Park** (Uttranchal), **Hazaribagh Sanctuary** (Bihar), **Sunderbans Tiger Reserve** (W. Bengal), **Ranthambore N. Park** (Rajasthan), etc.
3.	*Rhinoceros unicornis* **(Rhino)**	**Kaziranga National Park** (Assam)
4.	*Moschus mosciferus* **(Musk deer)**	**Shikari Devi Sanctuary** (H.P.)
5.	*Choriotis nigriceps* **(Great Indian Bustard)**	**Desert National Park** (Rajasthan)
6.	*Cervus elephus hanglu* **(Kashmiri stag)**	**Dachigam National Park/Sanctuary** (J&K).

Table : Some national parks of India.

	Name, location and *area* (in sq. km.)	Important animals found
1.	**Kaziranga National Park,** District; Sibsagar (Assam) ***430***	**One-horned Rhinoceros**, elephant, wild buffalo, bison, tiger, leopard, sloth bear, sambhar, swamp deer, barking deer, wild boar, gibbon (hoolock gibbon), python and birds like pelican, and ring-tailed fishing eagles.
2.	**Sundarbans (Tiger Reserve)** 24-Pargana (West Bengal) ***2,585***	**Royal Bengal tiger**, wild boar, deer, gangetic dolphin, eustuarine crocodile.
3.	**Hazaribagh National Park,** Hazaribagh (Bihar) ***186***	Tiger, leopard, hyaena, wild boar, gaur, sambhar, nilgai, chital, slot.
4.	**Corbett National Park ,** District Nainital (**Uttar Pradesh** now in **Uttaranchal Pradesh**) ***525***	**Tiger**, elephant, panther, sloth bear, bear, wild boar, nilgai, sambhar, chital, crocodile, python, king cobra, peafowl, partridge. This is the **first National Park of India and is famous for tigers**.
5.	**Gir National Park,** District Junagarh **(Gujarat)** ***1,412***	**Asiatic lion,** panther, striped hyaena, sambhar, nilgai, chital, 4-horned antelope, chinkara, wild boar, langur, python, crocodile, green pigeon, partridge. **This National Park is famous for the Asiatic lions**.
6.	**Kanha National Park,** Mandla and Balaghat **(Madhya Pradesh)** ***940***	**Tiger**, panther, chital, chinkara, barking deer, blue bull, four horned deer, langur, wild boar, black buck, nilgai, wild dog, sloth bear, sambhar, crocodile, grey horn bill, egret, peafowl.
7.	**Tandoba National Park,** Chandrapur **(Maharashtra)** ***116***	**Tiger,** sambhar, sloth bear, bison, chital, chinkara, barking deer, blue bull, four horned deer, langur, peafowl, crocodile.
8.	**Bandipur National Park,** District Mysore **(Karnataka)** ***874***	**Elephant, tiger,** leopard, sloth bear, wild dog, chital, panther, barking deer, langur, porcupine, gaur, sambhar, malabar squirrel, green pigeon.
9.	**Desert National Park,** Jaisalmer (Rajasthan) ***3,000***	**Great Indian Bustard,** black buck, chinkara; desert cat, desert fox.

Some Other Important National Parks

1.	**Arunachal Pradesh**	Namdapha National Park
2.	**Assam**	Manas National Park
3.	**Bihar**	Palamau National Park
4.	**Kerala**	Silent Valley National Park, Periyar National Park
5.	**Madhya Pradesh**	Pench National Park
6.	**Meghalaya**	Nokrek National Park
7.	**Orissa**	Simlipal National Park
8.	**Rajasthan**	Ranthambore National Park, Sariska National Park
9.	**Sikkim**	Kengchend Zong National Park **(For Red Panda)**
10.	**Tamil Nadu**	Marine National Park (Gulf of Mannar)
11.	**Uttar Pradesh**	Valley of Flowers National Park, Nanda Devi National Park
12.	**Uttaranchal**	Dudhwa National Park
13.	**West Bengal**	Buxa National Park

Table : Some important sanctuaries of India.

	Name, location and *area* (in sq. km.)	Important animals found
1.	**Annamalai Sanctuary,** Coimbatore **(Tamil Nadu),** ***958***	Elephant, tiger, panther, gaur, sambhar, spotted deer, sloth bear, wild dog, barking deer.
2.	**Jaldapara Sanctuary,** Madarihat **(West Bengal),** ***1,155***	Rhino, elephant, tiger, leopard, gaur, deer, sambhar, **different kinds of birds.**
3.	**Keoladeo Ghana Bird Sanctuary,** Bharatpur **(Rajasthan)** (*Earlier it was once the duck shooting ground of a king*), ***29***	Siberian crane, storks, egrets, herons, spoon bill, etc. Drier parts of this marshy sanctuary have spotted deer, black buck, sambhar, wild boar, blue bull, python. **This sanctuary is famous for aquatic birds**.
4.	**Sultanpur Lake Bird Sanctuary,** Gurgaon **(Haryana),** ***12***	**Crane, sarus,** spotbill, duck, drake, green pigeon, wild boar, crocodile, python.
5.	**Bir Moti Bagh Wildlife Sanctuary,** Patiala **(Punjab),** ***8.3***	Nilgai, wild boar, hog deer, black buck, blue bull, jackal, peafowl, partridge, sparrow, myna, pigeon, dove.
6.	**Shikari Devi Sanctuary,** Mandi **(Himachal Pradesh),** ***213***	Black bear, snow leopard, flying fox, barking deer, **musk deer,** chakor, partridge.
7.	**Dachigam Sanctuary** Srinagar, **(Jammu and Kashmir),** ***89***	**Hangul or Kashmiri stag,** musk deer, snow leopard, black bear, brown bear.
8.	**Mudumalai wildlife Sanctuary** Nilgiri **(Tamil Nadu),** ***520***	**Elephant,** gaur, sambhar, chital, barking deer, mouse deer, four horned antelope, langur, giant squirrel, flying squirrel, wild dog, wild cat, civet, sloth bear, porcupine, python, rat, snake, monitor lizard, flying lizard.
9.	**Nagarjuna Sagar Sanctuary** Guntur, Kamool and Nalgonda (Andhra Pradesh)**,** **3, 568 km**	**Tiger**, panther, wild boar, chital, nilgai, sambhar, black buck, fox, jackal, wolf, crocodile.
10.	**Periyar Sanctuary**, **Idduki (Kerala),** **777 km**	**Elephants**, gaur, leopard, sloth bear, sambhar, bison, black langur hornbill, egret. It is **famous for elephants**.
11.	**Chilka Lake Bird Sanctuary**, Balagaon **(Orissa)** (*Largest brackish water lagoon in Asia*), **900 km**	**An oasis of birds like water fowls ducks**, crane's, Golden plovers, sand pipers, flamingoes.
12.	**Manas Wildlife Sanctuary**, Kamrup **(Assam)**	**Tiger**, panther, rhino, gaur, wild buffalo, sambhar, swamp deer, golden langur, wild dog, wild boar.

Some Other Important Sanctuaries of India

1.	**Andhra Pradesh**	Pulicat (Lake) Sanctuary
2.	**Chandigarh**	Sukhna Lake Sanctuary
3.	**Haryana**	Sultanpur Lake bird Sanctuary
4.	**Himachal Pradesh**	Govind Sagar bird Sanctuary
5.	**Karnataka**	Ranganathittu bird Sanctuary (Mysore)
6.	**Tamil Nadu**	Kalakad Sanctuary

Table : Biosphere reserves of India

	Biosphere Reserve	State(s)
1.	Nilgiri [First *biosphere reserve established in India (1986)*]	Kerala, Karnataka and Tamil Nadu.
2.	Namdapha	Arunachal Pradesh
3.	Nanda Devi (1988)	Uttar Pradesh
4.	Uttarakhand (Valley of flowers)	Uttaranchal in North Western Himalayas
5.	North Islands of Andamans	Andaman and Nicobar Islands
6.	Gulf of Mannar	Tamil Nadu
7.	Kaziranga	Assam
8.	Sunderbans	West Bengal
9.	Thar Deserts	Rajasthan
10.	Manas	Assam
11.	Kanha	Madhya Pradesh
12.	Nokrek (Tura range)	Meghalaya
13.	Great Nicobar	Andaman and Nicobar
14.	Little Rann of Kutch	Gujarat

Table : Some special projects for endangered animal species.

	Name of Project	Characters
1.	**Tiger project**	There are 25 tiger reserves in 13 or 19 states to save tigers. It was launched on 1st April, 1973.
2.	**Lion project** (Gir Lion Project)	Asian lion is found only in Gir forest of Gujarat. It was started in 1972.
3.	**Crocodile breeding project**	It was started in Orissa to save crocodiles in 1975. There are three species of crocodiles in India : (i) saltwater (*Crocodylus porosus*), (ii) fresh water muggar (*Crocodylus palustris*), (iii) gharial (*Gavialis gangeticus*). Being run by UNDP and central govt.
4.	**Rhino conservation project**	It was started in Assam in 1987. Dudhwa National park was selected for the rhino reintroduction project.
5.	**Snow leopard project**	There are 12 snow-leopard reserves in Himalayas.
6.	**Hangul project**	It was started in 1970 to protect hangul or Kashmiri stag (*Cervus elephus hanglu*).
7.	**Brow-antlered deer project**	It was started in Manipur since 1977 to protect brow-antlered deer (*Cervus eldi eldi*).
8.	**Musk deer project**	It was started by U.P. Government, IUCN and Central Government to protect musk-deer (*Moschus moschiferus*).
9.	**Elephant project**	It has been recently started (1991) to protect elephants.
10.	**Yak Project Research Centre**	It is in Arunachal Pradesh.

End of the Chapter

Chapter 64

Biotechnology & Genetic Engineering

BIOTECHNOLOGY

- Biotechnology means **any technological application that uses biological systems, living organisms, or derivatives thereof, to make or modify products or processes for specific use**.
- Biotechnology is an **important tool used for the production of food crops, livestock management, human health care, chemical industries and environmental management**.
- "Biotechnology" **generally refers to recombinant DNA based and/or tissue culture based processes** that have only been commercialized since the 1970s.
- One aspect of biotechnology is the direct use of organisms for the manufacture of organic products (examples include beer and milk products).
- Biotechnology is also used to recycle, treat waste, clean up sites contaminated by industrial activities **(bioremediation)**, and produce biological weapons.
- There are also applications of biotechnology that do not use living organisms. Examples are DNA microarrays used in genetics and radioactive tracers used in medicine.
- **Red biotechnology** is applied to medical processes. Some examples are the designing of organisms to produce antibiotics, and the engineering of genetic cures through genomic manipulation.
- **White biotechnology**, also known as **grey biotechnology**, is biotechnology applied to industrial processes.
- **Green biotechnology** is biotechnology applied to agricultural processes. An example is the designing of transgenic plants to grow under specific environmental conditions or in the presence (or absence) of certain agricultural chemicals.
- **Applications of biotechnology** are –
  - **Food and dairy products :** Yoghurt, cheese and butter require specific strains of micro-organisms during their preparation.
  - **Alcoholic and non-alcoholic beverages :** Beers, wines, etc. are produced through fermentation of different food by suitable micro-organisms. Curing of coffee beans and tea leaves is also a microbial process.
  - **Biofertilizers :** They are nitrogen fixing micro-organism which may live freely in soil or in association with plants.
  - **Organic acid :** A number of organic acids (acetic acid, lactic acid, etc.) are obtained through biotechnology.
  - **Vitamins :** Some vitamins are still manufactured with the help of micro-organisms. Food yeast is rich in both proteins and vitamins.
  - **Antibiotics :** Barring a few, all others are products of micro-organisms.
  - **Vaccines :** These contain attenuated or killed pathogens or their antigens.
  - **Monoclonal antibodies :** Antibodies against pathogen can now be obtained in pure form from clonal cultures.
  - **Hormones :** Insulin, growth hormone and other hormones are presently synthesized through the use of microbes and genetic engineering.
  - **Tissue culture :** An important tool for improvement of agriculture, forestry, synthesis of specific biochemicals etc.
  - **Genetic engineering :** Recombinant DNA technology is applied to several

biotechnological processes in obtaining particular biochemicals, improvement of genetic make–up of an organism and fighting undertaken for production of offspring of desired parents.

– **Steroids :** Micro-organisms are employed for transformation of one type of steroids into other types. These are required in antifertility formulations.

- **Yeast**, (*Saccharomyces cerevisiae*) is **the most important and most extensively used micro-organism** in **biotechnology**.
- Yeast cells are used in the manufacture of bread and also as a source of food, vitamins and other growth factors.
- There are **two types of yeasts: baker's yeast** and **alcohol yeast**.
- **Baker's yeast** is **grown on molasses** and sold as a food flavouring agent.
- **Alcohol yeast** is used by brewing industry for the production of different types of alcoholic beverages depending upon the medium and fermenting agent.
- There are two types of fermentation process: **batch fermentation** (or **closed system**) and **continuous process** (or **open system**).
- **Downstream processing** is the name given to the **stage after fermentation** when **desired product** is **recovered and purified**.
- **Cheese** is prepared by the **coagulation of casein** and other minor milk proteins (curdling of milk) by an **enzyme rennin extracted from calf gastric mucosa**.
- *Streptococcus* and *Lactobacillus* species are involved in the manufacture of most cheese.
- In cheese manufacture, micro-organisms are important in both souring and ripening processes.
- Semisoft blue **Roquefort cheese** of France is produced using the mold *Penicillium roqueforti.*
- **Yoghurt** is a preserved milk product having a distinct taste and a thick texture than milk.
- Yoghurt is made by fermenting whole milk with a mixture of *Lactobacillus bulgaricus, Streptococcus lactis* and *S. thermophilus* at 40º to 46ºC.
- **Gibberellins**, a plant growth hormone or phytohormone is obtained from a fungus called *Fusarium moniliformae* (or *Gibberella fujikuroi*). This was isolated by **Yabuta and Sumuki** (1939). At this time, over 52 gibberellins have been discovered from different plants.
- Louis Pasteur found that beer is produced by activity of yeast and yeast like micro-organisms. Yeast species used in alcoholic fermentation are *Saccharomyces cerevisiae* (Brewer's yeast), *S. ellopsoidens* (Wine yeast), *S. sake* (Sake yeast) and *S. pireformis* (Ginger beer/Ale yeast).
- **Acetic acid** is the most important organic acid used in industry.
- **Vinegar** is the **product resulting from the conversion of ethyl alcohol to acetic acid** by the bacteria *Acetobacter*.
- **Lactic acid** was the **first acid to be produced** microbially by *Lactobacillus delbrueckii*.
- *Aspergillus niger* and *Mucor* sp and yeast can ferment sugar to produce **citric acid**. It is used in medicine, flavouring extracts food and candies, manufacturing of ink, dyeing and engraving.
- **Gallic acid** is obtained using *Aspergillus niger.*
- **Gluconic acid** is manufactured with the help of *Penicillium purpurogenum* and *P. chrysogerium*. It is used in pharmaceuticals. **Calcium gluconate is used as a source of calcium in feeding infants** and **pregnant women** and **for treatment of milk fever in high producing dairy cows**.
- **Dextran** is a **plasma expander used in blood transfusions**.
- Dextran is a **complex polysaccharide prepared either through partial hydrolysis of starch or polymerization of sucrose** by the bacterium *Leuconostoc mesenteroides.*
- Some important enzymes produced industrially by microbes are **amylase**, **glucoamylase**, **glucose isomerase** and **proteases**.
- **Amylase** which attacks starch is **used in the manufacture of beer**, **bread and textiles**.
- Glucose can be attacked by **glucose isomerase** to **produce fructose corn syrup** which is sweeter than either glucose or sucrose and is **used in the production of soft drinks** and in **baking industry to sweeten biscuits and cakes**.
- The enzyme **Tissue Plasminogen Activator** (TPA) is **used for dissolving blood clots**.
- The technique of anchoring an enzyme in or on support material is called **immobilization**.
- Immobilized enzymes are generally used for bioreactors in a continuous process.
- **Cross-linking of enzymes** involves the chemical

reaction of the amino group of enzyme protein with glutaraldehyde.

- The **bonding** of enzyme can be done through **adsorption**, **ionic bonding or covalent bonding**.
- **Enzyme inclusion** involves the incorporation of enzyme into a semipermeable membrane.
- Most of the **vitamins** are made **commercially by chemical synthesis**.
- **Vitamin C** was the **first vitamin to be produced** by a fermentation process using *Acetobacter,* a wild bacterium.
- Bacteria used for industrial production of **vitamin B_{12}** are *Propionibacterium shermanii, P. frendenreichii* and *Pseudomonas denitrificans*.
- **Vitamin B_2** (Riboflavin) is synthesized by many micro-organisms including bacteria, yeasts and fungi. The fungus, *Ashbya gossypii* is **used for the microbial production of vitamin B_2**.
- **Antibiotics** are chemical substances produced by certain micro-organisms that kill or inhibit the growth of other micro-organisms.
- **Alexander Fleming, Howard Florey** and **Ernst Boris Chain** received **Nobel Prize** in 1945 **for the discovery and development of Penicillin**.
- **Streptomycin** was first isolated by **Selman A. Waksman**.
- **Gram-positive bacteria** are **usually more sensitive to antibiotics** than Gram-negative bacteria.
- An antibiotic that acts on a variety of pathogenic organisms is called a **broad spectrum antibiotic**.
- **Vaccination** or administration of vaccine was **discovered by Edward Jenner** (1796) when he immunised a boy against small pox by inoculating him with milder cow pox. The technique of attenuating or weakening of pathogen was

Table : Types of antibiotic with their source and action

Antibiotics	Source	Action
Penicillin	*Penicillium chrysogenum*, *P. notatum* + Phenyl Acetic Acid	Tonsilitis, Sore Throat, Gonorrhoea, Rheumatic Fever, some Pneumonia types
Griseofulvin	*Penicillium griseofulvum*	Antifungal, especially for Ringworm
Nystatin	*Streptomyces noursei*	Antifungal for Candidiasis and overgrowth of Intestinal Fungi during excessive antibiotic treatment.
Hamycin	*Streptomyces pimprei*	Antifungal for Thrush
Fumagillin	*Aspergillus fumigatus*	Broad spectrum antibacterial especially against *Salmonella* and *Shigella*.
Bacitracin	*Bacillus licheniformis*	Syphilis, Lymphonema or Reticulosis.
Streptomycin	*Streptomyces griseus*	Meningitis, Pneumonia, Tuberculosis and Local Infections. Toxic in some through eighth cranial nerve.
Chloramphenicol Chloromycetin	*Streptomyces venezyelae, S. lavendulae,* Now synthetic	Typhoid, Typhus, Whooping cough, Atypical Pneumonia, Bacterial Urinary Infections
Tetracyclines/ Aureomycin	*Streptomyces aureofaciens*	Viral pneumonia, Osteomyelitis, Whooping Cough. Eye infections.
Oxytetracycline/ Terramycin	Chlorotetracycline $\rightarrow$ Hydrogenation *Streptomyces rimosus*	Intestinal and Urinary Infections (Spirochaetes, Rickettsiae, Viruses)
Erythromycin	*Streptomyces erythreus* (= *S. erythraeus*)	Typhoid, Common Pneumonia, Diphtheria, Whooping Cough, etc.
Gentamycin	*Micromonospora purpurea*	Effective against Gram (+) bacteria
Polymixin	*Bacillus polymyxa*	Antifungal

discovered by Louis Pasteur (1879, against cholera).

- **Vaccines** are suspensions or killed or modified pathogenic micro-organisms; when injected into an animal, these produce immunity to a particular disease.
- Biotechnology has proved successful in the development of recombinant vaccines also known as '**second-generation vaccines**' and even **'third-generation vaccines'** (synthesized vaccines).
- **Hepatitis B vaccine is** a **second generation vaccine**.
- Vaccines produced using genetic engineering can usually be made faster than those manufactured by traditional methods.
- Genetically engineered vaccines are safer, more reproducible and can be administered in high doses without fear of side effects.
- **Monoclonal antibodies** are made outside the body by the hybrid cell cultures known as **hybridomas**.
- The cells obtained from cancerous tumors are known as **myeloma**.
- B-lymphocytes are mixed with myeloma cells resulting in hybridoma.
- The hybridoma cells are identified when all cells are grown in a medium deficient in the nutrient needed by myeloma cells.
- To produce monoclonal antibodies, B-cells are removed from the spleen of an animal that has been challenged with the relevant antigen.
- These B-cells are then fused with myeloma tumor cells that can grow indefinitely in culture (myeloma is a B-cell cancer).
- This fusion is performed by making the cell membranes more permeable.
- The fused hybrid cells (called hybridomas), being cancer cells, will multiply rapidly and indefinitely and will produce large amounts of the desired antibodies.
- They have to be selected and subsequently cloned by limiting dilution. Supplemental media containing Interleukin-6 (such as briclone) are essential for this step.
- Monoclonal antibodies are true **magic bullets**, striking specific molecules and leaving the rest of the body unharmed.
- Monoclonal antibodies (mAb) are antibodies that are identical because they were produced by one type of immune cell and are all clones of a single parent cell.
- One clinical application of monoclonal antibodies is **immune suppression for kidney transplantation**.
- Monoclonal antibodies have also been used in **genetics engineering for identifying and measuring levels of gene products not detectable by other methods**.
- Monoclonal antibodies are **used in pregnancy testing**, **diagnosis of disease, treatment of disease, preventing rejection of transplants and tissue typing for transplants**.
- They are **also very useful in immunohistochemistry** which detect antigen in fixed tissue sections. Monoclonal antibodies can also be used to purify a substance with techniques called immunoprecipitation and affinity chromatography.
- One possible treatment for cancer involves monoclonal antibodies that bind only to cancer cell-specific antigens and induce an immunological response against the target cancer cell.
- Such mAb could also be modified for delivery of a toxin, radioisotope, cytokinin or other active conjugate; it is also possible to design bispecific antibodies that can bind with their Fab regions both to target antigen and to a conjugate or effector cell.
- In fact, every intact antibody can bind to cell receptors or other proteins with its Fc region.
- **Insulin** is a protein consisting of two short polypeptide chains **A** and **B** of 21 and 30 amino acids respectively interconnected by two **disulphide bridges**.
- Insulin **regulates sugar metabolism and insufficiency or lack of insulin leads to high blood sugar level** and the disease is called **diabetes**.
- **Banting and Best** (1921) isolated insulin from pancreas of dog and demonstrated its efficacy in curing diabetes in humans.
- In 1983, 5 July, American Company Eli Lilly prepared two DNA sequences corresponding to A and B insulin chains when introduced in plasmids of *E. coli*, insulin chains were formed. They were extracted and fused to produced **humulin (human insulin)**.
- **Growth hormone** is required to overcome pituitary dwarfism caused by nonsecretion of hormone from anterior pituitary.
- The DNA/gene cDIVA (without introns) required for synthesis of growth hormone is first synthesized

and integrated with bacterial plasmid (trp gene). The latter produces the required hormone. It has been also been produced produced inside silk worm.

- **Interferons** (antiviral proteins) were produced by Charles Weismann of Zurich University through recombinant-DNA technology in *E. coli* in 1980.
- **Transgenic plants** are plants with specific genes or traits obtained through genetic engineering of DNA recombinant technology, *e.g.*, resistance to hornworm larvae (tomato), resistance to corn borer (Bt corn with gene from Bacillus *thuringiensis*), resistance to over-ripening (tomato), good protein content (potato), herbicide resistance (tobacco).
- **Transgenic animals** are animals having specific genes obtained from outside, *e.g.*, tissue plasminogen activator in milk (goat), blood clotting factor VIII (sheep from progeny of ewe Eithel).
- Cowdung, farm refuse, garbage etc are placed in biogas plants where anaerobic conditions allow methane bacteria to produce methane and other fuel gases called as biogas. The organic remains of the biogas plants are used as manure.
- **Biofertilizers** are mostly nitrogen fixing micro-organisms which may live free in the soil or form associations with plants. Special strains of these organisms are now inoculated to soil or seeds.
- The main technique involved in agricultural biotechnology is called **tissue culture**.
- The medicinally important plant products can be manufactured on a commercial scale by using cell and tissue culture techniques.
- Recombinant DNA technology is applied to several biotechnological process in obtaining particular biochemicals, improvement of genetic make up of an organism and fighting genetic defects.
- **Test tube babies and embryo transplants** are now being routinely undertaken for production of offspring of desired parents.
- **Steroids** are complex crystalline lipids having tetracyclic hydrocarbon core, with one 5-carbon ring and three 6-carbon rings.
- Most steroid bioconversions involve **hydroxylation** and **a variety of different fungi are used industrially to carry out one or another specific hydroxylations**.
- **Four major steroids** currently produced by bioconversion are **hydrocortisone, cortisone, prednisone** and **prednisolone**.
- Some microbes used in microbial transformations of steroids are *Rhizopus nigricans, R. arrihizus, Cunninghamella blakesleeana, Curvularia lunata* and *Corynebacterium simplex*.
- Steroids are **used medicinally in correcting hormonal imbalance**, as **anabolic stimulants, birth control pills** (progesterone ± estrogen), **antifertility drugs** (*e.g.*, diosgenin), **anti-inflammatories**, **for relieving pain** and **suppressing immune responses**.

Biopatent, Biopiracy and Biowar

- A **patent is a monopoly granted to a person** who has either invented a new and useful article, made and improvement of an existing article or invented a new process of making an articles.
- A patent is granted by the legal system, therefore it is a subject which cannot be fully understood without knowing the law on the subject.
- Biopatents are awarded for the following as strains of micro-organisms, cell lines, genetically modified strains of plants and animals, DNA sequences, the proteins encoded by DNA sequences, various biotechnological procedures, production processes, products and product applications.
- The **human breast cancer gene** (BRCA1) was patented in the US once its base sequence had been determined and attempts are being made to patent the second breast cancer gene (BRCA2).
- **Biopiracy** (or **biocolonialism**) is the appropriation of another's knowledge of use of biological resources.
- **Intellectual Property Right** (IPR) claims by the formal sector over the work of the informal constitutes biopiracy.
- Three **aspects of biopiracy** are –
  – **Intellectual Piracy:** This makes a false claim to novelty and invention, even though the knowledge has evolved since ancient time.
  – **Resource Piracy:** This divests scarce biological resources to monopoly control of corporations thus depriving communities and indigenous practitioners.
  – **Economic Piracy:** It creates market monopolies and excludes the original innovators from their rightful share to local, national and international markets.

- Neem, *Azadirachta indica,* has been used by the people of India in a variety of ways for time immemorial.
- The patenting of the fungicidal properties of neem was an example of biopiracy.
- An American university patented the healing properties of **turmeric powder,** cherished in India since ancient times for its powder to cure the wounds.
- **Biological resources** or **bioresources** include all those organisms that can be used to derive commercial benefits.
- Traditional knowledge related to bioresources is the knowledge developed by various communities over long periods of history, regarding the utilization of the bioresources, *e.g.,* use of herbs as drugs.
- **Biowar** or **biological war** or **bioterrorism** is the deployment of biological weapons against people, their crops and animals.
- A biological weapon or bioweapon **carries and delivers to the target organism a pathological biological agent or a toxin derived from it**.
- Mass-produced pathogens or their toxins are delivered either as powder or in the form of spray, using a variety of delivery devices.
- Among weapons of mass destruction, biological weapons are more destructive than chemical weapons including nerve gas.
- Bioweapons (a) are low-cost weapons, (b) cause far more casualities than chemical or conventional weapons, and (c) bioweapon agents are invisible and extremely difficult to detect.
- The first reported use of biological weapons was in 5th century BC, when **Assyrians** poisoned enemy wells with rye ergot.
- During many occasions, **smallpox** was used as a biological weapon.
- Iraq is reported to have conducted research and development work on anthrax, botulin, aflatoxin, wheat cover smut and ricin.
- Anthrax spores were used against USA and her allied countries by Al-Qaeda activists.
- Various poisons produced by different biological pathogens act like some neurotoxin, such as **saxitoxin** can kill individuals by blocking nerve conduction directly.
- The possible defences against bioweapons include the use of respirator or gas mask, vaccination, administration of appropriate antibiotics and decontamination.
- Biological warfare agents include –
  - **Pathogens :** Smallpox virus, Viral encephalitides, Viral haemorrhagic fevers, *Bacillus anthracis*, *Brucella suis*, *Coxiella burnetii*, *Francisella tularensis*, *Yersinia pestis*.
  - **Toxins :** Botulinum, Ricin, Stylococcal enterotoxin B.
  - **Anticrop agents :** Rice blast, Rice stem rust, wheat stem rust.
- **Bioethics** is the branch of ethics, philosophy and social commentary that deals with the biological sciences and their potential impact on society.
- The **major bioethical concerns pertaining to biotechnology** are –
  - Use of animals in biotechnology causes great suffering to them.
  - When animals are used for production of pharmaceutical proteins, they are virtually reduced to the status of a 'factory'.
  - Introduction of a transgene from one species into another species violates the 'integrity of species'.
  - Transfer of human genes into animals (and *vice-versa*) dilutes the concept of 'humanness'.
  - Biotechnoloy is disrespectful to living beings and only exploits them for the benefit of human beings.
  - Biotechnology may pose unforeseen risks to the environment, including risk to biodiversity.
- **Bioinformatics** is an interdisciplinary field which addresses biological problems using computational techniques.
- The field is also often referred to as computational biology.
- It plays a key role in various areas, such as functional genomics, structural genomics, and proteomics, and forms a key component in the biotechnology and pharmaceutical sector.

GENETIC ENGINEERING

- Genetic engineering is the **technology involved in synthesis of artificial genes, repair of genes through fusion, deletion, inversion, shifting of genes, products of recombinant DNA** & **manipulating them** for improvement in human beings, plants, animals and microbes.

- Genetic engineering is the **most powerful technique available in applied genetics**.
- An **important aspect** of genetic engineering is **recombinant DNA technology**.
- Recombinant DNA technology is **employed for** combining **DNA from two different organisms to produce recombinant DNA**.
- The process involves the following steps –
  - Separation of a desired DNA segment from donor organism
  - Selection of suitable vector
  - **Cutting DNA into specific fragments** using enzyme restriction endonuclease and **joining the fragments with the help of enzyme ligase**.
- The technology of genetic engineering came into existence after the **introduction of genes of SV-40 into the bacterium with the help of lambda phage (Berg 1970s)**.
- **Paul Berg** is the **father of genetic engineering** (Nobel Prize, 1980).
- **First nonfunctional artificial gene** of alanine *t* RNA having 77 nucleotides pairs was synthesized by **H.G.Khorana *et al* (1968)**.
- **First functional artificial gene** was tyrosine *t*RNA gene with 207 nucleotide pairs (H.G.Khorana *et al* 1971).
- In 1981, **Edge *et al*** synthesized **IFN-α gene** (human leucocyte interferon gene) with 514 base pairs.
- Addition of DNA ligases produces **recombinant DNA**.
- The technology associated with the construction and application of **recombinant DNA** (which is generated *in vitro* by covalently joining DNA molecules from different sources) is referred to as **genetic engineering** or **gene splicing** or **gene manipulation**.
- **Enzymes used in genetic engineering** to perform specific functions are –
  - **Restriction endonuclease** (cut DNA at specific sites)
  - **DNA ligase** (join the cut DNA)
  - **Exonuclease** (digest the base pairs on 5′ or 3′ end of a single stranded DNA or at single stranded nicks or gaps in double stranded DNA)
  - **Endonuclease** (cleave the double stranded DNA at any point except the ends)
  - **DNA polymerase** (polymerises the DNA synthesis on DNA template)
  - **Reverse transcriptase** (used to synthesize cDNA by using *m*RNA template).
- **Vectors** (also known as **vehicle DNAs**) are those DNA molecules that can carry a foreign DNA fragment when inserted into it.
- The vectors are grouped into **bacterial plasmids**, **bacteriophage**, **cosmids** and **phasmid**.
- **The vehicle DNA carrying passenger DNA is called recombinant DNA (chimeric DNA)**.
- **Plasmids** (like p^{BR322}, p^{BR324}, p^{C194} etc) are the extrachromosomal, self-replicating and double stranded closed and circular DNA molecules present in the bacterial cell.
- **Cohen *et al*** (1973) for the first time reported the cloning DNA by using plasmid as vector.
- Bacteriophages (a virus that eats upon bacteria) are **required for cloning of large DNA fragment**.
- The **cosmids** (like p^{JC74}, p^{JC720} etc.) can be defined as the **hybrid vectors derived from plasmids which contain *cos* site of phage l**.
- A phage genome containing *att* site and one or more plasmid molecule (s) is known as **phasmid**.
- One use of transgenic animals is to produce relatively large quantities of rare and expensive proteins for use in medicine, a process sometimes referred to as '**pharming**' of drugs.
- Detecting mutant genes in an individual is known as **genetic screening**.
- Genetic screening **reduces suffering of both victims of genetic disease** (Thalassemia, sickle cell anaemia) and their families.
- **Eugenics** is the study of the possible improvement of the genetics of a species.
- **Genetic counselling** is the advice given to a couple or prospective couple or their families about the possibility of genetic disorders in the future (unconceived) baby and in an early foetus as an aid to decision making about marriage or having children. Advice is given by physicians or professional human geneticists. They are called **genetic counsellors**.
- Genetic engineering techniques give a scope to learn a great deal about the **human genome**.

- The human genome contains some **3.2 billion bases**.
- **Genome sequencing** has revealed that organisms have many genes in common. Surprisingly, humans have a small genome, only a third larger than nematode worm.
- **Proteomics**, the next step of human genome project deals with cataloguing and analysis of every protein in the human body.
- A **biochip** is a discrete collection of gene fragments on a stamp-sized chip that can be used to screen for the presence of particular gene variants.
- Biochips allow rapid screening of gene profiles, a tool that promises to have a revolutionary impact on medicine and society.
- Biochips can **help in identifying precise forms of cancer**.
- **Gene therapy** is the treatment of disease by replacing, altering, or supplementing a gene that is absent or abnormal and whose absence or abnormality is responsible for the disease. Gene therapy is unique in that it employs the genetic material, DNA, itself as the means of treatment.
- During gene therapy, DNA that codes for specific genes is delivered to individual cells in the body.
- Gene therapy is **being used in many ways**. For example, to:
  - Replace missing or defective genes
  - Deliver genes that speed the destruction of cancer cells
  - Supply genes that cause cancer cells to revert back to normal cells
  - Deliver bacterial or viral genes as a form of vaccination
  - Provide genes that promote or impede the growth of new tissue
  - Deliver genes that stimulate the healing of damaged tissue.
- A large variety of genes are now being tested for use in gene therapy. *Examples include :* a gene for the treatment of cystic fibrosis (a gene called **CFTR** that regulates chloride); **genes for factors VIII and IX**, deficiency of which is responsible for classic haemophilia (haemophilia A) and another form of haemophilia (haemophilia B), respectively; genes called **E1A** and **P53** that cause cancer cells to undergo cell death or revert to normal; **AC6** gene which increases the ability of the heart to contract and may help in heart failure; and **VEGF**, a gene that induces the growth of new blood vessels (angiogenesis) of use in blood vessel disease.

Cloning

- Cloning is the production of copies that are genetically identical to the parent.
- Cloning is **absent in higher animals except** for occasional monozygotic split ups.
- Cloning is of **three types** – **cell cloning, gene cloning** and **organismal cloning**.
- **Cell cloning** is the formation of multiple copies of the same cell. Cells of a clone are identical genetically, morphologically and physiologically.
- **Totipotency** or ability to divide indefinitely and differentiate into full fledged organisms is present in most plants cells. In case of animals, it is found only in zygote (fertilized egg) and embryonic stem cells.
- Animal cells can **have pleuripotency or potential ability to develop into any other type of cell in the animal body,** *e.g.*, kidney cells, heart cells, liver cells, nerve cells.
- **HeLa cells** are **aneuploid strain of cell lines** from cervix carcinoma of a patient Henrietta Lacks which have been grown continuously since 1952. They have been used in the study of various life processes including infection by viruses.
- **Hybrid cells** are obtained through protoplast fusion of human and mouse cells (first carried out by Burski *et al*, 1960). Hybrid cells can be made to grow and divide indefinitely under proper culture conditions. The **cells are used for mapping genes, study of cancer formation and regulation of gene expression**.
- Recently techniques are being perfected to grow full fledged organs from small pieces containing stem cells and organ cells. Pig organs can also be used in organ transplantation provided they are genetically modified to prevent rejection from human immune system. This technique is called **organ culture**.
- **Gene cloning** is the formation of multiple copies of same gene.
- It is achieved by recombinant DNA technology. The steps include –
  - The production of a lineage of cells all of which contain one kind of DNA fragment of

interest derived from a population of many kinds of DNA fragments.
- Operational by inserting (recombining) a population of DNA molecules.
- Known to contain the DNA of interest, into a population of vector DNA molecules in such a way that each vector molecule contains only a single DNA molecule from the original population.
- Transforming a population of host cells with the vector DNA recombinants such that each host cell takes up only one vector.
- Growing single host cells separately (cloning) by plating at low density to form a collection of separate colonies.
- Screening the colonies (clones) formed for the presence of the DNA of interest.

- **Organismal cloning** is the formation of one or more genetically identical individual from a single parent.
- The lamb **Dolly** is the **first successful clone** derived from differentiated animal cell **(Wilmut and Campbell 1997)**.
- They took cells from the udder of a six year old sheep. The cells were arrested in G_0 – phase by serum starvation. Unfertilized egg of another adult sheep was taken out when it was receiving optimum amount of maturation promoting factors. The egg was denucleated. Nondividing nucleus of an udder cell was taken out and inserted in the denucleated egg. In nutrient medium the egg began to undergo cleavage. The young embryo was implanted in the womb of a third sheep. The surrogate mother gave birth to normal healthy lamb, Dolly, on February 13, 1997.
- In **molecular cloning**, the DNA fragment of interest is amplified *in vivo* in a population of proliferating cells.
- A **cloning vector** is a genetic element derived from a plasmid or virus which is exploited to carry extra DNA (**donor**, **foreign**, **insert** or **passenger DNA**).
- Crown gall producing bacterium, *Agrobacterium tumefaciens*, possesses tumor inducing or Ti plasmids. The plasmids pass the tumor producing gene into the genome of the host plant. The transformed host genome produces galls. Because of this *Agrobacterium* functions as **natural genetic engineer of plants**.
- The modified plasmid of *Agrobacterium* is made to carry the desired gene. It is called **T-DNA**. The same can be directly inserted into nucleus of host plant cells.
- Alternately T-DNA is also made to carry a gene for antibiotic resistance.
- *Agrobacterium* mediated gene cloning has been carried out in many dicotyledonous plants (*e.g.*, sunflower, cotton, potato, tomato) as well as all the major cereals recently (*viz.* wheat, maize, rice).
- The animal, derived from a mixture of two genetically different types of cells, some derived from the normal stem cells and some derived from the transformed stem cells, is known as **chimera**.
- **Gene bank** or **genomic library** is a complete collection of cloned DNA fragments which comprises the entire genome of an organism.
- **Gene banks** are a means of preserving genetic material, be it plant or animal. In plants, this could be freezing the plant, or the seeds themselves.
- In plants, it is possible to unfreeze the material and sow it, however, in animals, a living female is required for artificial insemination.
- Despite this, it has proven very difficult to utilize the genes after freezing.

Techniques of genetic engineering

PCR

- **Polymerase chain reaction** (**PCR**) is a biochemistry and molecular biology technique for enzymatically replicating DNA without using a living organism, such as *E. coli* or yeast.
- Like amplification using living organisms, the technique allows a small amount of DNA to be amplified exponentially.
- PCR can amplify specific sequences or add sequences (such as endonuclease recognition sequences) as primers to cloned DNA.
- The **enzyme used in PCR** is **Taq polymerase**.
- As PCR is an *in vitro* technique, it can be performed without restrictions on the form of DNA and it can be extensively modified to perform a wide array of genetic manipulations.
- PCR is **commonly used in medical and biological research labs for a variety of tasks,** such as the

Table : Products from genetically engineered microbes

1.	*Escherichia coli* (gut bacterium)	Human insulin, human growth factor, interferons, interleukin, tissue plasminogen activator, epidermal growth factors, lung surfactant protein, factor VIII, viral vaccines.
2.	*Bacillus thuringiensis* (soil bacterium)	Endotoxin (Bt toxin), highly potent, safe and biodegradable insecticide.
3.	*Rhizobium meliloti* (symbiont nitrogen fixing bacteria)	Transfer of 'Nif' genes to cereal crops.
4.	*Pseudomonas fluorescence* (bacterium)	Prevents frost damage (e.g., Strawberry) on which it grows. Biochemicals extracted from bacterium also have similar effect.
5.	*Pseudomonas putida* (bacterium)	Bioremediation or purification of environment – scavenging oil spills by digesting hydrocarbons, metabolism of heavy metals and other biochemicals.
6.	*Trichoderma* (fungus)	Produces enzyme chitinase for biocontrol of fungal diseases in plants.
7.	*Trametes* (fungus)	Removal of lignin from wood pulp.

detection of hereditary diseases, the identification of genetic fingerprints, the diagnosis of infectious diseases, the **cloning of genes, paternity testing,** and **DNA computing**.

- The reaction is easy to execute.
- It requires no more than a test tube, a few simple reagents, and a source of heat."

RAPD

- **RAPD stands for random amplification of polymorphic DNA**.
- It is a **type of PCR reaction,** but the segments of DNA that are amplified are random.
- The scientist performing RAPD creates several arbitrary, short primers (8-12 nucleotides), then proceeds with the PCR using a large template of genomic DNA, hoping that fragments will amplify.
- No knowledge of the DNA sequence for the targeted gene is required, as the primers will bind somewhere in the sequence, but it is exactly not certain where.
- This makes the method popular for comparing the DNA of biological systems that have not had the attention of the scientific community, or in a system in which relatively few DNA sequences are compared (it is not suitable for forming a DNA databank).
- Due to the fact that it relies on a large, intact DNA template sequence, it has some limitations in the use of degraded DNA samples.
- Its resolving power is much lower than targeted, species specific DNA comparison methods, such as short tandem repeats.

RFLP

- In molecular biology, the term **restriction fragment length polymorphism** (or **RFLP**, often pronounced "rif-lip") is used in two related contexts: as a characteristic of DNA molecules (arising from their different nucleotide sequences) by which they may be distinguished, and as the laboratory technique which uses this characteristic to compare DNA molecules.
- The technique is utilized in genetic fingerprinting and paternity testing.

DNA fingerprinting or Genetic fingerprinting

- DNA finger printing is the technique in which the banding pattern of DNA fragments is compared and can be used in many species, including human, to indicate relatedness (used for rape victim, paternity, other criminals).
- **Dermatoglyphics** is the **science of finger printing** which was developed during a murder investigation in Jalpaiguri (WB) in 1897.
- It deals with the study of pattern of ridges of the skin of fingers, palms, toes and soles.
- Dermatoglyphics is **used in establishing identity of individuals**. It can **also indicate genetic abnormalities**.

- **More sensitive version of DNA finger printing is DNA profiling** (most commonly used method in forensic work).
- **Genetic fingerprinting**, **DNA testing**, **DNA typing**, and **DNA profiling** are **techniques used to distinguish between individuals of the same species using only samples of their DNA**.
- Its invention by Sir Alec Jeffreys at the University of Leicester was announced in 1985. Two humans will have the vast majority of their DNA sequence in common.
- Genetic fingerprinting **exploits highly variable repeating sequences called minisatellites** (VNTR's).
- DNA of each individual has some noncistronic hyper variable repeat minisatellite sequence. These repeat minisatellite sequence flanked by conserved restriction site are commonly called as (VNTRs) **variable number of tandem repeats**.
- **VNTRs** are **similar in twins only**.
- Two unrelated humans will be likely to have different numbers of minisatellites at a given locus.
- By using PCR enough DNA is obtained to detect the number of repeats at several loci.
- It is possible to establish a match that is extremely unlikely to have arisen by coincidence, except in the case of identical twins, who will have identical genetic profiles.
- Genetic fingerprinting is **used in forensic science,** to match suspects to samples of blood, hair, saliva or semen.
- It has also led to several exonerations of formerly convicted suspects.
- It is also used in such applications as identifying human remains, paternity testing, matching organ donors, studying populations of wild animals, and establishing the province or composition of foods.
- It has also been used to generate hypothesis on the pattern of the human diaspora in prehistoric times.
- Testing is subject to the legal code of the jurisdiction in which it is performed.

Southern blotting

- Southern blotting is a method in molecular biology of enhancing the result of an agarose gel electrophoresis by marking specific DNA sequences.
- The method is named after its inventor, the British biologist Edwin Southern.
- This caused other blot methods to be named similarly as plays on Southern's name (for example, Western blot, Northern blot, Southwestern blot (Detection of RNA is termed northern blotting.).

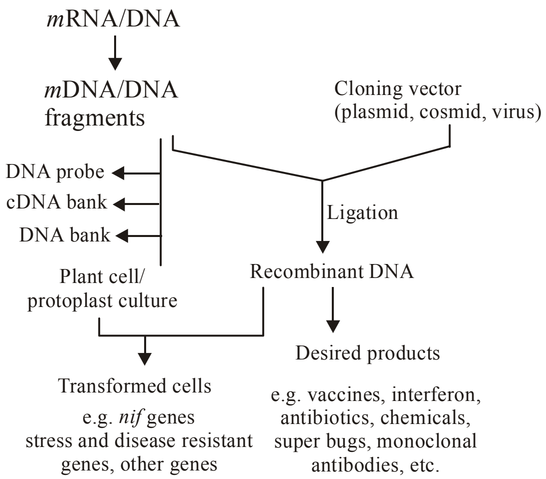
Western blotting

- A western blot is a **method in molecular biology/ biochemistry/immunogenetics to detect protein in a given sample of tissue homogenate or extract**.
- It uses gel electrophoresis to separate denatured proteins by mass. The proteins are then transferred out of the gel and onto a membrane (typically nitrocellulose), where they are "probed" using antibodies specific to the protein.
- As a result, researchers can examine the amount of protein in a given sample and compare levels between several groups.
- Other techniques also using antibodies allow detection of proteins in tissues (immunohisto-chemistry) and cells (immunocytochemistry).
- The name **western blot** was given to the technique by **W. Neal Burnette (1981)**.

Application of genetic engineering

- **Human insulin** or **humulin** is the first genetically engineered pharmaceutical product, developed by Eli Lilly and company in 1982.
- Genetech, a California-based company, have produced **human growth hormone** (hGH) from genetically engineered bacteria.
- **Somatostatin** is the first polypeptide, which was expressed in *E. coli* as a part of the fusion peptide.
- **BST** or **Bovine Somatotropin** is produced for a large quantity of milk production in cows.
- It is possible to cure **phenylketonuria** disease by using recombinant DNA techniques in early period of pregnancy.
- **Urokinase** is involved in dissolution of blood clots. It has been synthesized in huge quantity by using genetically engineered bacteria with urokinase genes.

Outline of applications of genetic engineering techniques in different areas



- **Human globin genes** has also been developed and cloned.
- By using gene cloning techniques the clotting factor VIII:C gene was cloned which expressed in mammalian cell lines and produced the protein VIII:C responsible for **blood clotting**.
- Recombinant DNA technology has helped in **increased production of antibiotics**; for example, the rate of penicillin produced at present is about 1,50,000 unit/ml against about 10 unit/ml in 1950s.
- A genetically engineered bacteria is capable of **cleaning up oil spills**.
- Organisms that have been genetically altered using the techniques of genetic engineering are generally referred to as **transgenic**.
- **Transgenic salmon** (a fish) is produced by inserting recombinant growth hormone genes into developing salmon embryos. They are 11 times heavier than non-transgenic salmon.
- **Weevil-proof peas, herbicide resistant crops** and **wilt-proof flowers** are produced by using genetic engineering.
- **Human enkephalin gene** has been expressed in plants thus producing medical drugs from crops instead of food.
- **Gene transfer** during transgenic plant formation includes (i) electroporation, (ii) particle bombardment (iii) micro injection, (iv) *Agrobacterium* - mediated gene transfer, (v) co-cultivation (protoplast transformation method), (vi) leaf disc transformation method, (vii) virus-mediated transformation, (viii) pollen-mediated transformation, (ix) liposome mediated transformation etc.
- In 1999, the Indian scientist at ICGEB, New Delhi have successfully produced transgenic maize, tobacco, rice etc. capable of producing **interferon gamma** (INF-γ).

End of the Chapter

Chapter 65

Domestication of Plants & Crop Improvement

DOMESTICATION OF PLANTS

- **Domestication** is a phenomenon whereby a wild biological organism is habituated to survive in the company of, or by the labour of, human beings.
- Domesticated animals, plants, and other organisms are those whose collective behaviour, life cycle, or physiology has been altered as a result of their breeding and living conditions under careful human control for multiple generations.
- **Humans have brought these populations under their care for beneficial uses**. It may be to produce food or valuable commodities (such as wool, cotton, or silk), for help with various types of work, transportation and to enjoy as pets or ornamental plants.
- Plants domesticated primarily for aesthetic enjoyment in and around the home are usually called **house plants or ornamentals**, while those domesticated for large-scale food production are generally called **crops**.
- All the present species of cultivated plants are of wild species origin and this **process of cultivation of wild species in order to fulfil human needs is called domesticaton of plants**.
- Domestication plays foremost role in development of human civilization.
- **Effective agriculture** is the result of domestication of crop plants.
- Origin of agriculture dates back to **7000–13,000 years ago** in high and well watered lands of Indus, Tigris, Nile and Euphrates.
- According to **Carl Scanner**, **nitrogen loving plants were the first wild weed plants**, which were then brought under cultivation.
- Cultivation of plants started with the help of vegetative parts in the form of tubers, bulbs, rhizomes, etc., but later on ability of seed to develop into new plant was recognized and most of the early civilizations like Babylonian, Egyptian, etc., developed on the basis of seed-generated crops like wheat, rice, maize, barley, etc. (cereals).
- Actually, the method of obtaining plants from seeds, is known as **cultivation**.
- The earliest human attempts at plant domestication occurred in Asia.
- There is early evidence for conscious cultivation and trait selection of plants by pre-Neolithic groups in Syria: grains of rye with domestic traits have been recovered from Epi-Palaeolithic (ca. 11,000 BC) contexts at Abu Hureyra in Syria, but this appears to be a localised phenomenon resulting from cultivation of stands of wild rye, rather than a definitive step towards domestication.
- By 10,000 BC the bottle gourd (*Lagenaria siceraria*) plant, used as a pre-ceramic technology container, appears to have been domesticated.
- The domesticated bottle gourd reached the Americas from Asia by 8000 BC, probably with peoples migrating into the continent from Asia.
- Cereal crops were first domesticated around 9000 BC in the Fertile Crescent in the Middle East.
- Origin of cereals actually took place in montaineous parts of both **old world** (Asia, Africa and Europe) and **new world** (America) and present day cereals were infact wild weeds.
- **Cereals** were actually the **first group of plants,** which were **brought under domestication** because of rapid growth, sufficient amount of reserve food and weediness.
- After direct food plants like cereals, plants with cooking qualities were brought under cultivation.

- Discovery of fire was an important reason behind it.
- So, now different other food plants like pulses, oil seeds along with cereals were discovered and man turned into actual farmer.
- The first domesticated crops were generally annuals with large seeds or fruits. These included pulses such as peas and grains such as wheat.
- The Middle East was especially suited to these species; the dry-summer climate was conducive to the evolution of large-seeded annual plants, and the variety of elevations led to a great variety of species.
- Domestication was gradual, a process of trial and error that occurred slowly.
- Over time perennials and small trees began to be domesticated including apples and olives.
- In different parts of the world very different species were domesticated.
- In the Americas squash, maize, and beans formed the core of the diet. In East Asia millets, rice, and soya were the most important crops.
- Some areas of the world such as Southern Africa, Australia and California and southern South America never saw local species domesticated.
- Over the millennia many domesticated species have become utterly unlike their natural ancestors.
- Corn cobs are now dozens of times the size of their wild ancestors.
- A similar change occurred between wild strawberries and domesticated strawberries.
- After discovery of single purpose plants, multipurpose plants were known and these brought into cultivation, *e.g.,* coconut, date palm, hemp, mulberry, etc.
- Despite long enthusiasm about revolutionary progress in farming, few crops became domesticated.
- Domesticated species, when bred for tractability, companionship or ornamentation rather than for survival, can often fall prey to disease: several sub-species of apples.
- One side-effect of domestication has been causing of disease.
- Domestication of wild species is still being done and is likely to continue for a long time in future. This is because the human needs are likely to change with time.
- The wild species of little importance today may assume great significance tomorrow. This is particularly true for micro-organisms producing antibiotics, involved in nitrogen-fixation and producing timber and other commercial products, medicinal plants.
- A notable case of recent domestication is that of several members of Euphorbiaceae producing latex. The latex of these plants may be commercially used for extraction of petroleum products including petrol and diesel.

Origin of cultivated plants

- The earliest view of origin of cultivated plants is that these plants are given by god in form of gifts. Later on it was said that wild types converted into cultivated types due to their cultivation under good agronomic conditions.
- Most important contribution made by a Russian worker called **N. I. Vavilov** (1926), who on the basis of his studies reported that there are eight primary centres of origin of cultivated plants, where all grades of variations from wild type species to cultivated types occur.
- These **primary centres** are dominated by **dominant genes**. In the course of cultivation, the plants spread to different parts of the world.
- In some **areas certain crop species show considerable diversity to form although they did not originate there**. Such areas are known as **secondary centres of origin of** these species.
- The centres of origin are **also called the centres of diversity**.
- There are 8 **main centres of origin as proposed by Vavilov**- China, Hindustan, Central Asia, Asia Minor, Mediterranean, Abyssinia, Central America and South America.
- **China** – This centre consists of the mountainous regions of Central and Western China and the neighbouring low lands. It is the **largest and the oldest independent centre of origin**. It is the **primary centre of origin** for **soyabean**, **radish**, **opium**, **poppy**, **brinjal**, **pears**, **peaches**, **plums**, **oranges** and **chinese tea** and **secondary centre of origin for maize**, **rajma**, **cowpea and sesame**.
- **Hindustan** – This includes Burma, Assam, Jalaya, Java, Sumatra and Phillipines but excludes North-Western India and North-Western Frontier provinces. It is the **primary centre of origin** for

rice, **pulses** (arhar, gram, cowpea, mung), **cucumber**, **nobel canes** (*Saccharum officinarum*), **cotton**, **mango** and **banana**.

- **Central Asia** – It includes North-Western India, whole of Afganistan, Tazakistan and Uzebekistan. It is the **primary centre of origin** for **wheat**, **pea**, **linseed**, **sesame**, **onion**, **garlic**, **spinach and grape** and the **secondary centre of origin** for **rye**.
- **Asia Minor** – It is also known as Near East Centre of origin and includes interior of Asia Minor, whole of Iran and high lands of Turkmenistan. It is the **primary centre of origin** for **rye**, **alfa alfa**, **carrot**, **oat**, **fig**, **pomegranate**, **apple and nuts**. and the **secondary centre of origin** for **rape** (*Brassica campestris*) and **black mustard** (*B. nigra*).
- **Mediterrean** – It is the **primary centre of origin** for **durum wheat**, **emmer wheat**, **barley**, **lentil**, **several species of *Lathyrus***, **pea**, **beets**, **lettuce**, **onion**, **garlic and cloves**.
- **Abyssinia** – It includes Ethopia and Eritrica. It is the **primary centre of origin** for **jowar**, **bajra**, **sem**, **safflower**, **castor**, **linseed and coffee** and **secondary centre** of **origin** for **broad bean**.
- **Central America** – It includes both Mexico and Central America. It is the **primary centre of origin** for **maize**, **cotton**, **rajma**, **pumpkin**, **papaya**, **guava and avacado**.
- **South America** – It includes high mountain regions of Peru, Bolivia, Eucador, Colombia, parts of Chile and Brazil and whole of Paraguay. It is **primary centre of origin** for **tomato**, **potato**, **tobacco**, **groundnut**, **rubber and pineapple**.

Degrees of domestication

- A classification system that can help solve the confusion might be set up on a spectrum of increasing domestication.
- **Wild** – These species experience their full life cycles without deliberate human intervention.
- **Raised at zoos or botanical gardens** – These species are nurtured and sometimes bred under human control, but remain as a group essentially indistinguishable in appearance or behaviour from their wild counterparts. (It should be noted that botanical gardens sometimes exhibit domesticated plants such as some orchids).
- **Domesticated** – These species or varieties are bred and raised under human control for many generations and are substantially altered as a group in appearance or behaviour.
- This classification system does not account for several complicating factors as genetically modified organisms, feral populations, and hybridization.
- Many species that are farmed or ranched are now being genetically modified.
- This creates a unique category because it alters the organisms as a group but in ways unlike traditional domestication.

Natural and artifical selection under domestication

- **Selection** may be described as the phenomenon in which some genotypes from a population leave behind more progeny than the others.
- In nature, there is a continuous selection by natural forces, eg., temperature, soil, moisture, pests, diseases, etc.
- The genotypes more suited to a given environment leaves behind more progeny than the less adapted ones. This process is known as **natural selection**.
- The **artificial selection** (selection by man) often permits only the selected plants to reproduce. Thus, man exerted considerable selection on the domesticated plant species.
- Artificial and natural selection have led to several distinct changes in characteristics of domesticated species.

Changes under domestication

- Some important changes that have occurred under domestication are enumerated as –
  - Reduction in shattering of pods, spikes, etc.
  - Elimination of dormancy in several crop species.
  - Decrease in toxins or other undesirable substances.
  - Cultivated plants show altered tillering, branching, leaf characters, etc.
  - Decrease in plant height as in the case of cereals and millets.
  - Increase in plant heights as in the case of jute, sugarcane and forage grasses.
  - Reduction in life cycle as in the case of cotton and arhar.
  - Increase in fruit and grain size.
  - Promotion of sexual reproduction as in the case of sugarcane, potato, sweet potato, etc.
  - Variability within a variety has drastically decreased under domestication (a negative effect).
  - Preference for polyploidy, for instance, potato, wheat, sweet potato, tobacco, etc. while, diploid plants are present in nature.

CROP IMPROVEMENT

- Crop improvement **proposes to obtain crops with higher yield, better quality, resistance to disease and shorter duration which are suitable to particular environmental conditions**.
- It involves two types of measures – **improved agricultural preparation** and **improvement of crop varieties.**
- Agricultural preparation includes, application of manures and fertilizers, protection against diseases and pests, proper irrigation, improved reaping, transport and storage of products.
- **Improvement of crop varieties** is a permanent measures which creates genetic potentiality in crop plants for higher and better yield.
- Genetic improvement of crops, along with the control of important diseases of crops, are very useful in increasing food production and food quality.
- Scientists connected with improvement of crop varieties are called **plant breeders**.
- **Plant breeding** is an applied branch of botany and deals with the improvement of cultivated varieties (cultivars) of plants.
- It is the improvement in the heredity of crops and production of new crop varieties which are far better than original types in all respects.
- The **aims of plant breeding differ with the type of crop, soil, climate,** etc. However, **some common objectives** are listed below –
  - To get higher yield.
  - To improve the quality, size, shape, colour, taste and storability (keeping quality) of the produce.
  - To improve resistance to drought, diseases, frost, salinity etc.
  - To prevent the premature falling of buds, fruits etc.
  - To change the duration of the crop *i.e.*, to develop early maturing (short duration) or late maturing (long duration) crops.
  - To increase the efficiency of use of fertilizer.
  - To change the growth habit *i.e.*, to produce dwarf or long varieties, profusely branched or sparsely branched varieties.
  - To make harvesting easier.
  - To induce the adaptability of a crop to different climatic and soil conditions.
- A cultivated variety having majority of the above characters is regarded as a **superior variety**.

Methods of plant breeding

- There are **different methods of plant breeding**. They are – introduction, selection, hybridization, mutation breeding, polyploidy breeding, tissue culture, and genetic engineering.
- Different methods of breeding are based on the type of reproduction and pollination operating in a crop.

Plant introduction

- It is the process of introduction of high yielding varieties of plants from their growing locality to another, with changed climatic condition.
- **Acclimatization** is the adaptation of introduced plant in the changed environment.
- Uncontrolled plant introduction in the past are responsible for introduction of hazardous diseases (like late blight of potato, flag smut of wheat, leaf rust of coffee, fire blight of apple and pear).

Indian Plant Breeders

- **Sir. T.S. Venkatraman** – Pioneer Indian Plant breeder famous for sugarcane improvement.
- **Choudhary Ram Dhan** – Wheat breeder, who is famous for C-591 variety of wheat, which made Punjab as wheat granary of India.
- **Dr. B.P. Pal** – Famous wheat breeder, who produced many NP wheat varieties.
- **Dr. K. Ramiah** – Famous rice breeder of international fame.
- **Dr. Pushkar Nath** – Famous potato breeder.
- **Dr. Boshi Sen** – Famous maize breeder.

Historical Account

- As early as 700 BC, Assyrians and Babylonians used to cross pollinate date palms artificially.
- In 1694 Camararius proved that there is sexual differentiation in plants.
- In 1717, Thomas Fairchild produced the first hybrid plant artificially.
- In 1761, Cotton Mather recognized the process of natural selection in maize.
- During 1706-66 Joseph Koelreuter produced many hybrids in tobacco.
- During 19th and 20th centuries, techniques of plant breeding like, selection, hybridization, were improved. L.L. Vilmorin (France), Burbank (USA), Michurin (USSR) are some of the famous plant breeder of that time.

- But achievements of plant introduction are also numerous, eg., new plants like maize, potato, groundnut, chillies, coffee etc. are the result of plant introductions.
- Similarly, many improved varieties of different crop plants are also outcome of these introduction, eg., Ridley and Sonora – 64 varieties of wheat.
- **Quarantine** is careful examination of all the introductions for the presence of weeds, insects, and disease-causing organisms. This is because with every introduction of new variety of a species, there are also chances of coming new weeds, insect pests and diseases from other countries. Quarantine is also applied to animals and, sometimes, to humans to **reduce the risk of entry of a pathogen in the country**.
- The progeny produced by crossing two varieties, species or genera having desired genes and bringing together the useful character in it is called **hybrid**.
- Introduced plants **serve as a good source of parental material for hybridization experiments**. Introduced plants can be subjected to "selection" to get better results.
- Plants pathogens and pests may also seek entry along with the introduced plant material. They may multiply rapidly in the new climate and cause serious damage to the introduced variety. For example, pathogens like *Phytophthora infestans* (late blight of potato) from Europe (1883), *Hemileia vastatrix* (coffee rust) from Ceylon (1876), *Urocystis tritici* (flag smut of wheat) from Australia were introduced into India.

Selection

- Selection is the **oldest breeding method**. It is of **two types** – **natural** and **artificial**.
- **Natural selection** is a natural process. Evolution is the ultimate result of natural selection only. According to the Darwin's principle – "Survival of the fittest", plants which survive through the adversities of nature are preferred and the weaker ones are wiped out. Thus, nature itself selects the fittest organisms.
- In **artificial selection** the selecting agent is man. Man exploits the variations existing among the species. He picks up a few plants of better qualities from mixed populations and tries to propagate them.
- There are **three methods of artificial selection– mass selection**, **pure-line selection**, and **clonal selection**.
- **Mass selection** is the **simplest** and the **oldest method** of crop improvement **practised by farmers**. It is **practised in cross pollinated crops**.
- Plants are in heterozygous condition. Seeds of best plants, showing high vigour are collected and pooled up. These seeds are used to raise the crop in the next year.
- The same process is carried out for 7 or 8 generations. Finally they will be multiplied and distributed to the farmers for cultivation.
- Good results are obtained if the existing variations are more in the population. Mass selection is based on external characters (phenotype) only. Hence it is easy to follow this.
- **Merits of mass selection** are –
  - It is the easiest and quickest method of crop improvement.
  - It needs no scientific knowledge.
  - The newly produced variety need not be tested.
  - Pollination need not be controlled to produce a new variety.
  - Mass selection is the only method of improving wild or local varieties.
- **Demerits of this process** are –
  - Importance is given to phenotypic characters only.
  - This method is applicable only to cross pollinated crop.
  - The new variety produced is always heterozygous.
  - There is no control over pollination as a result the degree of heterozygosity increases and the desirable qualities gradually diminish.
  - It is not possible to increase the yield of a variety because importance is given to maternal characters only and yield is subjected to environmental influences.
- A **pure line** may be defined as the "**progeny of a single individual obtained by selfing**" – Sinnot *et al.*
- A group of plants obtained from a single self fertilized homozygous plant is called a **pure line**. The **term pure line** was first **introduced by W.L. Johannsen in 1903**.
- This method is mostly **applicable to self pollinated crops**. The **progeny of a pure line selection are**

similar phenotypically and genotypically.

- Sometimes minor variations may occur in a pure line. These variations are simply due to the influence of environment.
- 50-100 plants or heads are selected from the mixed population of the field before harvest and seeds are collected separately.
- The progeny of each such plant are grown in a separate line. Plants with desirable characters are selected from each line again. 25-50 seeds from such plants will be grown in separate rows in a plot.
- The same process is followed for 7 to 8 generations until a new variety is isolated.
- **Merits of pure line selection** are –
  - This is the only method to improve local varieties of self pollinated crops.
  - This method is easier than hybridization.
  - New plant varieties produced by this method are uniform, similar in phenotype and genotype.
  - This method is also useful for the production of pure lines and inbred lines in cross pollinated crops.
- **Demerits of this method** are –
  - It is a very lengthy and laborious process.
  - New characters (new genotypes) cannot be introduced into a plant variety.
  - It is not possible to improve a variety beyond a certain level of homozygosity.
  - Extreme homozygosity may result in low yield and other undesirable characters.
  - Due to high degree of homozygosity, variations among the varieties are also limited. Therefore, their adaptability to varied conditions is also poor.
- Selection of desirable clones from the mixed population of a vegetatively propagated crop is called **clonal selection**.
- The progeny of a single plant obtained by vegetative propagation is known as a clone or all the vegetative progenies of a single plant are called a **clone**.
- Clonal selection is a method of improving vegetatively propagated crops such as sugarcane, banana, potato, citrus, mango, grapes, sugar beet etc. All the plants of a clone are similar in phenotype and genotype. Just like in pure-line selection, here also, importance is given to the phenotype only.
- **Merits of clonal section** are –
  - Varieties developed by clonal selection are more stable.
  - As there is no segregation, variations do not usually appear.
  - Even after many years of cultivation, the characters are not disturbed or lost.
  - Hybrid vigour of a plant can be maintained or preserved for many generations by clonal selection.
  - This is the only method to improve the vegetatively propagated crops improved by hybridization which are also finally selected by this method.
- **Demerits of this method** are –
  - This method is not applicable to crops propagated by seeds.
  - This method is useful only to isolate best genotypes already present in the populations.
  - New genotypes cannot be developed by this method.

Hybridization

- Hybridization can be defined as mating between two (or more) individuals or lines differing in genotype. It **is the most common method of creating genetic variation**.
- The technique of hybridisation involves crossing two plants to get a new synthetic one possessing the combination of good qualities of the parental plants. Hybridisation is often done in green house under controlled conditions.
- The **process of hybridisation involves following steps** –
  - **Selection of parents:** An individual /lines used in hybridization are called **parents**.
  - **Selfing of parents** to induce homozygosity.
  - **Emasculation:** If the two parents have bisexual flowers, before the flowers of female parent open and shed pollen, their anthers are carefully removed. This is called emasculation.
  - **Bagging:** This is the process by which male and female plants are kept in isolation by enclosing them in bag.
  - **Pollination:** Pollen is then collected from the flowers of male parent and placed on the stigma of flowers of female parent. The seeds produced by these flowers of female parent are the **hybrid** or **F_1 seeds**.

- Hybridization or crossing leads to **hybrid vigour or heterosis**, which is defined as "**superiority of hybrid over its parents**". Selfing results in **inbreeding**.
- The **term heterosis** was **given by G.H. Shull** in 1914 (*Heteros - different; Osis - Condition*), *i.e.*, different condition of hybrid from its parents.
- Hybrid vigour has been commercially exploited in different commercial crops like maize, sorghum, bajra, tomato, sugarbeet, petunia, zinnia and cucumbers.
- Heterosis is **used in genetics & breeding**. It is the possibility to obtain a "better" individual by combining the virtues of its parents. Heterosis is often the opposite process of inbreeding depression which increases homozygosity.
- **Effect of Heterosis** – Heterosis does not affect an individual as a whole but only in separate parts such as root in carrot, tuber in potato, hypocotyl in turnip, flower in cauliflower/fruits in pea, lobia, bhindi and curcurbits etc. The effects of heterosis in these plants can be expressed in the following ways – greater height, weight, size and number of the different parts of the plants, increase in yield and growth, greater fertility and viability, more efficient seed germination, longivity, earlier flowering and maturity, and increased resistance to disease.
- **Importance of heterosis** – This phenomenon results in hybrids that have better characters. Many ornamentals and fruit trees, valuable vegetables, good quality cereals are results of cross breeding inbreeds.
- Besides plant breeding, heterosis is also practicable in animal breeding.
- When the offsprings are produced by self fertilization or breeding between closely related parents it is called **inbreeding**. It is a form of mating system in a sexual organisms.
- Thus, self-fertilization or selfing is an extreme form of inbreeding. **Inbreeding results in increase in homozygosity**.
- The most revealing impact of inbreeding is the loss of vigour and physiological efficiency of the organisms characterized by reduction in size.
- A number of lethal and defective characters appear in the population which has undergone inbreeding (selfing). "This loss of fitness in the progenies or decline in character expression with decreased heterozygosity arising from self mating is known as **inbreeding depression or inbreeding decline**.
- Haldane (1948) referred inbreeding to be – "**the enemy of vigour and yield of plant**".
- The **effects of inbreeding are of great importance in plant breeding** and are given below as –
  - Inbreeding tends to increase the genetic correlation between relatives. It determines the success of pure line inbreeding for improvement of self pollinated crops.
  - Since inbreeding split the population into genetically divergent families with little additive variation at intra-family level but ample at inter-family level, selection is effective only between family.
  - Inbreeding is useful for progeny testing since close inbreeding (selfing) is the only effective method of differentiating heritable differences from non-heritable differences (characters).
  - Inbreeding is used to develop inbreeds in cross-pollinated crops.

Mutation breeding

- Hugo de Vries was the first person who defined "**mutation as sudden phenotypic changes which are heritable**". When mutated plants are used in plant breeding, new varieties of crops are produced.
- **Sharbati Sonora and Pusa lerma** are the **two important varieties of wheat** produced by gamma rays treatment of Sonora - 64 and Lerma - Roja - 64 (Mexican dwarf wheat varieties).
- **Sharbati Sonora** is the amber grain coloured variety of wheat produced by **Dr. M.S. Swaminathan** and is **responsible for green revolution in India**.
- **In rice**, about 45 varieties upto 1992 have been produced by mutation breeding. Important ones are - **Remei variety** and **Atomita - 2**.
- **Mutation breeding has some important limitations** as –
  - Most of the induced mutations are invaluable to the breeders and many of them are lethal.
  - Mutation rate is extremely low.
  - Stability of mutants is sometimes doubtful as some mutants have tendency to revert back to original type.
  - Most of the mutations are recessive.

– The main uses fall in 3 categories – genic manipulations, chromosomal engineering and diffusing specific plant breeding problem.

Polyploid breeding

- The organism (plant) which contains more than two complete sets of chromosomes, is called **polyploid**.
- Depending upon the number of chromosomal sets, the individuals are given different names as - monoploids, diploids, triploids, tetraploids, pentaploids and hexaploids (eg., wheat).
- Polyploids are characterized by gigantism or increase in cell size and hence organ size and thus overall size. These **polyploids are used in crops improvement**, eg., triploids are present naturally in different crop plants and generally in triploids, seedlessness is present.
- Most of the varieties of banana are triploids and hence their fruits are seedless.
- These triploids are not of any use in such plants where seeds are of commercial importance.
- Polyploidy can **also be induced artificially by colchicine treatment**. Colchicine is an alkaloid obtained from *Colchicum autumnale* (Liliaceae).

Tissue culture

- This is one of the latest and most promising methods of crop improvement in such plants, where all other conventional methods of breeding fail.
- Tissue culture **technique is based on totipotent nature of plant cell or phenomenon of totipotency,** *i.e*, each and every plant cell has inherent capacity to develop into complete plant [*For more detail refer chapter* '*Plant Tissue Culture*'].

Genetic engineering

- This is the latest method of crop improvement in which instead of involving whole chromosomal set (genome), manipulation of a segment of DNA (gene) is done.
- In this technique, introduction or deletion of one or more genes is done into an organism or plant. [*For more refer chapter Biotechnology & Genetic Engineering*].

Green revolution

- Green revolution is rapid increase in agricultural output as witnessed in India during 1970s.
- It has been achieved through introduction of high yielding varieties, increased irrigation facilities, fertilizer application, weed, pest and pathogen control, multiple cropping and better agricultural managment.
- **N.E. Borlaug** – Famous Mexican plant breeder, who was awarded Nobel Peace Prize (1970) for developing high yielding dwarf wheat varieties like Norin-10, Sonora-64, Lerma rojo-64, etc. He is known as **"Father of green revolution"**.
- **Dr. M.S. Swaminathan** – He is pioneer mutation breeder. He has produced Sharbati Sonora, a variety of wheat by mutation, which is responsible for green revolution in India. Dr. Swaminathan is **called** '**Father of green revolution in India**".
- **Dwarf Rice** – A dwarfing gene, **dee-geo-woo-gen**, was noted in Taiwan. It was introduced in Rice varieties (IR-8, IR-24) by IRRI. Philippines.
- To check Grassy stunt virus, Dr. Gurudev S. Khush crossed 13 rice varieties from six countries and *Oryza nivara* (Wild Rice from Central India) to produce early maturing, high yielding and resistant variety IR-36.

Transgenic crops/plants

- The most important use of plant biotechnology is the production of superior transgenic crops/plants which are having not only the resistance against a variety of biotic and abiotic stress, but also having some improved value added properties like nutritional quality of food.
- **Transgenic plants are those plants in which a foreign gene has been introduced and stably integrated into host DNA**.
- A gene that has been transferred using the tools of molecular biology is called **transgene**.
- The **first transgenic plants** are produced in tobacco (*Nicotiana tabacum*). Some other higher plants where transgenic plants have been produced are *Lycopersicum esculentum* (tomato), *Solanum melongena* (brinjal), *Vitis vinifera* (grapes), *Zea mays* (maize), *Avena Sativa* (oat) etc.
- India has permitted the commercial cultivation of three varieties of ***Bt*-Cotton**, the **first genetically modified crop of the country**. This has been developed by **MAHYCO** (Maharashtra Hybrid Seeds Company) in collaboration with American company **Monsanto**. *Bt*-Cotton is **resistant** to **Boll-worm disease of cotton**.
- Nowadays, there is a debate on biosafety issues of transgenic plants. The key points are –

  - Potential of GM crops to become weeds.
  - Opportunities of gene flow from a GM plant to other plants.
  - Impact of growing transgenic plants on biodiversity.
  - Capacity of pests and pathogens to adapt to the cultivation of GM crops.
- The area under transgenic crops will continue to rise and thus will result in more food derived from transgenic crops are called "GM foods" or genetically modified foods.
- The main concerns about the potential of GM foods/ crops relate to –
  - Increase in toxins.
  - Introduction to allergens.
  - Changes in the levels of essential nutrients.
  - Reduced efficacy of antibiotics.

Social forestry

- **Social forestry** is raising of fast growing and multipurpose species of trees and shrubs by local people on public and common vacant lands and roadsides etc for fulfilling their fodder, fuel and small timber requirement.
- The species of plants selected for social forestry vary from one locality to another. It reduces the pressure on real forests and also manages soil and water conservation, saves dung for manure and biogas and moderates climatic conditions.
- **Important plants recommended for social forestry programme** are – *Dalbergia sisso*, *Moringa*, *Morus*, *Tectona*, *Zizypus* etc.

New and under utilized crops

- Out of about 3,50,000 known plants at this time, a few, *i.e*, about 100 plants are being used for fulfilling man's daily requirements.
- Scientists are in search of less known and under utilized crop plants, which can be used for food and other purposes and thus exploitation of traditional plants can be reduced.
- Such under-utilized and under exploited plants are known as new crops.
- **Triticale** is the **first man made cereal or crop**, which has been produced by intergeneric hybridization between common wheat (*Triticum aestivum*) and European rye (*Secale cereale*) with a view to combine characters of these two parents plants.
- **Guayule** [*Parthenium argentatum* (Fam-Asteraceae), commonly known as carrot grass or congress grass] – This is native of America and nowadays it is most troublesome terrestrial weed in India and is present in almost all states of India. The roots of this plant secrete transcinnamic acid, which inhibits the growth of other plants (allelopathy). This is shrub and can grow on poor desert soils.
- **Subabul or Leucaena** [*Leucaena leucocephala* (Fam-leguminosae)] is a fast growing small tree and is native of Central America. This plant is nowadays being planted on a large scale under social forestry. These plants are used as wind breaks, fire breaks, wood as fuel timber etc.
- **Jojoba** (*Simmondsia chinensis*) is a shrub, which is native of Mexican deserts. It is important drought desert plant and hence is being grown in deserts. The seeds of this plants contain about 50% liquid wax, which is similar to sperms whale oil (spermaceti). This liquid wax was originally used in cosmetics, but now is also being used in high performance lubricants.
- **Winged bean** [*Psophocarpus tetragonolobus* (Fam- leguminosae)] is a herbaceous plant, which has capacity of nitrogen fixation. This plant can be used as a green manure plant, fodder plant and also as a cover crop.
- Some potential **oil yielding plants** are there, which provide edible and non-edible oils after suitable treatments. They are – Margosa or Neem, Mahua, Sal, Mustard tree etc.
- **Fodder trees** includes *Acacia nilotica* (Kikar or Babul), *Albizzia lebbeck* (Siris), *Ficus religiosa* (Peepal), *Morus alba* (white mulberry) etc.

Conservation of genetic resources

- It is the conservation of genetic diversities present in different varieties of a species and related species which are likely to be required for improvement of existing crop plants.
- FAO (Food and Agricultural Organisation of UNO) established an International Board for plant Genetic Resources in 1971 with several centres. Two of them are –
  - **IRRI** – International Rice Research Institute, Los Banos, Philippines.
  - **ICRISAT** – International Crops Research

Institute for Semi-Arid Tropics, Hyderabad, India- conserving germplasm of groundnut, pigeon pea, chick pea, pearl millet and sorghum.

Ex-situ conservation

- It is conservation of selected rare plants/animals in places outside their natural homes.
- *Ex-situ* conservation includes offsite collections and gene banks but it is often restricted to channeling the selected organisms into trade for nature lovers, agriculturists and horticulturists.
- *Ginkgo biloba* (ginkgo tree), once in the list of endangered species is now flourishing in gardens.

In situ conservation

- It is maintanance of biological diversity in natural habitats like forests and nature preserves by setting national parks, wildlife sanctuaries and biosphere reserves.

Gene banks

- For plant breeding purpose (*i.e.*, for improvement of plants), large number of varieties with different characters are needed.
- Hence number of plants (both wild and cultivated) are collected and stored at suitable place.
- The place or institution where different plant material (genes) are kept or preserved, is called a **gene bank**. In gene bank, storage is done either in the form of seeds or vegetative materials, but **best and convienent way is storage of seeds**.
- Storage of dry seeds is done at low temperature (–10 to – 20º C), because under these conditions, their metabolic activities are minimum which check their germination.
- Seeds are of **two types** – **orthodox seeds** and **recalcitrant seeds**.
- **Orthodox seeds** are those which are not killed or damaged as a result of decrease in moisture contents and temperature.
- These can even live upto – 196ºC, eg., seeds of wheat, rice, maize, oat, barley (cereals) and also different pulses or legumes.
- **Recalcitrant seeds** are those which are killed or damaged as a result of drying and decrease in temperature.
- These can be stored for a short span, eg., seeds of rubber, tea, coconut, jack fruit, litchi, oil palms etc.
- Conservation of crops with these types of seeds can be made by *In-situ* conservation method and also by tissue culture method.

GENETIC EROSION

- Genetic erosion is the appearance of genes/alleles from the gene pool and reduction in the genetic resources of the earth.
- 20th century has seen a loss of 75% genetic diversity of crop plants.
- By 1990 high yielding varieties had occupied more than 50% areas of wheat and rice lands.
- **Genetic erosion occurs due to** –
  - **Deforestation** – It not only reduces natural population of plants and animals but also causes disappearance of many species.
  - **Crop number** – Originally a large number of plants were exploited for different uses but slowly the number of exploitable plants have decreased. For example, out of 3000 food plant species, only 150 were commercialised. Agriculture is dominated by only 12 species out of which four yield more than 50% of the total (rice, wheat, maize, potato).
  - **Crop varieties** – There is a tendency to incorporate the maximum good qualities in a single variety. As soon as a better variety is developed, the same is distributed far and wide. The older varieties are discarded and their specific alleles lost for ever.

End of the Chapter

Chapter 66

Plant Tissue Culture

- Previously genes could be transferred only through hybridisation/breeding activity usually carried out in the field.
- In later half of 20th century techniques were developed which could transfer genes from any source.
- The phenomenon is called recombinant **DNA technology/Genetic engineering**.
- During the later half of the twentieth century, scientists made great strides to synthesize a plant in the laboratory from single cell, tissue or organ grown in nutrient medium in glass containers under specific conditions.
- The cultures of microbes are used in recombinant DNA technology and in variety of industrial processes while cultures of plant cells and tissues are used for variety of gene manipulation.
- **Plant tissue culture** is one of the latest and most promising methods of crop improvement in such plants where all other conventional methods of breeding fail.
- Plant tissue culture can be defined as **the maintenance and growth of plant cells, tissues and organs on a suitable culture medium *in vitro*** (in a test tube). Plant tissue culture is dependent on specialized laboratory facilities and technical skill.
- Plant tissue culture, also called **micropropagation**, **is a practice used to propagate plants under sterile conditions, often to produce clones of a plant**.
- Different techniques in plant tissue culture may offer certain advantages over traditional methods of propagation. Like –
  - The production of exact copies of plants that produce particularly good flowers, fruits, or have other desirable traits.
  - To quickly produce mature plants.
  - The production of multiples of plants in the absence of seeds or necessary pollinators to produce seeds.
  - The regeneration of whole plants from plant cells that have been genetically modified.
  - The production of plants in sterile containers that allows them to be moved with greatly reduced chances of transmitting diseases, pests, and pathogens.
  - The production of plants from seeds that otherwise have very low chances of germinating and growing, *i.e.*, orchids and *Nepenthes*.
  - To clean particular plant of viral and other infections and to quickly multiply these plants as 'cleaned stock' for horticulture and agriculture.
- The plant part which is cultured is called **explant**.
- Explant is excised from its original location and used for initiating a culture. The explants may be root, stem, shoot tip, leaf petiole, embryo etc. The growth regulators or hormones are required for cell division and organ regeneration from the cultures.
- The ability of plant cells to regenerate into complete plants is called **totipotency**.
- **Regeneration** is the development of an organized structure, like root, shoot or somatic embryo from cultured cells.
- **Gottlieb Haberlandt started the technique of plant tissue culture in 1902**.

TECHNIQUES OF PLANT TISSUE CULTURE

- There are **three important aspects of *in vitro* culture**, namely **nutrient medium**, **maintenance of aseptic conditions** and **aeration of the tissue**.
- **Nutrient medium** – Culture medium should

provide the nutrition that is required for the desired growth and development of the explants. Standard media are available for most purposes. These media contain –
- Inorganic salts of major and minor elements
- Vitamins
- Sucrose (as a source of carbon and energy)
- Growth regulators such as **auxins** (2,4-dichlorophenoxyacetic acid) and **cytokinins** (e.g., benzylaminopurine).

- Tissue culture can be **maintained in a solid medium or a liquid medium**. **Solid media** are particularly **suitable for callus culture**.
- Callus culture are prepared by mixing the liquid nutrient solution with gelling agent (usually agar) at a concentration of about 1-2%. It also contains the auxin 2, 4-D, and a cytokinin like BAP.
- Liquid media or suspension culture may be placed in test tube, stoppered by a plug of cotton wool or a metal cap. Adding a small quantity of cells to the medium is called **inoculation**. After inoculation, the medium is kept in incubator at the optimum growth temperature. Liquid medium usually contains the auxin 2,4-D.
- **Aseptic conditions** (germ free conditions) are maintained by preventing entry and growth of microbes, which can compete with growing tissue and finally kill it.
- There are **three main sources of contamination of the medium** –
  - The vessels, media(solutions) and instruments should be treated with steam, dry heat or alcohol, or subjected to filtration to make them free from microbes. This process is called as **sterilization.**
  - Microbes may be carried along with the tissue that is being cultured. The explants are therefore, treated with specific anti-microbial chemicals; this procedure is called **surface sterilization.**
  - Precaution should be taken to prevent entry of microbes during the culture experiment. The chamber used for culture is sterilized with ultra-violet light.
- **Aeration of growing tissue** is **necessary to provide air to the developing callus**. It is **achieved by** occasionally stirring the medium by stirrers or by automatic shaker.
- Plant tissue cultures are **classified according to the** –
  - **Type of *in vitro* growth**, *viz*., callus and suspension cultures
  - **Type of explant used** for culture initiation, e.g., embryo culture, anther culture, etc.
- In callus culture, **cell division in the explant forms a callus**. **Callus is an unorganised mass of cells**. It is maintained on gel medium usually with agar. When an explant is placed on such a medium, many of the cells become meristematic and begin to divide.
- **Suspension culture** grows much faster than callus culture. **Suspension culture consists of single cells and small group of cells suspended in a liquid medium**. This culture must be constantly agitated at 100-200 rpm (revolutions per minute).
- Agitation serves the following three purposes –
  - Aeration of culture
  - Constant mixing of the medium
  - Breakage of cell aggregates into smaller cell groups.
- Suspension cultures can be **maintained in any of two forms** –
  - **Batch culture** – It is initiated as single cells in a flask which are propagated by transferring regularly small groups of suspensions to a fresh medium.
  - **Continuous culture** – It is maintained in a steady state for long period by draining out the used medium and adding fresh medium.
- The following three things happen in all type of plant tissue cultures –
  - Cell/tissue dry matter (biomass) increases
  - The level of nutrients in the medium decreases
  - The medium volume declines due to evaporation.
- If tissue cultures are kept in the same culture vessel, they will die in due course of time. For this, **cells or tissues are regularly transferred into new culture vessels containing fresh media**. **This process is known as subculturing**.
- **Plantlets** can be **obtained from cultured cells by two different ways** –
  - **Shoot regeneration** followed by rooting of the shoots
  - **Somatic embryo regeneration** followed by their germination.

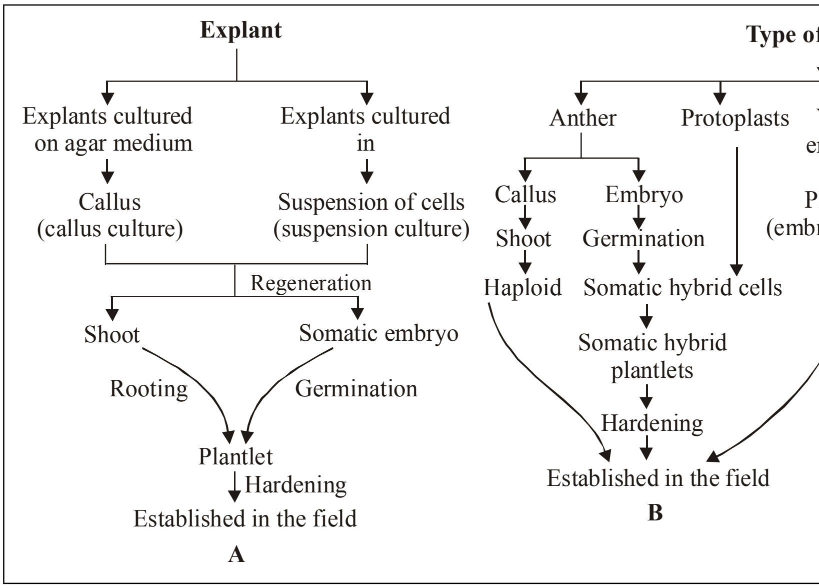
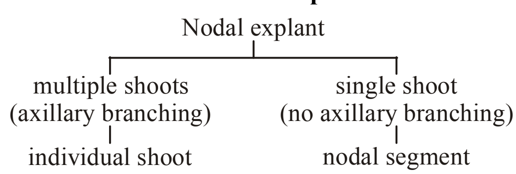


Fig. A flow chart showing the various types of plant tissue culture and recovery of complete plants from them. A : Callus and suspension culture B : Anther, protoplast, embryo and shoot type.

- Shoot regeneration is promoted by a cytokinin like BAP while root regeneration is promoted by an auxin like NAA (naphthalene acetic acid). In fact, shoot and root regenerations are basically controlled by auxin-cytokinin balance.
  - Cytokinin (BAP) → promotes shoot regeneration
  - Auxin (e.g., NAA) → promotes root regeneration
  - High Cytokinin/Auxin ratio → develops shoots only
  - Low Cytokinin/Auxin ratio → develops roots only
  - Intermediate Cytokinin/Auxin ratio → develops shoots as well as roots.
  - Intermediate Cytokinin/low Auxin ratio → continued growth as callus.
- Somatic embryo regeneration is induced usually by a relatively high concentration of an auxin, such as 2,4-D. These young embryos develop into mature embryos either on the same medium or on the other medium. Mature somatic embryos germinate and yield complete plantlets.
- One can use different type of explant for culture initiation, like meristems, anthers, protoplast, embryo etc.

Meristem culture

- Explants that contain pre-existing shoot meristems and produce shoots from them are used in **meristem culture**.
- **Shoot tips** and **nodal segments containing axillary buds are commonly used in meristem culture**.
- They are raised in cytokinin (eg., BAP) rich medium. Cytokinin promotes formation of axillary buds (it overcomes apical dominance). Therefore, multiple shoots are formed. The technique is therefore also called **multiple shoot culture**.



- **Meristem cultures** can be **used for** –
  - Rapid clonal multiplication
  - Production of virus free plants
  - Germplasm conservation
  - Production of transgenic plants.

Anther culture

- The technique was **developed by Guha and Maheshwari (1964)**. It is highly useful for immediate expression of mutations and quick formation of pure lines. Very young unopened floral buds are first sterilised in clorox (common bleach) for 10 – 20 minutes. They are then opened to remove anthers. Anthers are introduced over culture medium.

- When anthers, are used for culture in suitable medium they **produce haploid individuals**. This is called **anther culture**.
- The plants produced through anther culture are **homozygous**. In many species, the pollen grains can be isolated and cultured to obtain haploids.
- **Haploids are important** because they are used to produce homozygous lines in 2-3 years. The progeny from homozygous plants are subjected to selection to isolate superior homozygous lines. This approach has been successfully used to develop several varieties.

Year 1(Field)	Parent 1 × Parent 2 (AA ↓ aa)	
Year 2 (Greenhouse)	F1 hybrid Aa	
	↓	↓ Meiosis
Tissue culture laboratory	A	a
	↓	↓ anther culture
Year 2 (Greenhouse)	A	Haploid plants a
	↓	↓
Year 2 (Greenhouse)	AA	aa

Somatic hybridization

- A hybrid produced by fusion of somatic cells of two varieties or species is called somatic hybrid and the process of producing somatic hybrids is known as **somatic hybridization**.
- The somatic hybridisation **helps in transfer of desirable characters from wild or unrelated crop species to our crop plants**. Somatic hybrids can be identified by using several approaches.

Plant cell $\xrightarrow{\text{Cellulose + pectinase}}$ Protoplast (plant cell lacking cell wall)

Parent A protoplast   Parent B protoplast
↓ polyethylene glycol (PEG)
cell fusion
↓
nuclear fusion
↓
somatic hybrid cell

Embryo culture

- Excision of young / fragile / dormant embryos from developing seeds and their cultivation on a nutrient medium is called **embryo culture**. Embryo culture has many applications.
- The plantlets obtained from this culture can be removed from culture vessels and established in the field. During **hardening process** plantlets are kept under reduced light and high humidity for a suitable period of time. It makes the plantlets capable of tolerating the relatively harsher environments outside the culture vessels.
- Embryo culture is **used in** –
  - **Embryo Rescue :** It is taking out the fragile embryos from fertilised ovules of interspecific crosses before their abortion (due to nonfunctioning of endosperm and other postfertilisation barriers) and culturing them to form viable hybrid seedlings, *e.g.*, Jute (*Corchorus oliorius* X *C. capsularis*), Tomato (*Lycopersicon peruvianum* X *L. lycopersicum*), Bean (*Phaseolus vulgaris* X *P. angustissimus*), Rice (*Oryza sativa* X *O. officianalis*).
  - **Orchids :** Orchid seeds lack stored food. Embryo culture helps in developing seedlings from all the seeds. The technique is also used in clonal multiplication.
  - **Dormant seeds :** Inhibitors present in endosperm and other parts of seeds do not allow the embryos to grow. Embryos of such seeds can be excised and grown over culture medium to form seedlings. It eliminates the action of inhibitors and dormancy.
  - **Rare plants :** The technique is useful in multiplication of some rare plants, *e.g.*, Makapuno nut.

Nucellus culture

- Strictly **parental type plants can be obtained through nucellus culture**, which is completely free of micro-organisms including viruses. Such plants obtained through nucellus culture maintain their characters for a long time.
- In plant biotechnology, most useful product is a plantlet that have been genetically altered.
- There are many uses of genetically altered plantlets. These are as follows –
  - **Rapid clonal propagation :** A **clone** is a group of individuals or cells derived from a single parent individual. All plantlets regenerated from a callus or suspension culture have same

genotype and constitute a clone. These plantlets can be used for rapid clonal propagation of superior lines.

– **Somaclonal variation :** It is genetic variation present among plant cells of a culture. It has been used to develop several useful varieties.

– **Transgenic plants :** A gene that is transferred into an organism by genetic engineering is called **transgene**. An organism that contains and expresses a transgene is known as transgenic organisms. The cells containing and expressing transgenes can be easily selected *in vitro*. Ultimately, plantlets can be regenerated from these cells. These plantlets give rise to the highly valuable transgenic plants.

Application of plant tissue culture

- Some important applications of plant tissue culture are – micropropagation, production of disease free seeds, androgenic haploids, somatic hybridization, cryopreservation etc.
- **Micropropagation** – Micropropagation or cloning is applied to a technique devised to produce strong and healthy plantlets by vegetative multiplication in large quantity. It has been successfully used for commercial production of potato, bananas, cardamoms, orchids, gerberas etc.
- **Production of disease free-plants** – The multiple shootlet production technique is used to get disease – free healthy plants such as cassava, potato, sugarcane, strawberry, dahlia, sweet potato etc..
- **Androgenic haploids and uses** – Haploid plants are very useful because they possess only one set of chromosomes. The advantage of haploids in crop improvement are that they are useful for induction of mutations, when haploids are treated with colchicine, they produce homozygous diploids, during hybridization, haploids combine the advantage of recombination, segregation etc.
- **Protoplast technology and somatic hybridization** – The naked protoplast of two different plants fuses together to form a hybrid. This is known as somatic hybridization. Somatic

Table : Important applications of micro-organisms, animal cells and plant cells in agriculture, industry and human health

S.N.	Organism/cell	Applications Agriculture	Industry and Human health
		Non-transgenic strains/lines	
1.	Micro-organisms	Biofertilizer, Biopesticide	Vaccine production, antibiotic production, vitamins, organic compounds, single cell protein
2.	Animal cells	–	Vaccine production, animal proteins (including antibodies)
3.	Plant cells, tissues and organs	Micropropagation Haploid plants Somatic hybrids Somaclonal variants	Secondary metabolites including pharmaceutical compounds, micropropagation
		Transgenic strains/lines	
4.	Micro-organisms	–	Noval pharmaceutical proteins vaccines, new products
5.	Animals cells	–	New pharmaceutical proteins, vaccines, antibodies
6.	Plant cells	Transgenic crops with resistance to herbicides, insects, viruses; modified quality; improved nutrition	New pharmaceutical proteins, New high value products, genetically modified food

hybridization has been successfully used in many crops. **Pomato in an example of somatic hybridization between tomato and potato**.

- **In vitro plant germplasm conservation & cryopreservation** – Storage of plant germplasm can be done by storing their seeds and their propagules. Seeds and their vegetative materials are stored and maintained in gene bank. It **provides valuable materials to plant breeders**.
- **Artificial seeds** – Artificial seeds of those plants which either do not produces seeds or produces seeds in very less quantity, are produced through biotechnology. **Artificial seeds are produced by cellular totipotency and somatic embryogenesis**.
- Biotechnology is **involved in the preparation of useful products** (like - foods, dairy products, alcohol beverages, biogas, biofertilisers, organic acids, enzymes, vitamins, antibiotics, vaccines, hormones monoclonal antibodies) and used in sewage treatment, tissue culture, genetic engineering by using microbes.

GENETICALLY MODIFIED CROPS (GM CROPS)

- **Genetically modified or GM crops** contain and express one or more useful foreign genes or transgenes.
- Genetically modified crop or **transgenic crop** are prepared by transferring genes from one plant to other. The plant in which foreign genes are introduced are known as **transgenic crops**.
- There are **two ways to introduce foreign genes in plant cells** –
  – Through vector
  – Through direct introduction of DNA involves co-cultivation, electroporation and microinjection.
- This technology is **superior to breeding programmes** because in breeding only the already present genes are reshuffled and that changes would occur in all traits for which the parents are different.
- A transgene can **perform four functions** –
  – **Mask expression of a native genes.** In 'Flavr Savr' variety of Tomato, expression of gene for production of polygalacturonase was blocked. Enzyme polygalacturonase degrades pectin. In the absence of enzyme, pectin degradation is stopped and the fruit remains fresh for long. It retains flavour, has superior taste and higher quantity of total soluble solids.
  – **Modify an existing biosynthetic pathway :** Transgenic Golden Rice and transgenic Potato produce respectively higher content of vitamin A and protein.
  – **Produce a protein of interest :** The protein **hirudin** present in leech prevents blood clotting. Its gene was chemically synthesised and introduced in *Brassica napus*. The seeds of the latter came to have hirudin which could be extracted and purified.
  – **Produce a phenotype :** Soil bacterium *Bacillus thuringiensis* possesses a gene *cry* which produces a number of crystal or **Cry proteins**. Each type of Cry protein is toxic to certain group of insect larvae. *cry* gene of *Bacillus thuringiensis* has been successfully transferred to a cotton variety called Bt cotton. It is not attacked by bollworm and other insects. The variety is being sown in India and several other places. Other GM crops are being cultivated in USA, Europe and many more countries. However, caution is required in developing GM crops without proper safeguards because (i) Pollen of transgenic crops may carry the transgenes to wild relatives. (ii) Gene transfer from GM crops to weeds would make them more virulent. (iii) Transgenic crops may become persistent weeds. (iv) Transgenic crops would disturb the balance of nature and damage the ecosystem.
- In India, it has been argued that transgenic crops may be harmful to the environment. The transgene may be transferred through pollen from these crops to their wild relatives. In many cases, such a gene transfer may make the weeds more persistent and damaging. In view of this, transgenic crops should not be grown in those areas where their wild relatives occur in the fields or the surrounding areas.
- The food prepared from the product of genetically modified (=transgenic) crops is called **genetically modified food** or **GM food.**
- GM food **differs from the food prepared from the product of conventionally developed varieties because** it contains the protein produced by transgene, enzyme produced by antibiotic resistant

gene that was used during gene transfer by genetic engineering and contains the antibiotic resistant gene itself.

- GM food could lead to the some problems when they are consumed such as it may cause toxicity or produce allergies, bacteria present in the alimentary canal of the human could take up the antibiotic resistant gene and become resistant to the concerned antibiotic. As a result, these bacteria could become difficult to manage.

SUSTAINABLE AGRICULTURE

- **Sustainable agriculture** is the practice of management and successful use of bioresources in agriculture to meet the present demand without compromising the ability of future generations to meet their own needs.
- Sustainable agriculture should use renewable resources, should not cause pollution and should maintain optimum yields.
- Biotechnology contributes to sustainable agriculture by developing **biofertilisers, biopesticides, disease – and insect resistant varieties** and **single cell proteins.**
- **Biofertilisers** are micro-organisms that make available to plants either atmospheric oxygen or soil phosphorus. There are several micro-organisms such as bacteria, cyanobacteria that can fix atmospheric nitrogen and make them available to plants. Some of these are *Rhizobium*, *Anabaena* and mycorrhiza.
- **Biopesticides** consists of viruses, bacteria, protozoa, fungi or mites that help control diseases, insects or weeds. Biological control of pests (organisms that damages plant or plant product) involves bioherbicide and bioinsecticides.
- **Bioherbicides** utilizes insects which would feed selectively on a weed, e.g., a cochineal insects, feed upon *Opuntia*.
- **Bioinsecticides** includes **pathogen, parasites and predators**. A large number of harmful insect pest are controlled by other insects, pathogens, parasites or predator, e.g., frogs, birds etc. eat insect pests.
- **Integrated pest management** involves various types of controls to ensure continued production from soil without excessive use of synthetic pesticides. IPM suggest different physical, chemical and biological methods integrated to provide better protection.
- Genetic engineering has enabled the development of crop varieties resistant to certain insects and diseases. Plant diseases are caused by viruses, bacteria, fungi and nematodes. The **most successful approach for the production of virus-resistant plants is the transfer of virus coat protein gene into the plants**.
- Incorporation of Bt/cry gene in cotton has made it largely resistance to bollworm and other insects. Similar resistance is being developed in other plants.
- Development of disease and insect resistant varieties would minimise the use of pesticides, prevent pollution and enhance agricultural production.
- **Single cell protein** (SCP) is production of microbial biomass for consumption as human food or animal feed by growing algae, fungi, yeasts and bacteria over agricultural wastes (*e.g.*, sawdust, paddy straw, paddy husk) and organic wastes of industry.
- Commercially SCP is being produced by yeasts and *Fusarium graminearum*.
- SCP provides a valuable protein rich supplement in human diet. It also reduce the pressure on agricultural production systems for the supply of required proteins. SCP production based on industrial effluents helps reduce environmental pollution.

End of the Chapter

Chapter 67

Economic Botany

- **Economic botany** is broadly defined as the study of the relationship between humans and plants.
- This interdisciplinary study encompasses the fields of arthopology and botany as it explores the countless ways humans employ plants for **food, medicine, textiles, shelter** and more.
- Economic botanists explore the interface between people and plants to describe the cultural uses of plants, explain the origin of specific useful plants and develop strategies of the sustainable use of plant resources.
- **Ethnobotany** is the study of how people of a particular culture and region make use of indigenous plants.
- Ethnobotany has its roots in botany, the study of plants. Botany, in turn, originated in part from an interest in finding plants to help fight illness.
- **Pharmacognosy** is the study of medicinal and toxic products from natural plant sources.
- As modern medicine and drug research advanced, chemically-synthesized drugs replaced plants as the source of most medicinal agents in industrialized countries.

FOOD PLANTS

- Food plants can be classified as **cereals**, **pulses**, **nuts**, **vegetables**, **fruits**, **spices** and **beverages**.

Cereals

- The term cereals has been derived from the Roman Goddess namely 'ceres'. According to Romans 'ceres' is **giver of grains.**
- The cereals are **caryopsis fruits** belonging to family **Poacea**.
- Cereals are **major** (paddy, wheat, maize), **minor** (rye, barley, oats), **small grains** and **millets** (jowar).
- **Rice** (*Oryza sativa*) probably originated in **Indo-china** or **India**.
- Rice is the principal cereal of tropics. A.P., Assam, Bihar, M.P., Maharashtra, Tamilnadu and West Bengal are the **main rice growing states in India**.
- Rice grains are used as **first staple food** in World and India. It is also **used as stock and poultry feed**.
- These plants are 60 – 120 cm. tall herbs with **adventitious fibrous root system**.
- The inflorescence is **terminal** and the spikelets are arranged in **panicles**.
- Rice grains contain about **90% carbohydrate, 8–10% proteins, 1% fats** and about **1% mineral matter**.
- The grain with its brown lemma and palea is termed as **hull**.
- The polished rice has **low nutritive value** as it lacks proteins, vitamin and fat contents.
- Some of the common varieties of rice are **Basmati 307**, **IR-24**, **IR-48**, **Krishna**, **Jaya**, **Padma**, **Ratna**, **Pankaj**, **Jamuna**, **Sabermati**, **ADT-27 etc.**
- New varieties of rice are being developed at Indian Agricultural Research Institute, **New Delhi**, Rice Research Institute, **Cuttack** and International Rice Research Institute, **Manila** (Philippines).
- Its **flour is used in** pastries, puddings, ice-creams etc. **Rice bran oil** is **used in preparing soap and cosmetics**. Sake (beverage of Japan) is obtained by fermenting rice.
- **Wheat** is the **principal food in temperate countries** and the **second staple food** of our country.
- Wheat has multiple origin: **soft wheat** from south west India and Afghanistan, **Durum wheat** from Algeria and Greece and **Einkorn** from Asia minor.
- The plants are **annual herbs** whose grains contain **69–70% carbohydrates**.
- USA is the **largest wheat producing country** in the world.
- The **main wheat producing states** in India are

Bihar, **Madhya Pradesh**, **Maharashtra**, **Punjab**, **Rajasthan and Uttar Pradesh**.

- The grains are generally sown in the months of **October/November** in our country (**Rabi crop**).
- At least **nine kinds of wheat** has been identified namely – **Einkorn, Emmer, Spelt, Polish wheat, Poulard wheat, Club wheat, Durum wheat, Common wheat and Tinopheevi.**
- The diploid wheat is the **oldest** and **unfit for human consumption**. The **tetraploids** came into being due to a probable crossing of diploid with the grass *Aegilops speltoides*. The **hexaploids** are the most **recent**.
- Some high yielding varieties of wheat include **Kalyan Sona** (HD-1593), **Sonalika** (HD-1553), **Pratap** (HD-1981) and disease resistant varieties like **HD-2135**, **HD-2189**, Lerma Rojo, Sonara-64, Arju, Hera, Janak, WH-147, KSML-3, C-306, UP-115 etc.
- **Norman Borlaug** is **called the father of green revolution for his discovery of Sonara-64, Lerma rojo-64 etc**.
- The flour of wheat is used for various purposes. The **straw** is **used as fodder**.
- Corrugated paper is made from wheat straw.
- **Maize** (*Zea mays*) or 'Indian corn' is the **gift of America** of cereals.
- In India, it is grown in **Andhra Pradesh**, **Bihar**, **Jammu-Kashmir**, **Madhya Pradesh**, **Punjab** and **Uttar Pradesh**.
- **Maize** is **grown as kharif crop in India**.
- The **important varieties of maize** are – **Ganga Safed-2**, **Ganga-5**, **Him-123**, **Decan 101**, **Vijay**, **Ganga-9**, **Histarch**, **Jowahar**, **VL-54**, **Amber**, **Deccan etc**.
- The plants are tall herbs measuring from 1 to 4.5 meters in height, with **adventitious fibrous** and **stilt root systems**.
- The fruit is a caryopsis **possessing two types of endosperm**, **white and yellow, thus exhibiting the phenomenon** of **Xenia**.
- Maize grains are **deficient in amino acid lysine, tryptophan** and **rich in thymine**.
- Beside pop corn, flakes, poultry grit and animal feed, corn starch, industrial alcohol and syruph are also made from maize grains.
- An artificial fibre is also prepared from the maize protein, **Zein**.
- **Barley** (*Hordeum vulgare*) was **first domesticated cereal**.
- It is **sown as rabi crop** and **used in** making malt, whisky, and other alcoholic beverages.
- Its flour is used for making chapatis.
- **Oat** (*Avena sativa*) is **most nutritious among cereals as it contains high proteins, fats and minerals**.
- United States leads the world in production of oats.
- Oats are thought to be having multiple origin.
- Oat meal is **used mainly in cakes biscuits, etc. It is not good for preparing breads** because glutein content is absent in grains.
- **Rye** (*Secale cereals*) is of more recent origin as compared to other cereals. It is probably a native of Black and Caspian Seas region of Central Eurasia.
- It is **mainly used in preparing bread as the grain contains glutein**.

Triticale (*Triticosecale*) is the **first man made cereal** or crop produced by intergeneric hybridization between wheat (*Triticum* sps.) and European rye (*Secale cereale*), i.e.,
Triticum × *Secale cereale* → *Triticosecale* or *Triticale*.
It is like wheat but grains are shrievelled.

- Small sized grains are called **millets** whose edible portion is endosperm.
- The **important millets** are – Jowar (*Shorghum vulgare*), bajra (*Pennisetum typhoides*), Ragi (*Eleusine corana*), common millet (*Panicum miliacium*), foxtail millet (*Setaria italica*) etc.
- Sometimes seeds of other plants are used like cereals and millets as source of food, although they are not grasses, these seeds are known as **pseudocereals**.
- There are two widely used pseudocereals –
  - **Buck wheat** : *Fagopyrum sagittatum* or *F. esculentum* (Kuttu).
  - **Gorgannut** : *Euryale ferox* (Makhana).
- The seeds of buck wheat are grinded and flour is used for porridge, pancakes, etc.
- Buck wheat is a source of a glucoside, rutin which is used in the treatment of hypertension and high blood pressure.

Pulses

- Pulses are next to cereals as source of human food. They belong to family Leguminosae which has a characteristic fruit called a legume or pod.
- Type of foods present in the pulses are **proteins, carbohydrates** and **oils**.

- Proteins occur as aleurone grains. This high protein content is due to the presence of root nodules in legumes.
- Pulses **store food materials in their cotyledons**, seeds of pulses are **non-endospermic**.
- Cultivation of pulse crops **increases the fertility of land** since *Rhizobium* are present in their root nodules which fixes atmospheric nitrogen for plant.
- Pulse crops are **useful for crop rotation** and **in mixed cropping**.
- Some of the **important pulses** are : gram (Chick Pea) – *Cicer arietinum*, Red Gram (Pigeon Pea, Arhar, Tur) – *Cajanus cajan*, Black Gram (Urd) – *Vigna* or *Phaseolus mungo*, Green Gram (Mung) – *Vigna radiatus* = *Phaseolus aureus*, Pea (Mattar) – *Pisum sativum*, Soyabean – *Glycine max*, Mat Bean (Moth) – *Vigna aconitifolia* = *Phaseolus aconitifolius*, Lentil (Masur), *Lens culinaris* (*L. esculenta*), Red kidney bean (Rajmah) – *Phaseolus vulgaris*, Lablab – *Lablab purpureus* (*Dolichos lablab*), Guar/cluster bean – *Cyamopsis tetragonoloba*, Cow Pea/Lobia – *Vigna unguiculata* (*V. sinensis*), *Phaseolus lunatus*.
- Soyabean contains 40% proteins, lower cholesterol and LDL. An anticancer ingredient called **genistein** is also present. Also yields oil. Soyabean milk is a refreshing drink.

Lathyrism, a crippling disability marked by muscular weakness, tremors and paraplegia is **caused by eating seeds** of *Lathyrus sativus* (Grass Pea, Chickling Vetch, vern, Khesari Dal). The seeds contain osteotoxin β-amino propionitrile (BAPN) and water soluble neurotoxin β-N-oxalyl amino alanine (BOAA). Red Kidney Bean and French Bean possess lectins which are destroyed only on boiling for some time. Low temperature cooking or eating raw soaked beans can be dangerous.

- **Urease enzyme** is **obtained from arhar** which is **used in estimation of urea in urine and blood**.
- Ardil protein is obtained from ground nut (=*Arachis hypogea*, pea nut) which is used in manufacturing fibres.
- Tree legume is *Prosopis juliflora*.
- **Rotenone** is a white crystalline substance obtained from dry roots of *Derris* and *Lonchocarpus*. It is **used in fish poisoning and as insecticide**.

Nuts

- Literally a nut is defined as a **simple**, **dry**, **indehiscent fruit having a hard pericarp**.
- The nuts have **high protein** contents (*Prunus, Pistacia*), **high oil** content (*Cocos, Anacardium, Juglans*), and **high carbohydrate content** (*Castanea, Quercus*).
- The **cashew nut** (*Anacardium*) is a **native of Brazil**. It's seeds contain 47% fats, 22% carbohydrates and 21% proteins. They are **eaten raw or roasted**. Besides, a **beverage** is also prepared from it.
- The **almond** (*Prunus amygdalus*) is a **native at Mediterranean region**. The trees produce **drupes** and the seeds may be sweet or bitter.
- The pistachio nut (*Pistacia vera*) originated in **West Asia**. The **drupes** contain green seeds which are eaten raw or roasted or salted.
- The English walnut (*Juglans regia*) are trees producing **drupes with edible cotyledons** and the plant produces useful timber.
- The coconut (*Cocos nucifera*) is a native of **Malaya**. The plants are trees showing **palm habit**. It is perhaps the economically most useful plant. All parts are used, as kernels are edible, endosperm edible, copra yields oil, mesocarp provides coir, dry leaves used for thatching.

Vegetables

- The vegetables store food material in different parts. They may be classified as **earth vegetable, herbage** (leafy) **vegetables** and **fruit vegetables**.
- The **earth** (**underground**) **vegetable** may **store food material in their root**, **stem or leaves**.
- Among the most common **edible roots** are *Beta vulgaris* (beet), *Brassica rapa* (turnip), *Daucas carota* (carrot), *Ipomoea batata* (sweet potato) and *Raphanus sativus* (radish), *Manihot esculenta* (Tapioca), *Dioscorea alata* (yams).
- The **underground stem vegetables** include *Solanum tuberosum* (potato), *Colocasia esculenta* (Arvi), *Helianthus tuberosus* (Hathichuk) etc.
- The **underground leaves** include *Allium cepa* (onion) and *A. sativum* (garlic).

Onion is a tunicated bulb and store reserve food in its scaly leaves. It has a pungent taste which is due to presence of an acrid oil, allyl sulphide.

- The **herbage vegetables** include *Brassica oleracea* var. *botrytis* (Cauliflower), *B. oleraceae* var.

Table : Important fruit vegetables

	Common name	Botanical name	Edible part
1.	Cucumber	*Cucumis sativus*	pepo
2.	Bottle Gourd (Lauki)	*Lagenaria vulgaris* (*Syn. L. siceraria*)	pepo
3.	Karela	*Momordica charantia*	pepo
4.	Tomato	*Lycopersicon esculentum*	berry
5.	Brinjal	*Solanam melongena*	berry
6.	Lady's finger	*Abelmoschus esculentus*	capsule
7.	Hyacinth bean	*Dolichos lablab*	legume
8.	Garden pea	*Pisum sativum*	legume

capitata (Cabbage), B. *oleraceae* var. *gongylodes* (Knolkhol), *Lactuca sativa* (Lettuce), *Spinacia oleracea* (Spinach), *Chenopodium album* (Bathua), *Trigonella foenum-graecum* (Methi), *Amaranthus blitum* (Chulai).

Spices

- Spices are the various parts of the plants used as **flavouring material**.
- The spices **obtained from the underground parts** include *Ferula asafoetida* (asa-foetida), *Curcuma domestica* (turmeric), *Zingiber officinalis* (ginger) from rhizome.
- The **bark** of *Cinnamomum* spp. and *Sassafras albidum* is also **used as flavouring material**.
- The flavouring agents obtained from flowers or their parts are *Crocus sativus* (saffron), *Syzygium aromaticum* (clove), *Capparis spinosa* (capers) and *Rosa* sp. etc.
- Spices are **also obtained from the fruits** of *Capsicum frutescens*, C. *annuum* (red pepper), *Coriandrum sativum* (coriander), *Cuminum Cyminum* (cumin), *Foeniculum vulgare* (fennel), *Piper nigrum* (black pepper), *P. longum* (long pepper) and many other plants.
- The **seeds** of *Amonum subutalum* (greater cardamum), *Elettaria cardamomum* (cardamum), *Myristica fragrans* (nutmeg) and *Trigonella* (fenugreek) are **used for flavouring food**.
- Spices obtained from **leaves** are *Cinnamomum tamala*, *Coriandrum sativum* (coriander), *Mentha sp. Murraya* (meetha neem) etc.
- Coriander oil is used in **medicine and to flavour beverages** such as gin, whisky, etc.
- **Turmeric powder mixed with milk** is used as **pain killer**.
- The clove oil has **medicinal properties** and used to **aid digestion** and in **toothaches**. It is also used in perfumery. Cloves are ingredient of betel.
- The pungent taste of chillies is due to presence of a volatile compound **capsicin**. They also contain vitamins A, C and E.

Beverages

- The beverages can be broadly classified into two categories, **non-alcoholic and alcoholic**.
- The **non-alcoholic beverages include** tea (*Camellia sinensis*), coffee (*Coffea* sp.), cocoa (*Theobroma cacao*), cola (*Cola acuminata*) etc.
- While tea is prepared from the **leaves**, coffee is obtained from the **seeds**. They contain alkaloids like **theine** and **caffeine** respectively.
- The **alcoholic beverages are mainly obtained from** polymer palm, barley, rice, date, sugar cane, grape and maize.
- The alcoholic fermentation involves participation of enzymes like **invertase, zymase,** and **diastase** depending upon the base.
- The alcoholic beverages may be **fermented or distilled**. The **fermented beverages** include **beer** (from *Hordeum vulgare*) and **wine** (from *Vitis vinifera*).
- The distilled beverages include whisky (fermented grains mashes), brandy (fermented juice), gin (distilled spirit), rum (molasses), and fenny.
- The **peculiar flavour of gin is due to oil of *Juniperus***.
- Best grade of tea is prepared using only young buds. It contains **2-5%** theine, a small **amount of caffeine** and **volatile oil** and **13-18% tannin**.
- Coffee seeds contain **0.75 to 1.5% caffeine** which **acts as stimulant and relieves body fatigue**.

Fruits

- The term fruit is usually applied to the seed bearing portion of the plant that has developed from the **ripened ovary** and its contents.
- Fleshy fruits are eaten raw because they are palatable and sweet.
- Fruits may also be without seeds and are termed as **parthenocarpic fruit**.

Table : Some common edible fruits

	Common Name	Botanical name	Type of fruit	Edible part	Uses
1.	Apple	*Pyrus malus*	Pome of false fruit	Thalamus	–
2.	Mango	*Mangifera indica*	Fleshy drupe	Mesocarp	Rich source of vitamin A, C and K
3.	Lemon	*Citrus limon*	Hesperidium	Juicy placental hairs	Source of vitamin C
4.	Orange	*Citrus reticulata*	Hesperidium	Juicy placental hairs	Source of vitamin C
5.	Grapes	*Vitis vinifera*	Berries	Pericarp and placenta	–
6.	Banana	*Musa paradisiaca*	Berries	Pulp (mesocarp and endocarp)	High content of carbohydrates, fats proteins. Plantain is cooked, or make into flour
7.	Litchi	*Litchi chinensis*	One seeded nut	Fleshy aril	–
8.	Pineapple	*Ananas comosus*	Sorosis	Mesocarp and endocarp (juice)	–
9.	Pomegranate	*Punica granatum*	Balausta	Succulent testa	–
10.	Mulberry	*Morus alba*	Sorosis	Perianth	–
11.	Guava	*Psidium guajava*	–	–	–
12.	Papaya	*Carica papaya*	–	–	Papain enzyme is obtained from papaya used for digesting protein
13.	Custard apple or Sugar apple	*Annona squamosa*	–	–	–
14.	Fig	*Ficus carica*	Syconus	–	–
15.	Bel	*Aegle marmelos*	Balausta	–	–

INDUSTRIAL PLANTS

- Plants which are used for obtaining industrial raw materials are called **industrial plants.**
- Common industrial material obtained from plants are **wood**, **latex**, **oils**, **gums**, **dyes**, **sugar** and **paper** etc.

Wood

- Forest besides **regulating the climate, temperature** and **checking erosion,** produces wood and industrial materials.
- The wood is **superior to any metal** in it's availability, cheapness, toughness, strength and elasticity.
- The **secondary xylem** mainly constitutes the **'wood'**.
- The secondary xylem formed in spring forms the **spring wood** or **early wood** and the one formed in autumn forms the **autumn wood** or **late wood.**
- The spring wood is **light coloured** whereas, the autumn wood is **dark coloured**.
- The wood is made up of **tracheids, vessels, fibers and parenchyma**. It is also identified on the basis of ray characteristics, it's grain, figure and texture.
- Due to **absence of vessels** in gymnosperms its wood is called **non-porous wood.**
- The structural arrangement of various wood components is called as **grain of wood.**
- The relative size and quality of various wood elements is termed as **texture of wood.**
- The design or pattern that appears on the surface

of wood is referred to as **figure of wood.**

- The **properties** possessed by any wood are it's strength, stiffness, toughness, hardness and cleavability. The **lightest wood** is that of *Ochroma lagopus* (specific gravity 0.12) and **heaviest** south American iron wood (*Krugiodendron ferreum*) and *Guaiacum officinals*.
- The **reaction wood** is formed in response to a physical stress. It is of **two types** : **compression wood** and **tension wood**.
- Removal of moisture from the wood is called as **timber seasoning**. It is **done in two ways** : **air seasoning** and **kiln seasoning**.
- Some specific items are made from specific wood such as –
  - **Cricket bat** – *Salix alba* and its other species.
  - **Hockey sticks** – Stick from *Morus alba* and blade from *Dalbergia sissoo.*
  - **Pencils** – *Juniperus sp.*
  - **Gun stocks** – *Juglans regia.*
- Some **other wood obtained from various trees** are – Indian black wood (*Dalbergia latifolia*), ebony wood (*Diospyros ebenum*), red wood (*Sequoia Sempervirous*).

Table : Common wood plants

Scientific name	Used for
Tectona grandis (Sagoun)	Construction purposes, furniture, railway sleepers, carving etc.
Shorea robusta (Sal)	Used for railway sleepers, doors, windows, beams, planks, bodies of carts and boat building.
Dalbergia sissoo (Shisam)	Used for making musical instruments, shuttles, sports goods, shoe heels, hookah tubes and tobacco pipes. The timber is also used for furniture, cabinet and carriages.
Pinus roxburghii (Pine)	Used in packing boxes, match boxes, household goods, construction works and cheap furnitures.
Cedrus deodara (Deodar)	Used for house building, railway - sleepers, ports, floor boards, window frames and light furnitures.

Sugar

- The main source of **sugar** is *Saccharum officinarum*. Beside this *Beta vulgaris* (sugarbeet) and palm are also the source of sugar.
- Sugarcane stem contains about **80% juice.**
- **Glucose** is the **first sugar manufactured** by a green plant. Commercially the **glucose or grape sugar** is prepared from **starch**.
- **Fructose** is also called as **fruit sugar**. It is present in many fruits along with glucose. Commercially, it is prepared from **inulin**, a polysaccharide present in the roots of *Dahlia* and *Helianthus*.
- **Mannose** does not occur freely in plants. However it can be **obtained from the juice of** *Fraxinus ornus* (Manna ash) by **oxidation**.
- **Maltose** does **not exist freely** in plants but can be **obtained from starch by the action of the enzyme diastase**.
- **Molasses** is the juice left after the crystallization of sugar.
- From molasses, ethyl alcohol, rum, acetic acid and glycerine are prepared. Bagasse (fibrous residue left after the extraction of juice) is used in the manufacture of paper and cardboard.
- Some other sugar yielding plants are *Phoenix sylvestris*, *Borassus flabellifer*, *Caryota urens*.

Paper

- **Egyptians** made paper from *Cyperus papyrus* and from this, the name is derived.
- Paper is a **felted or matted sheet of cellulose** (or synthetic) **fibres**.
- The raw materials for paper manufacture are contributed by **wood fibers, cotton and linen** etc.
- **Wood pulp** is generally obtained from *Picea, Abies Betula lutea* etc.
- **Fine grade paper** is prepared from cotton and linen fibres.
- Pulp of bamboo (*Bambusa arundinacea*) is used for the manufacture of **printing paper.**

Dyes

- Different parts of many plants produce **dyes** which are **chiefly used in textile industry**.
- Dyes come from the **roots** of *Berberis, Moringa, Rubia* and **rhizomes** of *Curcuma*. They are also produced in the **bark** of *Quercus*, *Tectona* etc. and also in the **leaves** of *Indigofera* and *Lawsonia.*
- The **flowers** of *Butea, Carthamus, Crocus, Nyctanthes, Toona* and *Wrightia* **produce dyes**.
- Dyes are also obtained from the **fruits** of *Mallotus* and *Rhamnus,* **seeds** of *Bixa* and *Wrightia* and **gum-resin** of *Garcinia.*

Fibres

- Fibres fulfill the **second most necessary requirement** of human beings *i.e.*, clothings.
- Botanically fibres are the **sclerenchymatous cells** occurring in different parts of the plants.
- They are made up of **cellulose** or **hemicellulose** with deposition of **lignin**.
- The **longest fibre** of *Boehmeria nivea* measures 55 cms in length.
- Some other fibre yielding plants are *Hibiscus cannabinus* (bimbli juli), *Boehmerea nivea* (remie), *Cannabis sativa* (hemp), *Agave sisalana* (sesal hemp) etc.
- **Largest, toughest, strongest and most durable fibres are obtained from secondary phloem**, used for ropes, brushes, carpets etc.
- **Textile fibres** are categorised in **three categories** surface fibers, soft fibers and hard fibers.
- **Surface fibres** are short fibers occurring on surface eg. cotton.
- **Soft fibres** are the bast fibers belonging to pericycle and phloem, e.g. jute, flax, hemp etc.
- **Hard fibres** are found particularly in the leaves of monocots, e.g. coir.
- **Brush fibres** are obtained from the leaves of *Borassus, Caryota,* inflorescence of *Sorghum* etc.
- Planting and rough weaving fibers are used for making hats, mats, baskets etc. In all these cases fibres from **palms** and **grasses** are used.
- The **filling fibres** comes from *Bombax, Calotropis* and *Typha.*

Oils

- The oils are generally classified as essential or **volatile oils** and **fatty or fixed oils**.
- The essential oils are extracted by **distillation or expression** or **by solvents**.
- They are **either used in perfumery or in other industries**.
- The **essential oils used in perfumery** are contributed by many plants such as *Cananga odorata, Jasminum spp., Lavendula officinalis, Rosa spp., Santalum album* (chandan).
- Several plants yield **essential oils used in other industries**, e.g., *Cinnamonum camphora* (kapur), *Eucalyptus spp., Syzygium aromaticum* (clove).

Table : Fibre yielding plants

Comman name	Scientific name	Fibre obtained from	Uses
Cotton	*Gossypium sp.*	Epidermal hair of seed	Important varieties of cotton are : Virnar, Jarlia, Daulet, Jayawant, Vijay, Digvijay, etc. Cotton is very useful raw material for various industries, *i.e.*, plastic, rayon and explosives fibres are present in the stalk of the plant which are used for paper making. Cotton seed oil is obtained from kernels which is one of the most important fatty oils.
Jute	*Corchorous capsularis*	Bast fibers obtained from secondary phloem of stem	These fibres are used in making carpets, curtains, twines, ropes, etc. Jute fibres deteriorate rapidly when exposed to moisture.
Sunhemp	*Crotolaria junceae*	Bast fibers present in phloem region just outside cambium	These are used in making coarse cloth, ropes and twine, etc.
Flax	*Linum usitatissimum*	Fibres occurring in pericycle	Flax fibres are moisture or water resistant so used in making fishing nets, ropes. These fibres become more strong when wet than dry.
Coir	*Cocos nucifera*	Mesocarp	Highly resistant to water.

- The fatty oils are categorised as **drying oils, semi-drying oils, non-drying oils, vegetable fats and waxes**.
- The **drying oils** dry up forming an elastic film. They are contributed by plants like *Glycine max, Juglans regia* and *Linum usitatissimum.* Besides, species of *Cannabis, Papaver* and *Perilla* also provide drying oils.
- The **semi drying oils** are contributed by plants like *Brassica spp., Gossypium spp., Helianthus annuus, Sesamum indicum, Zea mays.*
- The **non drying oils** are contributed by *Arachis hypogea, Olea europea, Ricinus communis* and also by *Camellia sansaqua* and *Moringa oleifera.*
- The **vegetable fats** come from *Cocos nucifera*, *Elaeis guinensis* (palm), *Madhuca indica* (mahua).
- The **waxes** are produced by plants like *Calathea lutea*, *Ceroxylon andicola, Euphorbia antisyphilitica*, *Myrcia* and *Simmondsia sinensis* (jojoba).

Rubber

- Rubber is **obtained from the latex of various woody plants**, especially from *Hevea brasiliensis* belonging to family Euphorbiaceae.
- The latex is **present in laticiferous cells** and **vessels** distributed in the bark, leaves and other tender parts of the tree.
- The **latex** is a milky white emulsion in water containing acids, salts, sugar, oils, resins, gums, proteins and hydrocarbons.
- Latex is **tapped** by making a sharp incision in the bark. Collected latex is processed to get rubber.
- **Vulcanization** is done by heating rubber with sulphur.
- Indian rubber (*Ficus elastica*) family moraceae is found in Assam and Khasia hills.
- Rubber is **also obtained from species of** *Castilla*, *Ficus*, *Manihot*, *Parthenium* and *Taraxacum*.
- **Other latex products** are **gutta percha** from *Palaquim gutta,* **chicle** from *Achras sapota* (for making chewing gum) and **balata** from *Malinkara bidentata.*

Tannins, resins and gums

- **Tannins** are complex organic substances, **chiefly glucosidal in nature** and **medicinally astringents**. They are **used for tanning hides and making inks**.
- Tannins is **obtained from various parts of plants**

Table : Essential oil and their uses

Type of oil	Scientific name	Uses
Khus oil	*Vetiveria zizanioides*	It is obtained from roots and rhizomes and is used for preparing and flavouring fruit juices, ice-creams, etc.
Terpentine oil	*Pinus longifolia*	It is obtained by distillation of oleoresin which is an exudate coming out after wounding the tree.
Jasmine oil	*Jasminum auriculatum*	This oil is obtained from flowers of the plant used in hair oils and perfumes.
Sandal wood oil	*Santalum album*	The oil is used in perfumes, soaps and in medicines.
Lavender oil	*Lavendula officinalis*	The fresh flowering tops of the plants are used for obtaining oil. It is a constituent of Eau de Cologne and other high grade perfumes.
Mandarin oil	*Citrus reticulata*	This oil is obtained from the peels of fruit and used in confectionery, soaps, etc.
Lemon-grass oil	*Cymbopogon citratus*	The leaves on distillation give a reddish-yellow oil with high citral content (70-80%), which is used in perfumes, cosmetics, toilet soaps, bath salts, etc.
Citronella oil	*Cymbopogan nardus*	This oil is obtained by distillation of leaves of this grass, which is used in cheap soaps, perfumes and also as an insect repellant.
Cedar wood oil	*Juniperus virginiana*	This oil is obtained by distillation of heart wood of this eastern red cedar. It is used as clearing agent in preparation of permanent microscopic mounts, in perfumes, soaps, deodorants and also used in fly sprays and as moth repellant.

like **roots** (*eg. Rumex, Polygonun*), **bark** (*eg. Acacia, Casuaria, Zizyphus*), **leaves** (*eg. Rhus*), **fruits** (*Terminalia, Quercus*).

- These are **basis of blue black inks**.
- **Gums** are complex carbohydrates which are widely distributed in the plants. They are **found as cementing substances** in the cell walls or produced by cellulose decomposition.
- **Commercial gum** is **obtained from the stems of** *Acacia senegal* (gumarabic), *Sterculia urens* (Kuteera gum), *Butea monosperma*, *Boswellia Serrata*, *Achras Sapota* (chewing gum) plants.
- The exudates of gum are collected after making incisions in the bark. It **exudes drop by drop as viscous liquid and finally hardens**.
- Different gums are used differently but in general they are **used as adhesive**, in **printing**, **polishes**, **syrups**, **cosmetics**, **as sizing material in cotton and paper industries and in medicines**.
- **Resins** are **oxidation products of essential oils.**
- Present in the specific canals resins are obtained by **tapping.**
- Resins possess **antiseptic qualities** and hence prevent the plant from decay.
- Being **insoluble in water** and **soluble in organic solvent** resins are **used in paints and varnishes**.
- Resins are classified as **hard resins, oleoresins** and **gumresins.**
- The common **hard resins** are damars, copals, ambers, shellacs, lacquers, and mastics.
- The **oleoresins** include turpentines, balsams etc.
- The common **gum-resins** are asafoetida, galbanums, ammoniacum etc.

MEDICINAL PLANTS

- Some plants have **medicinal value due to the presence of some chemical substances in their parts which have a definite physiological effect on body**.
- Depending upon the plant organ from which the drug is obtained, the drug plants are divided into following categories given in the table.

Table : Medicinal plants

Name of Drug/plant	Scientific name	Uses
Aconite	*Aconitum napellus*	For cholera and leprosy.
Belladona	*Atropa belladona*	Atropine alkaloid is obtained from it which is used for dilating pupil of eye (*i.e.*, in eye testing).
Liquorice	*Glycyrrhiza glabra*	The roots contain glycyrrhizic acid. It is expectorant, laxative given in bronchitis and chest complaints.
Serpentine	*Rauwolfia serpentina*	About 30 alkaloids are extracted from root of this plant. Out of which '**reserpine**' is the **most important one having sedative influence** and is **used in lowering the blood pressure**.
Ashwagandha	*Withania sominifera*	It is **effective in treatment of rheumatic pain, inflammation of joints**, **ulcers** and to **promote healing processes**.
Asafoetida	*Ferula asafoetida*	This is oleo-resin gum exuding from the roots. It is **carminative**, **digestive and antispasmodic**.
Holy basil	*Ocimum sanctum*	The leaf juice is **given in cold**, **cough** and **chronic fever** and is **used to check vomiting**.
Vasaka	*Adhatoda vasica*	The alkaloid vaccine is present in the leaves which is expectorant and antispasmodic.
Saffron	*Crocus sativus*	The dried stigmas and tops of the style are medicinally used.
Santonin	*Artemisia cina*	A valuable drug **santonin** is **present in the dried unopened flower heads of the plant**. This drug is one of the **best remedies of intestinal worms** (**wormicide**).
Violet	*Viola odorata*	The flowers are used for the treatment of coughs.

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Iron wood	*Mesua ferrea*	A tree and its flowers are source of 'Nagkesar'. The **flowers** are **used as astringent and stomachic**.
Quinine	*Cinchona calisaya*	The **only adequate cure of malaria** 'Quinine' is obtained from the thick bark of Cinchona sps.
Emblica	*Emblica officinalis*	It is one of the **richest sources of vitamin C**. Amla is a **good astringent** and **blood purifier**.
Bael	*Aegle marmelos*	The fruit is cooling, laxative, **stomachic and digestive**.
Opium	*Papaver sominiferum*	A brownish material (latex) is present in crude opium having 25 alkaloids, out of which **morphine** and **codeine have great medicinal value**.
Chebulic myrobalan	*Terminalia chebula*	The fruits of this tree are source of **Harad or Haritaki**, which is **important ingredient of ayurvedic medicine 'Trifla'**.
Croton	*Croton tiglium*	Croton oil is obtained from the seeds which is a **strong purgative**.
Isafgol	*Plantago ovata*	In the seed coat or husk a mucilagenous matter is found. Therefore, its husk is **used in treatment of dysentry**, **constipation** and **various diseases of digestive system**.
Nux-Vomica	*Strychnos nux-vomica*	The drug nux-vomica is **obtained from the ripe seeds** which is **used in the treatment of nervous disorders**, **chronic rheumatism**, **hydrophobia**, etc.
Catechu	*Acacia catechu*	Being a **valuable astringent** it is **used in chronic diarrhoea**, **dysentry**, **bleeding piles**, etc.

End of the Chapter

Chapter 68

Plant Pathology

- Any distortion from the healthy structure and normal physiological activities of the plant body is called **plant diseases**.
- Such type of structural and physiological abnormalities are harmful to the plant or its parts or products and thus, reduce its economic value.
- A simple dictionary meaning of disease is any departure from health, presenting marked symptoms, malady, illness and disorder.
- The branch of botany or biological science that deals with the study of nature, causes, development, resulting losses and control of plant diseases is known as **plant pathology** or **phytopathology** (*Phyton* = plant, *pathos* = suffering, *logos* = knowledge).
- The causal agent of a disease is called **pathogen**.
- The plant harbouring the pathogen is called **host**.
- The chain of events that lead to the development of disease in the host is **pathogenesis**.
- The establishment of a pathogen within the host after its entry or penetration is called **infection**.
- The potential ability of a pathogen to cause infection is called its **pathogenicity**.
- **Theophrastus** recorded his observations on plant diseases, such as rust of wheat and barley etc. in his book "*Enquiry into plants*".
- **Kuhn** (1856) published the first book on plant pathology entitled '*Die Krankheiten der Kultur Zewachge*'.
- Famous plant pathologists are **Butler**, **De bary**, **Micheli**, **K.C. Mehta**, **Mundukar**, **Tirumalachar Rangaswamy**.
- **Micheli** (1679-1737) was the **first scientist to study fungi and their spores**.
- Bacteria and fungi are pathogens postulated by **Robert Koch**.
- **K.R. Kirtiker** was the first Indian scientist who collected and identified fungi.
- Germ theory of disease was proposed by **Pasteur**.
- **Wheeler** (1969) classified plant diseases on the basis of symptoms.
- The science of plant pathology **deals with four major objectives**. These are –
  - **Etiology** - To study the living (animate) or non-living and environmental (inanimate) causes of plant diseases (*i.e.*, the study of pathogen).
  - **Pathogenesis** - To study the mechanisms of diseases development by pathogen (host-pathogen interaction).
  - **Epidemiology** - To study the spread of disease and modes of their transmission.
  - **Control** - To develop the suitable methods of controlling the diseases and reducing the losses caused by them.
- Pathogens are **divided into three groups** – **inanimate**, **viral** and **animate**.
- **Inanimate agents** are abiotic, non-parasitic and non-infectious agents, *e.g.* chemicals, pollution etc.
- **Viruses** are intermediate between animate and inanimate types, *e.g.* TMV, CMV. etc.
- **Animate** are biotic agents that remain in intimate association with their host plants, *e.g.* bacteria, fungi, algae, nematodes etc.
- **Incubation** is the interval between infection and appearance of disease.
- **Susceptible plants** are those which are easily attacked by some pathogen.
- **Resistant plant** are those which resists against the effect of pathogenic activity.
- **Inoculum** is the source of infection or the organism which initiates infection.

TYPES OF PLANT DISEASES

- **On the basis of causes**, plant diseases are –
  - **Non-infectious diseases :** The diseases which are not related to animate or viral pathogen are non-infectious and cannot be transmitted from one diseased plant to another associated with these diseases, they are **also known as non-parasitic diseases**.
  - **Infectious diseases** : These are caused by parasitic organisms or viral pathogens under a set of suitable environments. These diseases are always infectious, sometimes contagious (disease spread through pathogen very rapidly) and are transmitted from diseased to healthy plants in the field.
- **On the basis of their occurrence** diseases may be –
  - **Endemic disease :** A disease prevalent in and confined to a specific area (district or country) and occurs more or less constantly year after year, it is called endemic to that area.
  - **Epidemic or epiphytotic disease :** The epidemic or epiphytotic disease is one which occur severely and widely among a large section of population, but its occurrence is periodic.
  - **Sporadic diseases :** The disease occurs at very irregular intervals and is not confined to a particular area.
- A disease is said to be –
  - **Localized**, when it affects only and special organs or parts of the plant.
  - **Systemic**, when the effect is spread to entire plant.
- **On the basis of the nature of the causal agent**, the plant diseases may be grouped into following categories –
  - **Non-parasitic diseases :** The diseases caused by non-parasitic or abiotic agents are known as non-parasitic diseases. Many of the non-parasitic diseases cause heavy loss but cannot be readily controlled because they occur due to the improper environmental conditions that are beyond man's reach as – low temperature, high temperature, unfavourable oxygen relations, unfavourable soil moisture relations, accumulation of injurious impurities, lightening injury, mineral deficiencies, mineral excesses, injurious atmospheric gases, etc. Such diseases are not caused by animate agencies or viruses. Therefore, they remain non-infectious and are not transmitted from one plant to other plants.
  - **Parasitic diseases :** The diseases caused by fungi, slime moulds, bacteria, algae, parasitic, flowering plants, nematodes, protozoa, birds, rodents etc. are known as parasitic diseases.
- When the pathogen of a disease survives and spread through soil, it is called soil-borne pathogen and such disease is called **soil-borne disease**.
- When the perpetuation and dispersal of disease is through seed, they are known as **seed-borne disease**.

Common symptoms of plant diseases

- If entry of pathogens induces reactions in the body of their hosts, resulting in the appearance of certain abnormalities, such visible effects induced in a host by the presence of the pathogen are called **symptoms**.
- Symptoms may be **divided into two groups on the basis of whether the pathogen** makes **its external appearance or causes internal disorders resulting in symptoms**.
- Death and discolouration of tissues/parts of leaves, stems and roots is called **necrosis**.
- **Pustules** are small blister like elevations of epidermis which are produced by pushing of spores that are produced below.
- **Excessive growth of tissue** are of **two types** – **hypertrophy** (increases in cell size) and **hyperplasia** (increase in cell numbers).
- In **stunting** growth is poor so that the size of the plant and its leaves remain short.
- **Pitting** is the formation of series of depressions on the surface of stem and fruits.
- Discolouration, softening and degeneration of a succulent tissue is called **rot**.
- **Mosaics** are intermingled patches of green and yellow colouration.
- **Chlorosis** is yellowing of otherwise green structures such as leaves.
- **Wilting** is loss of turgidity and drooping of leaves or shoots generally due to insufficiency of water.
- **Excessive root branching** occurs in nematode infection.
- **Galls** are swelling or growth on all parts of plants.

- **'Witches Broom'** is broom like growth of a number of small narrow branches.
- **Damping off** is falling off of the seedling on the ground due to destruction of tissues at the level of soil surface.
- In **leaf curls** there is disturbance and curling of leaves. Parts may also become thickened.
- **Spots** are dead tissues killed by parasites present in leaves.
- In **blight** large number of leaves, blossoms and twigs die.

Types of pathogens

Fungi

- There are over 10,000 fungal pathogens of plants.
- The fungal plant pathogens themselves fall into two major groups, the **biotrophs** which feed from living plant tissue and the **necrotrophs** which kill plant cells and then live on the nutrients released.
- However, many plant pathogens adopt a hybrid lifestyle, initially acting as biotrophs before converting to a necrotrophic lifestyle. These are called **hemibiotrophs**.
- The majority of phytopathogenic fungi belong to the **ascomycetes** and the **basidiomycetes**.
- The fungi reproduce both sexually and asexually *via* the production of spores.
- These spores may be spread long distances by air or water, or they may be soil borne.
- Many soil borne spores, normally zoospores are capable of living saprophytically, carrying out the first part of their life cycle in the soil.
- Fungal diseases can be controlled through the use of fungicides in agriculture, however new races of fungi often evolve that are resistant to various fungicides.

Protozoa

- There are a few examples of plant diseases caused by protozoa.
- They are transmitted as zoospores which are very durable, and may be able to survive in a resting state in the soil for many years.
- They have also been shown to transmit plant viruses.
- When the motile zoospores come into contact with a root hair they produce a plasmodium and invade the roots.

Bacteria

- Most bacteria that are associated with plants are actually saprophytic, and do no harm to the plant itself.
- However, a small number, around 100 species, are able to cause disease.
- Bacterial diseases are much more prevalent in sub-tropical and tropical regions of the world.
- Most plant pathogenic bacteria are rod shaped (bacilli). In order to be able to colonise the plant they have specific pathogenicity factors. There are **4 main bacterial pathogenicity factors** –
  - **Cell wall degrading enzymes :** used to break down the plant cell wall in order to release the nutrients inside. Used by pathogens such as *Erwinia* to cause soft rot.
  - **Toxins :** These can be non-host specific, and damage all plants, or host specific and only cause damage on a host plant.
  - **Phytohormones :** For example *Agrobacterium* changes the level of auxin to cause tumors.
  - **Exopolysaccharides :** These are produced by bacteria and block xylem vessels, often leading to the death of the plant.
- Bacteria control the production of pathogenicity factors *via* quorum sensing.
- **Mollicutes** (bacteria that lack cell wall) are normally transmitted by sap-sucking insects, being transferred into the plants phloem where it reproduces.

Viruses

- There are many types of plant virus, and some are even asymptomatic.
- Normally plant viruses only cause a loss of yield and therefore it is not economically viable to try to control them. The exception being when they infect perennial species, such as fruit trees.
- Most plant viruses have small, **single stranded RNA genomes**.
- These genomes may only encode 3 or 4 proteins: **a replicase**, a **coat protein**, a **movement protein to allow cell to cell movement** and sometimes a **protein that allows transmission by a vector**.
- Plant viruses must be **transmitted from plant to plant by a vector**.
- The vector is normally an insect, but some fungi, nematodes and protozoa have been shown to be viral vectors.

Nematodes

- Nematodes are small, multicelluar worm like creatures.
- Many live freely in the soil, but there are some

species which parasitise plant roots. They are mostly a problem in tropical and subtropical regions of the world, where they may infect crops.

- Root knot nematodes have quite a large host range, whereas cyst nematodes tend to only be able to infect a few species.
- Nematodes are able to cause radical changes in root cells in order to facilitate their lifestyle.

Dissemination of plant diseases

- **Dissemination by wind :** The spores of many pathogens are disseminated by the wind. Sometimes, the diseased plant parts help dissemination of diseases. Eg Rusts of cereals, caused by *Puccinia graminis*, and late blight of potato, incited by *Phytophthora infestans*, are the common examples in which dissemination of disease occurs by means of wind.
- **Dissemination of water :** The diseases like, wart disease of potato, caused by *Synchytrium endobiotichum*, and club root of crucifers, caused by *Plasmodiphora brassicae*, are disseminated from one field to another through irrigation or flood water. Many of the bacterial diseases, e.g., citrus canker, caused by *Xanthomonas citri*, are disseminated by splashing of rain drops.
- **Dissemination by insects :** Insects act as important agents in the spread of plant diseases. A number of viral diseases are disseminated by insects like leaf-hoppers, mealy bugs and aphids. Some insects are known to feed on diseased host tissue thus carrying the inoculum. When such insects visit the disease-free plants, they cause infection (Ergot of rye disease, caused by *Claviceps purpurea*).

Prevention and control of plant diseases

- The main object of plant diseases control is to prevent the quantitative and qualitative loss of crops due to the attack of pathogen and to increase the economic value of the crop.
- The disease control follows two main principles - **prevention and cure**.
- **Prevention** is the protection of the host from infection and exposure to the pathogen or from environmental factors favourable to disease development. This is called **prophylaxis**.
- **Cure** involves the destruction of the pathogen after it has gained the entry of the host.
- Such methods are known as **curative** or **therapeutic measures**.
- The various methods of prevention and control of plant diseases are - physical, chemical and biological control methods.
- **Physical control method involves the following measures -**
  - **Quarantine :** Plant quarantine is the legal restriction that aims at preventing the entry of pathogens from infected to non-infected areas.
  - **Eradication of alternate hosts :** Many diseases persist through alternative hosts of the pathogen which provide shelter to them under unfavourable conditions. Due to removal of such host the pathogens are not able to complete the life cycle.
  - **Certification and inspection :** In various countries, there are inspecting departments which assure the entry of only certified seeds or planting materials from abroad, or from one part of the country to another.
  - **Crop rotation :** When a particular crop is grown for several years in the same field continously, the soil borne pathogens of that crop perennate in the soil and multiplies increasing its population. Crop rotation will not allow the pathogen to survive.
  - **Field sanitation :** Necessary for the control of soil borne, saprophytes and facultative parasitic pathogens.
  - **Environmental modification :** It includes the modifications of such cultural practices which discourage pathogen development and help in reducing disease incidence and loss in crop.
- **Chemical control methods** include the application of chemicals to plants for the control of pathogens.
- The chemicals used oppose the germination, growth and multiplication of the pathogen or directly destroy it by toxicity.
- Depending upon the nature of pathogen, the chemicals used are known as **fungicides**, **bactericides**, **insecticides**, **nematicides**, **viricides** and **herbicides** or **weedicides**. Commonly, they are togetherly termed as pesticides.
  [*For more on pesticides refer Chapter Pesticides and Biofertilizers*].
- **Biological control methods** can be **divided into three categories** –
  - **Breeding resistance varieties :** It is the development of varieties having resistance to pathogenic infection.

- **Hyperparasitism :** It involves the control of one pathogenic organism with the help of another organism parasitise or antagonize the pathogen.
- **Trap crops and antagonism :** Many plants secrete some substances after infestation by some pathogens, these substances become toxic to the pathogens. Such hosts are called traps or antagonistic plants.

Important plant diseases

- **Pathogens of damping off are** *Pythium, Phytophthora, Fusarium, Rhizoctonia, Helminth-osporium, Colletotrichum*.
- **Damping off of tobacco** is caused by *Pythium.*
- **Damping off of groundnut** is caused by *Rhizoctonia sps*.
- If rotting occurs in a root it is called **root rot**. If the root rot extends to the base of stem it is called **foot rot**.
- Root rot **affects the transport of water and mineral nutrients**. **Leaves turn yellow** due to root rot.
- **Pathogens of root rot** are *Ophiobolus graminis, Phymatotrichum omnivorum, Fusarium moniliforme, Fusarium solani var phaseoli, Thielaviopsis basicola, Sclerotium rolfsii.*
- *Thielaviopsis* & *Fusarium* survive in the soil in the form of **chlamydospores**.
- *Sclerotium* survives in the form of **sclerotia**.
- **Host plants** generally **affected by root rot** are – wheat, barley, paddy, cotton, bean, potato, tomato, carrot, beet.
- **Loss of turgor leads to vascular wilting**. The petioles of lower most leaves droop due to this disease and this phenomenon is called **epinasty**.
- **Xylem vessels** are blocked with fungal mats, tyloses, gums.
- **Bacteria** and **fungi** grow in the vascular tissues causing the non transportation of water and food materials.
- **Toxins** and **pectinolytic enzymes** produced by these pathogens **play an important role in vascular wilting**.
- **Bacterial wilts** are –
  - **Wilt of maize**, caused by *Erwinia stewarti*
  - **Wilt of potato**, caused by *Pseudomonas solanacearum.*
  - **Wilt of sugarcane**, caused by *Xanthomonas vasculorum*.
- **Fungal wilts** are –
  - **Wilt of cotton**, caused by *Fusarium vasinfecti*.
  - **Wilt of redgram**, caused by *Fusarium oxysporium*.
- **Downy mildews** appears when the atmosphere is with high humidity.
- Fungi causing downy mildews belong to the order **peronosporales**.
- White cotton like or grey coloured sporangiophores appear in clusters on the lower side of the leaves.
- **Downy mildew of sorghum** is caused by *Sclerospora sorghi.*
- **Downy mildew of bajra** is caused by *Sclerospora graminicola*.
- **Downy mildew of grapes** is caused by *Plasmopara*.
- **Downy mildew of cucurbits** is caused by *Pseudoperonospora*.
- **Downy mildew of millet** is caused by *Sclerospora graminicola*.
- **Downy mildew of onion** is caused by *Perenospora destructor*.
- **Powdery mildews** are caused by fungi belonging to the family **Erysiphaceae** (Class – Ascomycetes).
- **Pathogens of powdery mildews** are *Erysiphe*, *Sphaelotheca*, *Phyllactinia*, *Ansynula*.
- **Powdery mildew of wheat** is caused by *Erysiphe graminis*.
- **Powdery mildew of rose** is caused by *Sphaerotheca pannosa*.
- The rust symptoms appears **as small pustules of rusty spores formed by bursting of host epidermis**. Symptoms of rusts appear on vegetative parts.
- Fungi causing rusts belong to the order **uredinales** (Class – Basidiomycetes).
- **Pathogens of rust** are *Puccinia*, *Uromyces*, *Melampsora*, *Hemiliea*.
- **Host plants of rust** are cereals, millets, coffee, castor.
- **Rust of wheat** is caused by *Puccinia graminis.*
- **Rust of pea** is caused by *Uromyces fabae*.
- **Rust of linseed** is caused by *Melampsora linii.*
- **Rust of coffee** is caused by *Hemilia vastatrix*.
- **Smut** is named as smut due to **sooty black spore masses**.
- Fungi causing smuts belong to **ustilaginales** (Class : Basidiomycetes).
- Symptoms of smut are usually found in the **reproductive organ**.
- **Pathogens of smut** are *Sphaecelotheca*,

Tolyposporium, *Tilletia*, *Cladosporium*, *Entyloma*.

- **Smut of jowar** is caused by *Sphaecelotheca sorghi*.
- **Long smut of jowar** is caused by *Tolyposporium ehrenbergi*.
- The blighted host parts **turn yellow and gradually disintegrate**.
- **Pathogens of blight** are *Phytophthora*, *Alternaria*.
- **Late blight of potato** is caused by *Phytophthora infestans*.
- **Early blight of potato** is caused by *Alternaria solani*.
- **Charcoal black** coloured spotting on the infected region like leaves and fruits are called **anthracnose**.
- The causative fungi pathogen of anthracnose belongs to **Deuteromycetes**.
- **Acervuli** are **formed in these spots**.
- **Anthracnose disease of bean** is caused by *Colletotrichum spp*.
- **Anthracnose of lime** is caused by *Gloeosporium limetticola*.
- In the region of the leaf spot the tissue shrinks and separates from the healthy tissue leaving a hole called **shot hole**.
- **Pathogens of leaf spots** are *Cercospora, Pseudomonas, Pyricularia, Helminthosporium, Ascochyta, Botrytis*.
- **Leaf spot of groundnut** is caused by *Cercospora personata*. Leaf spot of **cherry** is caused by *Pseudomonas*.
- Infected leaves show uneven thickenings (wrinkles) due to **abnormal multiplication of palisade cells** along the veins. It is called **leaf curl**.
- **Leaf curl of peach** is caused by *Taphrina deformans*.
- **Witches broom of cherry** is caused by *Taphrina cerasi*.
- **Crown galls of apple** is caused by *Agrobacterium tumefasciens*.
- The tumors that develop on root system by nematodes are called **root knots**.
- **Root knot of tomato** is caused by *Meloidogryne hapla* (a nematode).
- **Canker** is a **dead area in the bark or cortex**.
- **Tumorous region of callus** is present around the canker.
- **Citrus canker** is caused by *Xanthomonas citri* (a bacterium).
- **Apple canker** is caused by *Nectria galligena* (a fungus).
- **Ergot of rye** is caused by *Claviceps purpurea*.
- **Red rust of tea plant** is due to *Cephaleurous* (a parasitic alga).
- **Blast disease of rice** is caused by *Pyricularia oryzae*.
- External seed borne inoculum in **blast of rice** can be eliminated by treating the seed with organomercurial compounds like **agrosan**.
- Use of **resistant variety** is the **most effective method to prevent blast of rice**.
- **Red rot of sugarcane** is caused by *Colletotrichum falcatum*.
- The perfect stage of *C. falcatum* is *Glomerella tucumanensis*.
- **Tikka disease of groundnut** is caused by *Cercospora* sp.
- The **main symptom of red rot of sugarcane** is the presence of **red coloured elongated spots** developed in the midrib. Minute, black coloured acervuli are present in these patches.
- **Ireland famine** of 1844-45 was due to late blight of potato caused by *Phytophthora infestans*.
- **Bengal famine** of 1940's is due to the attack of rice field by *Helminthosporium oryzae*.
- During 1867 - 1871 whole coffee plantations of Sri Lanka were cut down due to the attack by coffee rust caused by *Hemileia vastatrix*.
- In France, the whole wine industry was closed due to the attack of grape vine by the fungus *Plasmopora viticola*.
- **Black heart of potatoes** is due to poor ventilation and high temperature.
- **Tip burn** disease of paddy leaves is due to reduced oxygen supply and Zn deficiency.

End of the Chapter

Chapter 69

Pesticides & Biofertilizers

PESTICIDES

- Pesticide may be a chemical substance or biological agent (such as a virus or bacteria) used against pests including insects, plant pathogens, weeds, molluscs, birds, mammals, fish, nematodes (roundworms) and microbes that compete with humans for food, destroy property, spread disease or are a nuisance.
- **First commercial pesticide** was discovered by Millardet (1882). It is called **Bordeaux mixture** (after the name of university).
- Common household pesticides are baygon spray (propoxur, a carbamate), finit/flit (having malathion, an organophosphate), mosquito repellent cakes and coils and BHC (benzene hexachloride).
- **DDT** (dichloro-diphenyl-trichloroethane) is the most well known because of its being the **first major synthetic pesticide** and later its persistent toxicity.
- Pesticides are **generally biocides** because they are often broad spectrum.
- Pesticides includes **chemical pesticides** and **biopesticides**.

Chemical pesticides

- **Chemical pesticides** are very effective but are **poisonous chemicals** and **mostly non-biodegradable**. Therefore they can cause environmental pollution.
- It includes organochlorines, organophosphates, carbamates, triazines etc. (*Refer table*).

Biopesticides

- **Biopesticides** are certain pesticides derived from natural or biological agents like animals, plants, bacteria, viruses, fungi etc. to destroy or control weeds, insects and pathogens.
- **According to nature of organism** – **biopesticides are of different types** as microbial pesticides, plant pesticides and biochemical pesticides.

Microbial pesticides

- **Microbial pesticides** consist of a micro-organism (e.g., a bacterium, fungus, virus, or protozoan) as the active ingredient.
- Microbial pesticides can control many different kinds of pests, although each separate active ingredient is relatively specific for its target pest(s).
- For example, certain fungi control certain weeds; other fungi kill specific insects.
- The **most widely used microbial pesticides are subspecies and strains** of *Bacillus thuringiensis* **(Bt)**.
- Each strain of this bacterium produces a different mix of proteins and specifically kills one or only a few related species of insect larvae.
- Whereas some species of *B. thuringiensis* control moth larvae found on plants, others are specific for larvae of flies and mosquitoes.
- The target insect species are determined by whether the particular Bt produces a protein that can bind to a larval gut receptor, thereby causing the insect larvae to starve.
- **Microbial insecticides are applied as** sprays, dusts, or granules just as conventional pesticides.
- Microbials may kill insects a little more slowly than do conventional pesticides.

Plant pesticides

- Plant-pesticides [Plant incorporated protectants $(PIP_s)^4$] are pesticidal substances that plants produce from genetic material that has been added to the plant.

A **systemic pesticides** is a pesticides applied to a plant which is absorbed into its sap and so distributed throughout the plant to make all parts of it poisonous to pests, without harming the plant, although systemic insecticides which poison pollen & nectar in the flowers may kill needed pollinators.

- For example, scientists can take the gene for the Bt pesticidal protein and introduce the gene into the plant's own genetic material. Then the plant, instead of the Bt bacterium, manufactures the substance that destroys the pest. Both the protein and its genetic material are regulated by the **Environmental Protection Agency** (EPA); the plant itself is not regulated.

Biochemical pesticides

- Biochemical pesticides are **naturally occurring substances that control pests by nontoxic mechanisms**.
- Conventional pesticides, by contrast, are generally synthetic materials that directly kill or inactivate the pest.
- Biochemical pesticides include substances such as **insect sex pheromones** that interfere with mating as well as various scented plant extracts that attract insect pests to traps.
- Biochemical products also include **hormones such as growth regulators and enzymes**.
- **Insect growth regulators (IGRs) are nontoxic**. They disrupt the balance in the insect between juvenile hormone, which regulates development, and the hormone that regulates emergence into adulthood, causing abnormal pupation or adult development.
- **According to nature of action biopesticides** are of various types are as bioherbicides and bioinsecticides.
- **Bioherbicides** are those organisms or their extracts that destroy weeds without harming useful plants.
- Bioherbicides are of various types –
  - **Predator herbivore :** Specific insects that feed on weeds. *Cactoblastis cactorum* (Cochineal insect) has controlled spread of *Opuntia* in India and Australia. *Chrysolina* beetles have overcome Klamath weed (*Hypericum perforatum*) in U.S.A. Beetle *Zygogramma bicolorata* is biological control of *Parthenium hysterophorus.*
  - **Smoother crops :** Crops that **do not allow weed to grow**, e.g., sunflower, soyabean, barley, rye, sorghum, etc. Rotation with such crops gives protection from weed.
  - **Mycoherbicides (first bioherbicides) :** Fungi that are used as herbicide. *Phytophthora palmivora* does not allow milkweed vine to grow in *Citrus* orchards. 'Devine' and 'Collego' are fungal spores which can be sprayed over weeds for their elimination.
  - **Transgenic crops :** They are crops having genes of smoother crops, pest and herbicide resistance, e.g., transgenic tomato (against Hornworm larvae), transgenic tobacco (against herbicides).
  - **Vegetables :** Certain weeds can be eliminated or made useful by using them as vegetable or fodder, e.g., *Amaranthus, Chenopodium.*
- **Bioinsecticides** are organisms or their products which are used to kill or repel specific insects. They are of different types – predators, parasites and pathogen, sterile male, insect hormones and natural insecticides.
- **Predators** are specific natural organisms that are introduced to control plant pests without harming useful insects. Lady bug and praying mantis can control scale insects or aphides of vegetables, cotton and apple. Vedalia beetle (*Radiola cardinalis*) of Australia has been used in several countries against cottony cushion scale. Predator bug has been successfully employed in Hawaii in controlling sugarcane leaf hopper (*Perkinsiella saccharicida*).
- **Parasites** are organisms that feed on other living organisms (hosts) without devouring them.
- **Parasitoids** are organisms that live a parasitic life in younger stages (egg and larval) but lead a free life later on.
- **Pathogens** are disease producing micro-organisms. Egg parasitoids of *Trichogramma* are able to control a number of pests of cotton, sugarcane and pulses. Fungus *Bauveria bassiana* can control potato beetle and codling moth, fungus *Entomophthora ignobilis* green peach aphid, bacterium *Bacillus thuringiensis* cabbage looper (*Trichoplausian*), bacterium *Bacillus popilliae* causes milky diseases in Japanese Beetle *Popilia* (which is a serious pest of vegetable and fruits) and virus *Baculovirus heliothis* Cotton

Bollworm (*Heliothis zea*).

- **Sporeine** developed in Germany is the **first commercial bioinsecticide** obtained from *Bacillus thuringiensis*.
- A large number of **sterile males** are introduced that **mate without producing offsprings**.
- **Insect hormones** are different types of hormones used for controlling pests, like –
  - **Juvenile hormone :** Does not allow insect to reach maturity.
  - **Pheromone :** Biochemicals used to disrupt mating behaviour of insects. Pheromone traps like - cylindrical traps coated internally with female pheromones will attract all males. In confusion pheromone technique small paper pieces having female pheromones are thrown over the area. Males will not be able to locate females.
  - **Moulting hormone :** It causes premature moulting of larvae resulting in death.
- **Natural insecticides :** *Refer table : Types of pesticides (natural insecticide) on page no. 626-627.*

Hazards caused by use of pesticides

- **Storage** – Opened pesticide cans/bottles may poison food, stored fodder, implements, etc.
- **Field workers/sprayers** – Pesticides are inhaled, absorbed or ingested by persons involved in their spray.
- **Factory accidents** – Any slackness in control leads to accidents like the one at Bhopal (methyl isocyanate) in 1984 in Union Carbide Plant, Bolsover England (1968) and Soverso Italy (1976).
- **Pesticide treadmill** – It is the phenomenon of requirement of progressively larger and larger doses with the passage of time.
- **Persistance** – Most pesticides degrade very slowly and persist.
- **Resistance** – Pests tend to develop resistance to pesticides.
- **Biomagnification/Bioconcentration** – This is increase in percentage of a chemical in the body of organisms with the rise in trophic level. Most organochlorines are fat soluble and undergo biomagnification (13 - 31ppm of DDT in human body in India).
- **Biocides** – Pesticides are biocides and kill even the nontarget organisms.
- **Ecological imbalance** – Being biocides, pesticides often kill predators or higher trophic level organisms, bringing about ecological imbalance. (Environmental Protection Agency`).

Integrated pest Management (IPM)
IPM involves use of different pest control methods, which are ecologically sound (*i.e.,* not cause hazard to environment), *e.g.,* biological control methods, better agricultural practices like crop rotation, sanitation, etc., starvation method, *i.e.,* growing of target crop away from major crop, ultra low volume spraying method, *i.e.,* use of very low and most effective concentration of chemicals, which does not cause pollution, etc.

Organic farming
It is the technique of raising crops through the use of manures, fertilizers and pesticides of biological origin, resistant varieties, crop rotation, intercropping etc. It gives unpolluted plant and animal products.

Sustainable agriculture
It is the practice of obtaining optimum agricultural yield as per changing human needs while maintaining or enhancing the quality of environment and conserving natural resources through judicious management of available resources.

FERTILIZER

- **Fertilizers** are inorganic materials containing elements in the form of soluble or readily available chemical compounds.
- Fertilizer is a substance that is added to the soil or provided as foliar spray in order to provide required nutrients to plants.
- It is of **two types - chemical** and **biological**.
- **Chemical fertilizers** are synthetic or chemical formulations that **supply the soil with requisite minerals directly**.
- Mostly they are inorganic (eg., calcium ammonium nitrate etc.).
- Chemical fertilizers are **mostly synthesized from fossil fuels**.
- To increase agricultural productivity, chemical fertilizers and pesticides are being used by the farmers on a large scale.
- **The ill effects of chemical fertilizers** are –

Table : Types of Pesticides

	Types/Names	Character/effect	Examples
1.	**Algicides**	Chemicals that destroys algal pathogens and algal bloom	– Copper sulphate
2.	**Fungicides** (also called **antimycotic**)	Chemicals that destory fungal pathogen **Inorganic fungicide** (obtained from organic compounds)	– **Bordeaux mixture** (Composed of $CuSO_4$, lime and water) – **Burgandy mixture** (Composed of $CuSO_4$, Na_2CO_3 and water) – **Ammonical copper carbonate** (Composed of ammonia, $CuCO_3$ and water), mercuric **chloride**, **powder sulphate**, **lime sulphate**, Blitox-50, peronox etc.
		Organic fungicide - forms carbamate (derived from carbamic acid NH_2COOH)	– Dithane M - 22 – Dithane M - 45 – Dithane Z - 78 – Dithane S - 31
3.	**Weedicides/Herbicides**	Kill weeds and unwanted plants in cultivated land	– Use to remove weeds in tea, cotton, tobacco etc. – **Triazines** (urea derivatives), **carbamates** (thiocarbamates, phenyl carbamates) and **auxin derivativies** (2, 4-D, 2, 4, 5-T)
4.	**Insecticides**	Chemicals that destroy or kill insects **Natural insecticides** (obtained from microbes & plants)	– **Azadirachtin** [obtained from seed of *Azadiractita indica* (neem)] destroys Japanese beetles and other leaf eating insects – **Rotenones** (obtained from roots of *Derris elliptica* & *Lonchocarpus*) harmless to warm blooded animals – **Squill** (obtained from red squill) – **Nicotine** (obtained from *Nicotiana* species) – **Pyrethrin** (obtained from floral heads of *Chrysanthemum sp.*) used in fly spray, aerosols, mosquito coils – **Thurioside** (obtained from *Bacillius thuringiensis*) effective against moths flies, mosquitoes, beetles.
		Synthetic insecticides (chemicals obtained syntheti-cally)	– **Organochlorines** – chlorine containing hydrocarbon, non biodegradable, persistant, fat soluble, show biomagnification, e.g., DDT, BHC, aldrin, endrin, dildrin, endosulphane – **Organophosphates** – esters of phosphoric acid, malathion (as finit), parathion, ethion, tetraethyl pyrophosphate (TEPP) etc. – **Carbamates** - derivatives of carbamic acid, Baygon, carbofuran.

contd...

	Types/Names	Character/effect	Examples
			– **Pyrethroids** - synthetic derivatives of pyrethrum (pyrethrin), e.g., allethrin, cyclethrin & barthrin
		Volatile liquid (fumigant) Poisonous, kill insects, nematodes & other animals or plants that damage stored foods or seeds, human dwellings etc.	Ethyl dibromide
5.	**Nematicides**	Chemicals that destroy nematodes	Methyl bromide, ethylene dibromide, chloropicrin.
6.	**Rodenticides**	Chemicals that kill rodents	Sodium fluroacetate, warfarine, zinc sulphate
7.	**Bactericides**	Chemicals used for control of bacteria as – **Disinfectants** **Antibiotics**	– Active chlorine, active oxygen, iodine, alcohols etc. – Blasticidin, agrimycin, streptomycin, viridin
8.	**Virucides**	Chemicals used to control viruses	– Imaniun
9.	**Miticides**	Chemicals used to control mites	Phomix, fluvalinate

  – They are expensive
  – Their manufacture depends upon the dwindling resources of energy as petroleum and coal etc
  – Their production releases pollutants
  – They are lost readily when applied in field by surface run off and thus pollute soil & other water resources.
- **Biological fertilizers** are nutrient materials obtained from living organisms or their organic remains which are used for enhancing fertility of soils.
- Biological fertilizers are of **two types - manures & biofertilizers**.
- Green manures, biofertilizers and biological control methods have been introduced to combat the ill effects of agricultural chemicals.
- **Agricultural chemicals** are chemicals employed in agriculture for protecting crop plants from pests and enhancing the yield of crop plants by meeting their nutritional requirements.
- They include **chemical fertilizers**, **growth regulators** and **pesticides**.

MANURES

- Manure is a **semi-decayed organic matter** which is **added to the soil in order to maintain its fertility**, **crumb structure**, **aeration** and **hydration capacities**.
- It is of **three types** - farmyard manure, compost and **green manure**.
- **Farmyard manure** - Dung, farm refuse, fallens leaves, twigs, etc. are dumped in heaps to undergo decomposition and form dark amorphous manure.
- **Compost/composited manure** is rotten vegetable matter, garbage, sewage sludge and animal refuse often enriched with small amount of chemical fertilizers during decomposition stage.
- Ghai and Thomas (1989) have defined **green manuring** as 'a farming practice where a leguminous plant which has derived enough benefits from its association with appropriate species of *Rhizobium* is ploughed into the soil and then a non legume is grown and allowed to take the benefits of the already fixed nitrogen.
- **Various leguminous plants to be used as green manure** are : **cultivated annual legumes** (*e.g.*, *Crotalaria juncea*, *C. striata*, *Cassia mimosoides, Cyamopsis pamas, Glycine wightii, Indigofera linifolia, Sesbania rostrata, Vigna radiata*), **perennial legumes** (*e.g.*, *Acacia nilotica, Cassia hirsuta*, *Sesbania aegyptica*, *Leucaena leucocephala*), and **wild annual legumes** (*e.g.*, *Cassia cobanensis*, *Lathyrus sativus*, *Mimosa invisa*, *Mucuna bacteata*).

- In India, **for small and marginal farmers, green manuring may be important** because of high cost of chemical fertilizers.
- Moreover, reclamation of "Usar lands" can also be done by green manuring.
- In addition to nitrogen, **green manures also provide organic matter**, N, P, K (**nitrogen**, **phosphorus**, **potassium**) and **minimize the number of pathogenic micro-organisms in soil**.

BIOFERTILIZER

- Biofertilizers are ready to use live formulates of such beneficial micro-organism which on application to seed, root or soil mobilize the availability of nutrients by their biological activity in particular and help build up the micro flora and in turn the soil health in general.
- Nitrogenous biofertilizers harvest atmospheric nitrogen and converts into ammonical form, which in due course is made available to the plants or is released in the soil.
- Phosphate solutions solubilize fixed forms of phosphorus already present in the soil and make it available for use of plants.
- Compositing biofertilizers are used for hastening the process of compositing and for enriching its nutrient value.
- With the introduction of green revolution technologies the modern agriculture is getting more and more dependent upon the steady supply of synthetic inputs (mainly fertilizers) which are products of fossil fuel (coal + petroleum).
- Excessive dependence of modern agriculture and the supply of these synthetic inputs and the adverse effects being noticed due to their excessive and imbalanced use has compelled the scientific fraternity to look for alternatives.

Advantages of biofertilizers over chemical fertilizers

- **Availability and cost :** Increasing costs are getting unaffordable by small and marginal farmers.
- **Effect of chemical fertilizers in soil and environment**.
  - Excessive and imbalanced use of chemical fertilizers has adversely affected the soil causing decrease in organic carbon, reduction in microbial flora of soil, increasing acidity and alkalinity and hardening of soil.
  - Excessive use of N-fertilizer are contaminating water bodies thus affecting fish fauna and causing health hazards for human beings and animals.
  - Production of chemical fertilizers adds to the pollution.
- To overcome the deficit in nutrient supply and to overcome the adverse effects of chemical cultivation it is suggested that efforts should be made to exploit all the available resources of nutrients under the theme of integrated nutrient management.
- Under this approach the best available option lies in the complimentary use of biofertilizers, organic manures in suitable combination of chemical fertilizers.
- This **integrated approach of nutrient management not only ensures higher productivity but also ensures the good health of our soil and environment**.
- Biofertilisers are **essential components of this approach** and are being promoted to harvest the naturally available, biological system of nutrient mobilization.

Types of biofertilizers

- **For nitrogen**
  - *Rhizobium* for legume crops
  - *Azotobacter*/*Azospirillum* for non-legume crops
  - *Acetobacter* for sugarcane only
  - BGA and *Azolla* for low land paddy
- **For phosphorus**
  - Phosphatika for all crops to be applied with *Rhizobium*, *Azotobacter*
  - *Azospirillum* and *Acetobacter*
- **For enriched compost**
  - Cellulolytic fungal culture
  - Phosphotika and *Azotobacter* culture

Micro-organisms used as biofertilizers

- Bacteria, cyanobacteria (blue green algae) and fungi are the different types of organisms that act as biofertilizer.
- Bacteria and cyanobacteria (also *Frankia*) are known to fix atmospheric nitrogen while mycorrhizal fungi draw nutrients from organic matter to provide to the plant with which it is associated.

Bacteria as biofertilizers

- There are three major categories of bacteria that are used as biofertilizers.

- **Free living nitrogen fixing bacteria**
  – These are bacteria of diverse nutritional status which absorb molecular nitrogen (N_2) from soil, air and convert it into nitrogen salts or amino acids.
  – They include the following : *Azotobacter*, *Beijerinckia* - aerobic, *Clostridium* - anaerobic *Rhodospirullum* & *Chromatium* -photosynthetic.
- **Symbiotic nitrogen fixing bacteria**
  – These bacteria form a mutually beneficial associations with the plants.
  – The bacteria obtain food & shelter and in turn help the plants to obtain nitrogen by fixing it.
  – The most important of such type is *Rhizobium leguminosarum* which forms nodules on the roots of legume plants.
  – The other species of *Rhizobium* are *R. lupini*, *R. trifolii*, *R. phaseoli*, *R. meliloti*.
  – A root nodules has a growing point, vascular strand and reddish pigment **leghaemoglobin** but lacks root cap and root hair.
  – Its central infection zone has large cells with groups of bacteroids covered by membrane lined by leghaemoglobin.
  – *Frankia* is present in root nodules of nonleguminous plants, e.g., *Casuarina*, *Alnus*, *Myrica*, *Rubus*.
  – In *Sesbania* the stem nodule contains *Aerorhizobium caulinodans, Xanthomonas* is present in leaf nodules of *Ardisia*.
- **Phyllosphere and Rhizosphere nitrogen fixing bacteria** (loose association).
  – These bacteria live freely around roots and leaves of higher plants without any intimate relationship.
  – They provide the nitrogen fixed to the plants and obtain their nutrition from the exudations.
  – This relationship is termed as associative mutualism.

Cyanobacteria as biofertilizers

- Cyanobacteria or blue green algae are the simplest living autotrophic plants that act as biofertilizers which are of extremely low costs.
- Cyanobacteria derive the energy needed for nitrogen fixation through photosynthesis.
- They are of **2 main types** - free living & symbiotic nitrogen fixing bacteria.
- **Free living nitrogen fixing cyanobacteria**
  – They increase nitrogen content of the moist soil and water bodies.
  – The **most important nitrogen fixing cyanobacteria** are *Anabaena*, *Nostoc*, *Aulosira*, *Tolypothrix*, *Stigonema*.
  – *Aulosira fertilissima* is the **most active nitrogen fixer of rice fields**.
  – *Cylindrospermum licheniforme* grows in sugarcane and maize fields.
- **Symbiotic nitrogen fixing bacteria**
  – Nitrogen fixing cyanobacteria form symbiotic associations with many plants like *Cycas* roots, lichens, liverworts, *Azolla* etc.
  – *Azolla pinnata* is a small aquatic fern added to the rice fields of South-East Asia.
  – It contains symbiont *Anabaena azollae* in its leaf cavities which fixes atmospheric nitrogen.
  – A part of this nitrogen is excreted in the cavities for use of the fern.
  – The ferns in turn give this to the rice field while decay.

Fungi as biofertilizers/mycorrhiza

- Mycorrhiza (fungus roots) is a distinct morphological structure which develops as a result of mutualistic symbiosis between some specific root-inhabiting fungi and plant roots.
- **Plants which suffer from nutrient scarcity, especially P and N, develop mycorrhiza** *i.e.*, the plants belong to all groups, e.g., herbs, shrubs, trees, aquatic, xerophytes, epiphytes, hydrophytes or terrestrial ones.
- In most of the cases plant seedling fails to grow if the soil does not contain inoculum of mycorrhizal fungi.
- The shape of the root is irregular or coralloid with wooly covering but no root hairs or root cap.
- Mycorrhiza helps in absorption of water, minerals from organic matter and protection from soil borne pathogenic fungi.
- **Depending upon the location of the fungus** mycorrhiza are of **two types - ectomycorrhiza and endomycorrhiza**.
- **Ectomycorrhiza**
  – It is **found among gymnosperms and angiosperms**. In short roots of higher plants generally root hairs are absent. Therefore, the roots are infected by mycorrhizal fungi which, in turn, replace the root hairs (if present) and form a mantle.

- The hyphae grow intercellularly and develop Hartig net in cortex. Thus, a bridge is established between the soil and root through the mycelia.
- The root cells secrete sugar and nutrients into the intercellular spaces for fungal feed, e.g. *Eucalyptus*, oak, peach, pine etc.
- The **main functions of these fungi** are absorption of water, solubilization of organic matter of the soil humus, release of inorganic nutrients, absorption and transfer to roots.
- Plants with ectomycorrhiza are known to absorb 2-3 times more of nitrogen, phosphorus, potassium and calcium.
- The fungus secretes antimicrobial substances which protect the young roots from pathogen attack.

● **Endomycorrhiza**
- The morphology of endomycorrhizal roots, after infection and establishment, remain unchanged.
- Root hairs develop in a normal way.
- The fungi are **present on root surface individually**.
- They also penetrate the cortical cells and get established intracellularly by secreting extracellular enzymes.
- Endomycorrhizas are found in all groups of plant kingdom, eg., grasses, crop plants, orchids and some woody plants.
- **Intercellular growth occurs in order to obtain nourishment because unlike ectomycorrhiza, the cortical cells do not secrete sugars in the intercellular spaces**.
- The hyphal tips passing into cortical cells either produce swollen vesicles or finely branched masses called **arbuscules**.
- The major benefits of VAM (vesicular - arbuscular mycorrhiza) to the plant is the supply of inorganic nutrients as well as enchanced water absorption.
- Phosphate which is mostly present in the unavailable form in the soil, becomes abundantly available to the plant.

Utility of biofertilizers

● It is a low cost and easy technique, and can be used by small and marginal farmers.
● It is **free from pollution hazards** and **increase soil fertility**.
● On application of algal biofertilizers increase in rice yields ranges between 10 - 45 per cent and about 40 - 50 kg N is left over in the soil which in turn is used for the subsequent crops.
● Cyanobacteria secrete growth promoting substances like IAA, IBA, NAA, aminoacids, proteins, vitamins, etc. They add sufficient amount of organic matter in soil.
● Rhizobial biofertilizers can fix 50 - 150 kg N/ha/ annum.
● *Azotobacter* and *Azospirillum*, besides supplying N to soil, secrete antibiotics which act as pesticides.
● *Azolla* supplies N, increases organic matter and fertility in soil and shows tolerance against heavy metals.
● The biofertilizers increase physico-chemical properties of soils such as soil structure, texture, water holding capacity, cation exchange capacity and pH by providing several nutrients and sufficient organic matter.
● The mycorrhizal biofertilizers make the host plant available with certain elements, increase longevity and surface area of roots, reduce plant response to soil stresses, and increase resistance in plants. In general, plant growth, survival and yield are increased.

Precautions

● Biofertilizer packets should be stored in cool and dry place away from direct sunlight and heat.
● Right combination of biofertilizers must be used.
● *Rhizobium* is crop specific, so should be used in specified crop.
● Should not be mixed with chemicals.
● While purchasing ensure that each packet is provided with necessary information like name of the product, name of the crop for which intended, name and address of the manufacturer, date of manufacture, date of expiry, batch No and instructions for use.
● Packet should be used before expiry, only on the specified crop, by the recommended method.
● Biofertilizers are live product and require care in storage.
● For best results both nitrogenous and phosphatic biofertilizers must be used.
● Use of biofertilizers is being emphasized along with chemical fertilizers and organic manures.
● Biofertilizers are not replacement of fertlizers but can supplement their requirement.

End of the Chapter

Chapter 70

Mental health, Addiction and Community Health

- **Mental health** is an important aspect of physiological health & social effectiveness.
- Mental illness of a person is characterized by his abnormal behaviour and talk causing distress and suffering both to the person and people around him.
- Mental illness can be classified into **three types : psychosis, neurosis** and **epilepsy**.
- **Psychosis** is a severe mental disorder in which the individual loses contact with reality (madness), not aware of his illness, refuses to take help.
- A person suffering from psychosis is incapable of functioning normally in society and usually requires hospitalization.
- **Neurosis** is a mild type of mental illness with excessive or prolonged emotional reactions (anger, fear, sadness, vague aches, etc.).
- **Phobias** are generally **associated with neurosis**. Neurotic people remain in touch with reality and seek help.
- These disorders (psychosis & neurosis) are categorised into following types like anxiety, obsessive compulsive disorder (OCD), depression etc.
- **Anxiety** are a diverse group of disorders including **neurotic anxiety** (an over reaction to stressful events associated with bodily symptoms like palpitation, sweating, nausea, trembling, diarrhoea and muscular tension), **separation anxiety** and **school phobia**.
- **Obsessive-compulsive disorders** are characterised by compelled performance of an action/idea despite attempt to resist it, e.g., violence, constant doubts, concern about infection by germs/dirt.
- **Attention deficit disorder** occurs more in boys than in girls, which exhibits under achievement, behavioural problems and a tendency to be disliked by other children.
- **Mood disorders** are characterised by occassional doubts of high or low mood. These **include depression** which is characterised by sadness, hopelessness, low self esteem, decline in interest and concentration and change in sleep pattern and appetite, its cause may be death in family, failure in examination/interview or losing a job, the depressed mood may alternate with over activity like quick talking, talking multiple tasks at the same time and **endogenous depressions** which arise from internal, biochemical or genetic factors, and are symptomised by lethargy, self hatred, irratic sleep pattern and uncontrollable weeping.
- **Border line personality disorder (BPD)** is characterised by unpredictable moods, outbursts of emotion, quarrel some behaviour and conflicts with others. Individuals with BPD often attempt to injure or kill themselves and have little sense of self.
- **Epilepsy** is usually **characterised** by fits of convulsions, the person loses consciousness and falls down.
- **Parkinson's disease** is a sporadic disorder of middle and late life.
- Parkinson's disease is **characterised by** stooped posture, stiffness and slowness of movements, fixity of facial expression and rhythmic tremor of limbs (most pronounced in hands) which subsides on relaxation or actively willed movement.
- Parkinson's disease is **caused by development of melanin containing nerve cell aggregates in brain stem** with varying degree of nerve cell loss, Lewy bodies (eosinophilic, rounded concentrically laminated inclusions, Lewy 1913) in the cells and reduced secretion of dopamine in dopamine containing regions of brain.

- **Alzheimer's disease** is a progressive degenerative disease of brain which is **caused by senile plaques and neuro-fibrillary tangles** resulting in loss of choline acetyltransferase activity.
- Alzheimer's disease **commonly appears after the age of 40**, though it can occur in any age group.
- **Schizophrenia** is a type of mental illness or psychotic disorder which is characterised by progressive deterioration of personality, shallowness of emotional life, auditory hallucinations, delusions, illogical thinking, sense of being influenced by others and feeling of being controlled by outside forces.
- Schizophrenia can be **caused by excessive dopamine production**, alterations in neuropeptides, increased ventricular brain ratios and decreased frontal lobe activity.
- The **main causes of mental illness are :** changes in the brain, hereditary factors, childhood experiences, home atmosphere and special factors.
- Antipsychotic drugs like **phenothiazine** and **lithium** are **used to calm or sedate the cases of acute psychoses**.
- Most antipsychotic drugs **block the action of dopamine,** a chemical that stimulates nerve activity in the brain.
- **Shock treatment** (ECT) is suited in some cases and can bring about dramatic improvement in severe depression.
- **Psychotherapy** also assists a person in adjusting himself to the surroundings.
- **Social therapy** (rehabilitation) has an important role to play.
- **Psychology** is study of the behaviour of man and animals, and related mental and physiological processes.
- **Psychiatry** is a branch of medicine dealing with diagnosis, treatment and prevention of mental disorders.
- Mental health services in a community are concerned not only with early diagnosis and treatment, but with the preservation and promotion of mental illness. The mental health services comprise –
  - Early diagnosis and treatment
  - Rehabilitation
  - Group and individual psychotherapy
  - Mental health education
  - Use of modern psychoactive drugs
  - After-care services
- **Mental hygiene** is scientific study and application of methods to reserve and promote mental health.

ADDICTION

- The term **'addiction'** refers to a dependence on, and craving for, tobacco, alcohol or a particular drug.
- **Addictive disorders** are the state of body when it requires continuous presence of psycho-active substance within it.
- **Tobacco** is the dried leaves of the plant *Nicotiana tabacum* and *N. rustica* (family solanaceae).
- **Nicotine** is the substance that **causes addiction to tobacco**.
- Nicotine **acts as a tranquillizer**, but **also stimulates the release of adrenaline** leading to high blood pressure.
- Nicotine is **highly poisonous**; nicotine present in a cigarette is sufficient to kill a person if injected intravenously.
- Nicotine (a) stimulates passage of nerve impulses, (b) causes muscles to relax, (c) causes increased heart rate.
- In pregnant women, nicotine causes retardation of the growth of foetus.
- **Tobacco smoke contains** – carbon monoxide, polycyclic aromatic hydrocarbons, and tar.
- The **main harmful effects of smoking** are **respiratory diseases** (lung cancer, bronchitis and emphysema) and **cardiovascular diseases** (coronary artery disease and peripheral vascular disease).
- Smokers can expect to live about ten years less than the nonsmokers. Smoking causes greater ill-health than any other drug.
- One of the common cancers attributed to cigarette smoking is **lung cancer**.
- Mouth cancer is commonly found among tobacco chewers.
- The **withdrawal symptoms** includes irritability, anxiety, craving, sleep problems, headache, termor & lethargy. It may **continue for 4-6 weeks** & craving may continue for many month.
- **Central Tobacco Research Institute** is situated at **Rajahmundry** (A.P.)
- China has the biggest cigarette market.
- **Anti-tobacco Day** is **celebrated on May 31**.

- Ethanol or ethyl alcohol is the **active constituent of alcoholic drinks** such as **beer** (5 per cent by volume), **wine** (10 per cent by volume) and **whisky** (40 per cent by volume).
- In medicine, alcohol is used as an **antiseptic** and a **solvent**.
- **Low level of alcohol causes** facial flushing, talkativeness and increases social confidence.
- **High level of alcohol causes** disturbed thinking, irritability, reduced self-control, slurred speech, drowsiness, difficulty in remaining upright, etc.
- Alcohol **decreases the activity of CNS**, thereby reducing anxiety, tensions and inhibitions.
- Alcohol **decreases the secretion of ADH** (anti-diuretic hormone) from posterior pituitary causing increased urine output.
- Heavy drinkers become dehydrated. Thirst, dry tongue and hangover are associated with effects of alcohol.
- In the liver, alcohol is converted into a more toxic substance, **acetaldehyde**, which is used by cells for energy.
- Liver synthesises fats from alcohol; the extra fat decreases the production of enzymes and structural proteins.
- The accumulation of fat results in **'fatty liver syndrome'** leading to **cirrhosis** (replacement of liver cells by fibrous tissue).
- Alcohol addiction lowers blood sugar level, adversely affecting the brain.
- **Alcohol and driving do not go together** as alcohol causes –
  - Reduced ability to judge distance,
  - Reduced co-ordination of limbs, head and eyes,
  - Reduced alertness,
  - Reduced field of vision (**tunnel vision**),
  - Increased reaction time,
  - Changed behaviour.
- Physicians prescribe drugs to prevent or cure diseases or otherwise enhance physical and mental welfare.
- These drugs have sedative or intoxicative effects on the body. Constant & regular use of these drugs forms a habit and once acquired it becomes very difficult to leave these habits. This condition is called as **drug dependence**.
- **Drug abuse** is defined as self administration of a drug for nonmedical reasons. Abused drug include - anabolic steroids, analgesics and antibiotics.
- Drugs are classified on the basis of their **way of production** in two classes : **natural drugs** and **synthetic drugs**.
- Drugs are also classified on the basis of their **mode of action on brain** into two categories –
  - **Psychoactive or psychotropic drugs**
  - **Psychedelic or hallucinogenic drugs**
- **Psychoactive or psychotropic drugs** are also called as **mood altering or neurological drugs**.
- **Psychedelic or hallucinogenic drugs** produce psychological effect like illusions and hallucinations.
- Psychotropic drugs act on the brain and alter the behaviour, consciousness and powers of perception.
- **Four categories of psychotropic drugs are** – **sedatives** and **tranquillizers**, **opiate narcotics**, **stimulants** and **hallucinogens**.
- **Sedatives** and **tranquillizers** have a depressing (switching off) effect on the activity of the brain.
- Sedatives may produce a feeling of calmness, relaxation or drowsiness.
- In higher dose, sedatives induce deep sleep.
- **Tranquillizers** reduce tension and anxiety without inducing sleep.
- **Opium** is obtained from the unripe seed pods of the **poppy plant,** *Papaver somniferum.*
- Opium has an **analgesic (pain-killing) effect** and may also reduce anxiety and tension, and lowers the blood pressure and breathing rate.
- Opium and its derivatives, which include **morphine, codeine** and **heroin** are among the drugs collectively known as **narcotic drugs**.
- **Morphine** has sleep and dream inducing properties.
- **Codeine is milder than morphine** and **used in cough syruph**.
- **Narcotics** induce addiction if used repeatedly and **heroin is the most dangerous narcotic**.
- Another opium derivative is **brown sugar**, chemically known as **diacetyl-morphine hydrochloride**.
- **Stimulants** are also known as **'mood elevators'.**
- Stimulants **increase nerve activity in the brain by initiating the release of noradrenaline.**
- There are **two main groups of stimulant drugs**: **central nervous system stimulants** (*e.g.,* amphetamine drugs) and **respiratory stimulants** (*e.g.,* analeptic drugs).

- Mildest among the stimulants is **caffeine** which is commonly taken in the form of tea, coffee and cola drinks.
- **Caffeinism** is caffein intoxication characterized by restlessness, nervousness, excitement, insomnia, gastrointestinal complaints, etc.
- **Amphetamines** and **cocaine** are **strong stimulants**.
- Cocaine is obtained from the leaves of *Erythroxylon cocca.*
- **"Crack"** is a purified form of cocaine; it can cause seizures and cardiac arrest.
- **Hallucinogens** include certain drugs of abuse, also called **psychedelic** drugs, such as **LSD, marijuana, mescaline** and **psilocybin.**
- These drugs have a **strong effect on cerebrum and sense organs** and take the user to a world of fantasy giving him false and temporary happiness.
- **LSD (lysergic acid diethylamide)** is one of the most dangerous hallucinogens of modern times derived from **Ergot fungus,** *Claviceps purpurea.*
- The products of **hemp plant,** *Cannabis sativus,* like **bhang, marijuana, ganja, hashish-charas**, etc. are other examples of hallucinogens.
- **Reserpine** alkaloid is **obtained from the roots** of *Rauwolfia serpentina* (family apocynaceae).
- Reserpine is **used for the treatment of blood pressure, snake bite and mental disorders**.
- The drug **belladona** is extracted from the dried leaves and roots of *Atropa belladona* (family solanaceae).
- Belladona is a narcotic, diuretic and antispasmodic. Leaves contain **atropine,** used to dilate pupil of eye.
- **Mode of Drug Action**. Drugs act at the synapses by inhibiting (depressants) or accelerating (stimulants) secretion of neurotransmitter.
- **Pharmacology** is the science dealing with drugs, their sources, appearance, chemistry, actions and uses.
- **Community health** services give special attention to –
  - The sanitation of environment
  - Prevention and control of communicable diseases
  - Maternal and child health, and family welfare
  - School health services.
- **Universal immunization programme** was launched by **W.H.O.** in 1974 for the global immunization of children to protect them from six preventable diseases, *i.e.,* diphtheria, whooping cough (pertussis), tetanus, polio, tuberculosis and measles.
- **MMR vaccination programme** was launched in India for the first time on **14th November 1999**.
- This vaccine which is to be given to all children above 15 months of age only once, gives life long and complete protection from dreaded diseases like Measles, Mumps and Rubella.

Table : National immunization schedule

Age	Vaccine	Disease	Number of doses
3 – 12 months	DPT	Diphtheria, Pertussis (Whooping cough) and Tetanus	3
	Polio (Sabins oral)	Poliomyelitis	3
	BCG (intradermal)	Tuberculosis	1
9 – 15 months	Measles	Measles	1
18 – 24 months	DPT	Diphtheria, Pertussis and Tetanus	1
	Polio (oral)		1
5 – 6 years	DT	Diphtheria, Tetanus and Typhoid	1
	Typhoid vaccine		2
10 years	Tetanus toxide		1
	Typhoid vaccine		1
16 years	Tetanus toxoide		1
	Typhoid vaccine		1

ADOLESCENCE

- The period of rapid growth, the physical and mental development poised between childhood and adulthood (between 8-18 years for girls and 7-19 years for boys) is called **adolescence**.
- The period of adolescence extends from puberty to complete sexual maturity.
- **Changes taking place during adolescence** are – accelerated physical growth and development of reproductive organs; changes in functioning to the neuroendocrine system; shift of moods and emotional turbulance prompted by increased production of hormones, including sex hormones; and self assertion (egocentrism), and concurrent developments of self-identity, self esteem and self respect.
- **Common problems of adolescence** are – acne, phobias and post traumatic stress disorders.
- **Acne** (*pimples*) results from clogged pores of skin due to a side effect of the influx of sex hormone, androgen which increases self conciousness.
- **Hypochondria** is a form of anxiety and psychosomatic disorder characterised by undue concern about health.
- **Neurosthenia** is characterised by the inability to concentrate on or enjoy things, and may lead to irritability, fatique, insomnia, depression and headache.
- **Physiological aberrations** including absence of monthly periods in females or perpetual disturbances.
- **Phobias** are intense dread of things or creatures or situations like crowded places, vast open places etc.
- **Post traumatic stress disorder** are due to traumatic experiences like rape or robbery. In such cases surviving victims and bystanders are affected equally.
- Addiction to drugs, tobacco and alcohol is also common among adolescents. The main reasons of addicition are curiosity, advertisements, peer pressures, frustration and depression, feeling of independence, false belief of enhanced physical mental/intellectual performance.
- **Social and moral implications.** During adolescence an individual moves out from the familial periphery and begins to identify and define his/her position in relation to the outer world. He undergoes physiological and behavioural transformations, and acquires higher levels of moral standings.

End of the Chapter

Chapter 71

Immune System & Defence Mechanisms

- Animals including human beings are exposed to various infectious agents like bacteria, viruses, fungi and parasites. The system of animal body, which protects it from various infectious agents and cancer, is known as **immune system**.
- The immune system consisting several organs, as well as white blood cells in the blood and lymph has the job of fighting off invading pathogens and preventing the growth and spread of cancers.
- The lymphoid organs are divided into 3 categories – primary lymphoid organs, secondary lymphoid organs and dispersed immune cells.
- **Primary lymphoid organs** are bone marrow (in the hollow centre of bones), the thymus gland (located behind the breastbone above the heart) and foetal liver which are the major sites of production of lymphocytes.
- Bone marrow manufactures the billions of WBC needed by the body every day. Some newly produce WBC **remain in the bone marrow to mature** and specialize, while others travel to the **thymus** to mature.
- **Secondary lymphoid organs,** present at or near possible portals of entry for pathogens, includes **lymph nodes**, adenoids tonsils, spleen (located at the upper left of the abdomen, and groin), Peyer's patches (within the intestine), and the appendix.
- **Lymph nodes** filter pathogens from the lymph and expose them to WBC.
- The **spleen** filters pathogens from the blood. It is stocked with WBC that respond to the trapped pathogens.
- In addition to the organized lymphoid tissues, there are other sites, particularly the mucosae, where many immunocytes are dispersed between other cells, for example within gut epithelium and lamina propria.
- **Immunology** is the science of development of immunity against particular pathogen/pathogens.
- The foundations of science of immunology were discovered by 3 workers - **Edward Jenner** (1796); **Louis Pasteur** (1879); **Von Behring** (1891).
- **Immunity** may be defined as the body's ability to destroy pathogens or other foreign material and to prevent further cases of certain infectious diseases. This ability is of vital importance because the body is exposed to pathogens from the moment of birth.
- Immunity was defined by **Sir Mac Farlane Burnet**.
- Immunity developed in three ways – by vaccination, antitoxin and through diseases.
- The immune system has a series of dual natures, the most important of which is self/non-self recognition. The others are: general/specific, natural/adaptive = innate/acquired, cell-mediated/ humoral, active/passive, primary/secondary.
- Parts of the immune system are **antigen-specific** (they recognize and act against particular antigens), **systemic** (not confined to the initial infection site, but work throughout the body), and have **memory** (recognize and mount an even stronger attack to the same antigen the next time).
- **Self/non-self recognition is achieved by** having every cell display a marker based on the major histocompatibility complex (MHC). Any cell not displaying this marker is **treated as non-self and attacked**. The process is so effective that undigested proteins are treated as antigens.

TYPES OF DEFENCE MECHANISM

- There are **two kinds of defence mechanism** against microbes. These are **non-specific** and **specific defence mechanism**.

Non-specific defence mechanism

- Non specific defence mechanism is also known as **innate or inborn or natural immunity**.
- Innate immunity prevents entry of micro-organisms into tissues or, once they have gained entry, eliminates them prior to the occurrence of disease.
- Innate immunity **present from birth** are non-specific (acts on many organism) and does not become more efficient on subsequent exposure to same organisms.
- The non specific defence mechanism is further of two types – **external defence** (or **first line of defence**) and **internal defence** (or **second line of defence**).

External defence

- First line of defence **comprises physical and chemical barriers** to the entry of pathogens into the blood.
- Physical barriers are of **two kinds** – skin and mucous membrane and chemical barriers includes, chemicals secreted by skin and mucous membrane like skin secretion and bacteria, saliva, tears, bile, gut secretion and bacteria, nasal secretion, cerumen, vaginal bacteria.
- Mechanically, pathogens are expelled from the lungs by ciliary action as the tiny hairs move in an upward motion; coughing and sneezing abruptly eject both living and nonliving things from the respiratory system; the flushing action of tears, saliva and urine also force out pathogens, as does the sloughing off of skin.
- Saliva, tears, nasal secretions, and perspiration contain **lysozyme**, an enzyme that destroys gram positive bacterial cell walls causing cell lysis. Vaginal secretions are also slightly acidic (after the onset of menses). Spermine and zinc in semen destroy some pathogens. Lactoperoxidase is powerful enzyme found in mother's milk.
- The stomach is a formidable obstacle in sofar as its mucosa secrete hydrochloric acid (0.9 < pH 3.0, very acidic) and protein-digesting enzymes that kill many pathogens. The stomach can even destroy drugs and other chemicals.
- An **opsonin** is a plasma protein binding to bacteria. This promotes adheshion between the opsonised bacteria and macrophages because the opsonin binds to receptors on phagocyte membrane, e.g., complement with complement receptors and phagocytes. **Opsonisation and phagocytosis are more efficient** in immune individuals.
- A **phagocyte** is a cell that attracts (by chemotaxis), adheres to, engulfs, and ingests foreign bodies.

Internal defence

- When the first line of defence fails to prevent access of pathogens to the tissues, the body's second line of defence come into play.
- The body's internal defence is **carried on by white blood corpuscles**, **macrophages**, **inflammatory reactions**, **fever**, **interferons** and **complement system**. All the six devices operate together to check damage to the body by pathogens.
- **Macrophages** (big eaters) are large phagocytic cells that arise by enlargement of monocytes.
- Promonocytes are made in the bone marrow, after which they are released into the blood and called **circulating monocytes**, which eventually mature into macrophages.
- Some macrophages are concentrated in the lungs, liver (Kupffer cells), lining of the lymph nodes and spleen, brain, microglia, kidney mesangial cells, synovial A cells and osteoclasts. They are **long lived**, depend on mitochondria for energy, and are best at attacking dead cells and pathogens of living within cells.
- Macrophages are of **two types** - **fixed** and **wandering**.
- **Fixed macrophages** are located in the lining of blood and lymphatic capillaries in spleen, lymph nodes, liver and bone marrow.
- The **wandering (nonfixed) macrophages** occur in the connective tissue throughout the body. They move to the site of infection like the leucocytes and dispose of the microbes. They are called **histiocytes** also.
- The macrophages are among the first cells that respond to the infection.
- **Macrophages have many functions** –
  - **Defence :** Wandering macrophages (also called histiocytes) dispose of microbes in the connective tissue. Fixed macrophages destroy microbes in the blood and lymph.
  - **Giant cell formation :** Many macrophages

Table : Types of Macrophages.

Type	Location
• Histiocytes	Connective tissue
• Microglia	Brain
• Kupffer cells	Liver
• Alveolar macrophages	Lung
• Sinus lining macrophages	Spleen, lymph nodes, thymus gland
• Mesanglia cells	Glomerular of nephrons
• Osteoclast	Bone

may fuse to form a large multinucleate giant cell to capture a foreign body too big for a single macrophage to engulf.

– **Scavenging :** Macrophages also dispose of dead tissue cells and noncellular foreign matter.
– **Antigen display :** Macrophages carry the antigens of the engulfed microbes on their surface to display them to the lymphocytes in the lymphatic nodes. This activates the immune system.
– **Secretion of endogenous pyrogen :** Macrophages secrete interleukin-1 (IL-1), also called **endogenous pyrogen.** It plays a role in inflammatory response, in causing fever, and in activation of other phagocytic cells as well as the T- and B-cells to produce their effect.

- **Inflammatory response** is a reaction that causes redness, heat, swelling, and pain in the area of infection. Redness and heat are due to capillary dilation resulting in increased blood flow. Swelling is caused by the passage of plasma from the blood stream and into the damaged tissue. The pain is mainly due to the tissue destruction and to a lesser extent the swelling.
- **Inflammation** is localised to area of infection/tissue injury by release of substances from micro-organisms or chemicals (chemicals mediators) released from cells in tissues, e.g, histamine from mast cells. Once organisms destroyed inflammation settles down.
- **Body temperature in human is controlled by hypothalamus**. The body responds to activating heat promoting mechanism, eg. shivering and vasoconstriction untill the new higher temperature is reached. When the thermostat is reset to the normal level, heat loss mechanism are activated.
- Body temperature rise causes fever. **Fever** is often the result of infection and is **caused by release of chemicals (pyrogens) from damaged tissues** and the cells involved in inflammation. When enough pyrogens reach the brain, the body's thermostat is reset to a higher temperature, allowing the temperature of the entire body to rise.
- **Interferons** (discovered first by **Issacs** and **Lindermann**) are a heterogenous group of glycoprotein (Mol wt. 20,000-40,000 Dalton) produced by human and other animal cells against viral infections (or after exposure to other inducers) and which exerts many immunomodulating functions.
- Although **interferon cannot save an invaded cell**, it **works as a warning signal for healthy cells, in which it interferes with viral replication**. These effects on a virus slow down the progress of infection and often give the specific defenses of the immune system time to respond.
- Interferons are divided into three groups based on the cell of origin, namely **leucocyte (alpha)**, **fibroblast (beta)** and **lymphocyte (gamma)**.
- α and β are induced by virus whereas gamma interferon is induced by antigens and is one of the effectors of cell immunity.
- **Complement** is heat liable *i.e.* it is inactivated by heating serum at 56°C for 30 minutes. Immunoglobulins are not inactivated at this temperature.
- The **complement system** can be **activated in two main ways** –
  – The **first and most potent** occurs when **IgG** (or IgM) binds to antigen at the surface of a cell. This exposes the Fc region of the antibody such that the first complement protein (C1) binds.
  – **The second means of activation** is part of the **natural** (innate) immune response (*i.e.*; neither antibodies or T cell receptors are involved.) Here certain polysaccharides found on the surface of bacteria activate the system. This can occur immediately and does not require prior exposure to the molecules.
- The **complement system** plays an essential role in host defence against infectious agents and in the

inflammatory process. It **consists of about twenty plasma proteins that** function either as enzymes or as binding proteins. They are synthesized mainly in liver.

- When a pathogen invades the body, a macrophage brings the foreign antigen to the B cells (plasma cells). In this way, the B cells "LEARN" about the antigens on the pathogens surface and START to make appropriate antibodies. The B cells then circulate through the body, releasing antibodies that bind to the new antigen.
- The complement system triggers a constellation of effects that helps deal with an infection like opsonization, chemotaxis, inflammation, lysis antibody coated cells.

Specific defence mechanism

- If a pathogen is able to get pass the body's nonspecific defences the immune system reacts with a series of specific defences that attack the disease causing agent.
- Responses of the immune system to specific pathogens are called **specific defences.**
- Specific defence mechanisms is the **third line of defence** and developed by an animal in response to a disease caused by infections of microbes.
- This third line of defence will recognize, attack, destroy and remembers each foreign substance and pathogen that enters the body. It does this by making specialized cells and antibodies that make the pathogen useless. For each type of pathogen the immune system produces cells that are specific for that particular pathogen.
- Specific defence mechanism is also called **acquired immunity**.
- Acquired immunity occurs after exposure to an agent, is specific and is mediated by antibody and by T - lymphocyte namely T - cells, cytotoxic T cells.
- Acquired immunity is of **two types** – **natural or active and artificial or passive**.
- **Active immunity** is resistance induced after contact with foreign antigens, eg. micro-organisms and activated helper and cytotoxic T lymphocyte. **Main advantage of this immunity** is that resistance is long term and **its major disadvantage** is its slow onset especially the primary response.
- Active immunity is **produced by clonal selection and expansion**.
- Clonal selection leads to the eventual production of –
  - A pool of antibody-secreting plasma cells. Plasma cells are B-cells that have booled up (e.g., forming a large endoplasmic reticulum) for massive synthesis and secretion of an antibody. The antibody is the secreted version of the BCR (B-cell receptor for antigen).
  - A pool of "memory" cells. These are B lymphocytes with receptors of the same specificity as those on the original activated B cell.
- **Passive immunity** is developed to counteract snake venom, rabies, tetanus toxin and *Salmonella* infection.
- Passive immunity has the advantage of providing **immediate relief** having prompt availability of large amount of antibodies. However, **passive immunity offers some problems**: it is not long lasting (short life span of antibodies); antibodies, being foreign proteins, may cause reactions; body may produce its own antibodies to destroy the foreign antibodies, which may be useful.

IMMUNOGLOBULINS

- The **globulins, a plasma proteins**, plays a **major role in the immunological reactions**. These include reactions involving the antigens and antibodies.
- **Immunoglobulins** or **specific antibodies** or **gamma globulins** are blood proteins, which are found to be defensive only against the specific micro-organisms, or their toxins that evoked that particular antibody.
- The antibody molecules may be bound to a cell membrane or they may remain free. The **free antibodies have three main functions** –
  - Agglutination of particulate matter, including bacteria and viruses
  - Coating of bacteria to facilitate their subsequent phagocytosis by cells
  - Neutralization of toxins released by bacteria, e.g., tetanus toxin.
- Immunoglobulin are **glycoproteins**, made up of 4 polypeptide chains (linked by disulphide bonds). There are **two long chains**, called **heavy or H chains**, and **two short chains**, called **light or L chains**. The four polypeptide chains are held

together to form Y-shaped molecule. The top two tips of this Y- shaped molecule bind to the specific antigens in a lock and key fashion, forming an **antigen-antibody complex**.

- Light and heavy chains are subdivided into variables and constant. The **variable portion** is **used for binding to antigen** and a **constant portion determines its adherence and diffusivity** (*i.e.* for various biological functions), e.g. complement activation and binding to cell surface receptors.
- **Constant regions** of heavy chains **define five classes of Igs**, some with subclasses and two identical light chains belongs to one of 2 types—Kappa (k) and λ (lambda).
- **Types of immunoglobulins** are – IgG, IgM, IgA (IgA 1 and 2), IgD and IgE (IgE 1, 2, 3, and 4).
- **IgG**, **the most abundant immunoglobulin**, **is** found in blood, lymph and intestine, protects the body against bacteria, fungi and viruses by activating complement system, enhancing phagocytosis (opsonizes) and neutralising toxins.
- It is the **only isotype** that can **pass through placenta,** protects against blood cell antigens as well as **provide passive immunity to new born**. It is the **predominant antibody in secondary response**.
- **IgA** is the **second most abundants immunoglobulin** in human serum and is the **primary immunoglobulin of exocrine secretions**.
- It is available in colostrum and mother's milk, the immunoglobin is abundant in all secretions of the body including saliva and tears. It is also common in mucous membranes of throat, bronchi, nose, intestine, etc. It is effective against a number of antigens, providing local immunity.
- In milk these antibodies are thought to provide immune protection to nursing infants, whose own immune systems are not yet fully developed.
- **IgM (macroimmunoglobulin)** is the **largest** of the immunoglobulins and the **first to reach the site of infection** being present in circulating fluids.
- It **increases IgG production** and complement fixation. The immunoglobulin is **involved in ABO incompatibility**.
- IgM is the antibody **made in greatest amounts by the foetus**. It can be produced by the foetus in certain infections. Because it is a **large molecule**, it **cannot diffuse well**, and is **found in the interstitium only in very low quantities**.
- Due to its polymeric nature, IgM possesses high avidity, and is particularly effective at complement activation. It is also a so-called "natural antibody". It is found in the serum without any evidence of prior contact with antigen.
- **IgD** is present in small quantity in serum tissue where it **functions as a receptor for various toxins and allergens**. While lgD's functions is not yet completely understood, it is often coexpressed with lgM and is **used as a marker**, **naive B cells**. It may also be involved in the differentiation of B cells into plasma and memory cells.
- **IgE** is a monomeric immunoglobulin with the heavy chain. It is **involved in immediate allergic reactions triggering the release of histamine and other inflammatory chemicals**. It is concentrated in lungs, skin and mucous membrane. Excess secretion causes asthma. It is the **main host defence against helminthes infections**. They donot activate complement. Only IgE is heat labile.
- The **antibody molecule** is the **basic functional unit of the immune response**.
- **Antigen** is a substance that when introduced into a vertebrate host provokes an immune response leading to acquired immunity. It **stimulates the immune system to produce protective chemicals or special cells to destroy the antigens**.
- The protective chemicals are called **antibodies.**
- The ability of the antigen to stimulate antibody formation is called **antigenicity**.
- Antigens of proteinaceous nature are known as **complete antigens**.
- Some antigens consisting of lipids and carbohydrates cannot produce antibodies on their own, are known as **haptens**. Haptens **stimulate antibody formation by binding with proteins**.
- Antigen and antibody have complementary reactive sites that fit together like lock-and-key. Antibodies react with antigens and make them inactive or harmless.
- Interaction between antigen and antibody involve non-covalent binding of an antigenic determinant **(epitope)** to the variable region (complementary determining region CDR) of both heavy and light immunoglobulin chains.

Polyclonal or Monoclonal antibodies

Antibodies that arise in an animal in response to typical antigens are heterogeneous, because they are formed by several different clones of plasma cells; *i.e*, they are **polyclonal**. Antibodies that arise from a single clone of cells, e.g, in a plasma cell tumor (myeloma), are homogeneous; *i.e.*, they are **monoclonal**. **Monoclonal antibodies** also can be made in the laboratory by fusing a myeloma cell with an antibody-producing cell. Such hybridomas produce virtually unlimited quantities of monoclonal antibodies that are useful in diagnostic tests and in research. Hence **hybridoma** are hybrid cell culture formed of antigen sensitised cells, fused with myeloma cancerous bone marrow cells for indefinite production of monoclonal bodies. Monoclonal antibodies are also **used in immunoassay**. They are used to detect the hormones present in urine (pregnancy test kits), in detecting drugs in urine (for athletes) and in detecting HIV virus.

IMMUNE RESPONSE

- The immune response can be defined as a particular reactions induced in a host by an antigenic stimulation.
- Immune responsive cells can be divided into five groups based on (i) the presence of specific surface components and (ii) function: B-cells (B lymphocytes), T-cells (T lymphocytes), Accessory cells (Macrophages and other antigen-presenting cells), Killer cells (NK and K cells), and Mast cells.
- Immune response may be **primary** or **secondary**.
- The reaction of the body's immune system to the first attack of microbes (antigens) is called **primary immune response**.
- During a primary response, the antigens eventually disappear from the blood, having been destroyed by antibodies and killer T-cells or macrophages. This takes about a week (5-10 days) after the microbial attack. During this period, B cells divide and mature into plasma cells that produce enough antibodies to destroy the antigens. It takes about a week or so for the influenza symptoms to disappear. Recovery from an infection shows that the body's immune system is working.
- The reaction of the body's immune system to any subsequent infection of the same microbe is termed **secondary immune response**.
- This response is **quicker and more intense than the primary immune response**. This is so because

Table : Functions of the immune cells

	Immune cells	Features	Functions
		Lymphoid lineage cells	
(A)	**Lymphocytes**	– Main constituents of the lymphoid tissues – Functionally two types – T lymphocyte and B lymphocytes	– Secrete lymphokines to activate T_C, T_S and B cell response. – Activate macrophage system.
(i)	**T-lymphocytes** Subsets of T-lymphocytes are		
	– T helper	– Get mature in the thymus gland in the presence of thymic hormones	– T_H cells act as memory cells.
	– T suppressor	– Mainly responsible for cell mediated immunity	– Suppressor T cells offers immune tolerance
	– T cytotoxic	– Functionally heterogenous	– T_C cells destroy cancer cells
	– T delayed type	– Classified into regulator cells and effector cells	– T_D cells are involved in hypersensitivity
(ii)	**B-lymphocytes**	– Develop and mature in bone marrow of adult – Functional B-cells are called plasma cells – Plasma cells produces respective antibodies	– Specific antibodies for antigen is produced – Exhibit characteristic antigen – antibody reactions

contd ...

	Immune cells	Features	Functions
(B)	**Null cells**	– Cytoplasm bear large granules – Cell surface lacks immunoglobulins – Kidney shaped nucleus – Two types – NK and K cells	
(i)	Natural killer (NK) cells	– Non-phagocytic cells – Do not require antigenic stimulation	– Kill tumor cells – Defend viral infections
(ii)	Killer (K) cells	– Non-phagocytic cells – Requires antibody mediation – Requires participation of complement system.	– Kill tumor cells, viruses, bacteria, fungi and parasites.
	Myeloid lineage cells		
(A)	**Monocytes**	– Circulating phagocytic cells – Large, motile, amoeboid cells – Phagocytes of blood – These get differentiated into macrophages when migrate to body tissues	– Responsible for lytic activity – Remove dead cells, debris and pathogens by microbiocidal activity
(B)	**Polymorpho nuclear cells (PMN)**	– Contains multilobed nucleus – Cytoplasm contain rich granules – Exhibit staining property – Three different kind of PMN are neutrophils, basophils and eosinophils	– Destroy bacteria and viruses – Eosinophils provide immunity to helminthes parasites – Basophils participates in allergic reactions
(C)	**Accessory cells**	– Additional cells present throughout the body for assisting the immune response. – They are of three types - mast cells, Antigen presenting cells, Platelets	
(i)	Mast cells	– They are modified basophils – Present throughout the body tissue – Secretes serotonin, histamine, heparin etc.	– Mediators of hypersensitivity – Mediate the inflammatory reactions. – Immunity against parasites.
(ii)	Antigen presenting cells (APC)	– These are non-lymphocytic cells – Involved in the presentation of antigens – Some of the cells involved in the antigen presentation are – follicular dendritic cells, interdigitating dendritic cells and Langerhan's cells	– Process the antigens – Help in recognition of antigen – Assist the immunocompetent cells.
(iii)	Platelets	– They are non-nucleated cells – Spherical and colourless derived from megakaryocytes – They secrete histamine and serotonin	– Have role in blood clotting – Involved in inflammation – Contribute to immediate hypersensitivity reactions

the memory B cells are present to quickly deal with the invading microbes by forming antibodies. Body "remembers" that it has previously encountered this type of infection.
- Primary and secondary humoral response are of two types of humoral immune response.

CELLULAR BASIS OF IMMUNE SYSTEM

- Lymphocytes (a type of WBCs) are the main cells of immune system of the body.
- Lymphocytes, meant for immune system, are of two types: T-cells and B-cells. Both types of cells develop from the stem cells found in the liver and yolk sac of the foetus and in the bone marrow cells during adult life.
- Those lymphocytes that migrate to the thymus and differentiate under its influence are called **'T-cells'**, while those cells that continue to be in the bone marrow for differentiation are known as **'B-cells'.** The thymus and bone marrow (or the bursa in birds) are the primary lymphoid organs. The final maturation of young lymphocytes occur in secondary lymphoid tissues like lymph nodes, spleen and tonsils.
- **B-lymphocytes** are **independent of the thymus** and in man probably **complete their early maturation within the bone marrow**.
- T-cells are **responsible for cellular immunity**, however, **B-cells produce the antibodies**—about 20 trillions per day that **take part in the humoral immunity**.
- The B-lymphocytes and T-lymphocytes **form humoral** (**or antibody mediated**) **immune system (AMIS)** and **cell-mediated immune system** (**CMIS**) **respectively**. Both the immune systems need antigens to come into action, but they respond in different ways.

Humoral immune system

- **Antibody-mediated** (**or humoral**) **immunity** is associated with the appearance of antibodies, secreted by cells of the B-lymphocyte series, in the extracellular fluids such as plasma, lymph and external secretions.
- The AMIR **defends the body against** (a) some viruses, (b) bacteria with polysaccharide capsules and (c) toxins that enter the body fluids (blood and lymph).
- When antibodies on a B cell's surface bind antigens, the B cell is activated and divides, producing a clone of daughter B cells. The daughter cells specialise into **plasma B cells** and **memory B cells.**
- **Plasma B cells (also known as effector cells)** are antibody factories.
- Plasma cells are highly specialized cells that produce defensive proteins and secrete them into the blood.
- The plasma cells do not migrate to the site of infection and act through a fluid (lymph). Hence, they are said to form humoral immune system (L. *humor* = liquid). The **B-lymphocytes** are **short-lived** and are **replaced every few days from the bone marrow**.
- **Memory B cells** live for a long time and **serve to quickly dispose of the antigens in case reinfection of the same virus or bacterium occurs**.
- The antibodies **fight the antigens in five different ways** –
  – **Neutralization.** Some antibodies neutralize the antigens, termed **toxins** (viral toxins, bacterial toxins, snake venom), and make them ineffective. They are called **antitoxins.** The phagocytes dispose of the neutralized antigen-antibody complexes.
  – **Agglutination.** Certain antibodies cause the particulate antigens (bacteria, red corpuscles) stick together in clumps, thus immobilizing them for easy disposal by the phagocytes through ingestion. They are termed **agglutinins**.
  – **Precipitation.** Other antibodies combine with the antigens to form precipitates that are easily ingested by the phagocytes. They are known as **precipitins**.
  – **Opsonization.** Some antibodies coat the surface of the microbes and make them more susceptible to phagocytosis. Such antibodies are known as **opsonins.**
  – **Complement activation.** Antibody-antigen complexes activate complement proteins which may –
    – Lyse cells walls of bacteria, causing their disintegration
    – Incite inflammatory response
    – Opsonize antigens
    – Attract phagocytes to areas of infection.

Cell mediated immune system

- **Cell-mediated immunity** is mediated by cells of the **T-lymphocyte** series with antigen-specific receptors on their surfaces.
- The CMIR defends the body against viruses, fungi and some bacteria which have entered the host's cells.
- On stimulation by contact with antigens, the T-lymphocytes produce by division a clone of T-cells, the **lymphoblasts.** There are separate T-cells for each type of antigen that invades the body. The T-cells leave the lymphoid tissue and migrate to the site of infection. The **T-cells have a life-span of 4 to 5 years or even longer**. The T-cells comprising the clone are **committed T-cells** having specific functions.
- **T-cell perform several important function** which can be **divided into 2 categories** – **regulatory** and effector.
- The **regulatory functions** are **mediated by helper** (**CD 4 positive**) **T-cells** which produces interleukins and the **effector functions** are **carried out primarily by cytotoxic** (**CD 8 positive**) **T-cells** which kill virus infected cells, tumor cells and allografts.
- They are similar morphologically but of 4 types functionally - killer or cytotoxic cells, helper T-cells, suppressor T cells and memory T-cells.
- **Cytotoxic T cell** are WBCs that attack and destroy foreign and dangerous cells (cancer).
- Cytotoxic T-cells attach to foreign, antigen-bearing cells, such as bacteria cells, and interact directly-*i.e.*, by cell-to-cell contact. **This type of response is called cell-mediated immunity**.
- Cytotoxic or killer T cells (CD8+) do their work by releasing lymphotoxins, which cause cell lysis.
- **Helper T cells (CD4+)** serve as managers, directing the immune response. They secrete chemicals called lymphokines that stimulate cytotoxic T cells and B cells to grow and divide, attract neutrophils, and enhance the ability of macrophages to engulf and destroy microbes.
- **Lymphokines** are chemical factors produced by lymphocytes for regulating activity of various cells of immune system. They **include** interleukins, granulocyte monocyte colony stimulating factor, interferon-γ.
- **Suppressor T cells** inhibit the production of cytotoxic T cells once they are unneeded, lest they cause more damage than necessary.
- Suppressor T cells help to shut down the immune response after the pathogen has been cleared from the body.
- **Memory T cells** are programmed to recognize and respond to a pathogen once it has invaded and been repelled.

> - **Cytokines** are soluble, nonantibody proteins released by cells of the immune system, *e.g.,* interleukin-1 produced by macrophages, perforin secreted by killer T-cells.
> - **Antiseptic** is an agent that prevents the growth of micro-organisms by killing them. Examples : spirit, dettol.
> - The principle that the phylogenies of parasites and their hosts generally evolve in parallel are known as **Fahrenholz's Rule.**
> - **Herd immunity** is the indirect protection from infection of susceptible members of a population and the protection of the population as a whole, which is brought about by the presence of immune individuals.

DISORDERS OF IMMUNE SYSTEM

- An improper function of the immune system gives rise to the following groups of disorders : **hypersensitivity** (**allergy**), **auto - immune diseases**, and **immunodeficiency**.
- **Hypersensitivity** is the excessive immune response to common antigens. These antigens are present on/in certain substances called allergens (e.g., dust, pollen, moulds, certain foods, some medicines).
- Allergy **involves mainly IgE antibodies and histamine**.
- Asthma is a common manifestation of allergy. Sometimes a sudden violent and fatal reaction may occur in sensitive individual due to an allergen. It is called **anaphylaxis**.
- **Antihistamine** is a medicine that gives relief from allergy, eg avil.
- Types of hypersensitive reactions are –
  - **Type I reactions** (*i.e*, **immediate hypersensitivity reactions**) involve immunoglobulin E (IgE)–mediated release of histamine and other mediators from mast cells and basophils.
  - **Type II reactions** (*i.e*, **cytotoxic hypersensitivity reactions**) involve immunoglobulin G (IgG) or immunoglobulin

M (IgM) antibodies bound to cell surface antigens, with subsequent complement fixation.
  - **Type III reactions** (*i.e*, **immune-complex reactions**) involve circulating antigen-antibody immune complexes that deposit in postcapillary venules, with subsequent complement fixation.
  - **Type IV reactions** (*ie*, **delayed hypersensitivity reactions**, **cell-mediated immunity**) are mediated by T cells rather than by antibodies. One type of Type IV reaction involves patients who have become sensitized to tuberculin, found in *Mycobacterium tuberculosis*, the causative agent of tuberculosis.
- **Autoimmune diseases** result when the immune system attacks and destroys self-cells and molecules, e.g., multiple sclerosis (caused by the attack of antibodies on the myelin sheath of nerve cells), insulin dependent diabetes, rheumatoid arthritis, etc.
- Many autoimmune diseases are found more commonly in old age, for example rheumatoid arthritis and a number of autoimmune thyroidithis conditions (e.g., Hashimoto's disease).
- **Immunodeficiency diseases** are caused due to a defect in one or more components of the innate or adaptive immunity.
- Immuno deficiency **may result from** gene mutations, e.g., severe combined immunodeficiency (SCID); infections, e.g. AIDS caused by HIV, and malnutrition or accidents.
- **SCID**, due to defective gene for adenosine deaminase, is a congenital disorder in which both the B and T lymphocyte are absent and due to which patient dies of even minor infection.
- SCID is the **first genetic disorder to be combated with gene therapy**.
- **AIDS** is caused by the infection from a retrovirus known as human immunodeficiency virus (HIV). The virus has a single stranded RNA genome, which reverse, transcribed and incorporated into the host genome. HIV **specifically attacks T-helper cells of the immune system**.
  [*For more details on AIDS refer chapter Common Human Diseases*]
- Western blot test confirm the elisa test in AIDS, through the detection of HIV proteins.
- The Russian Biologist, **Ivanowsky** (1892) was the first to demonstrate the presence of viruses in tobacco leaves suffering from mosaic disease. Infact, the first virus was discovered by Ivanowsky.
- **W.M. Stanley** (1935) an American microbiologist and Nobel Prize Winner (1946) isolated Tobacco Mosaic Virus (TMV) from infected leaf.
- **Arthur Ashe,** a ground breaking Black tennis player died of AIDS. He was infected by a blood transfusion during his heart bypass surgery, probably in 1983.
- Lentivirus is a slow acting virus, eg. HIV.

IMMUNISATION

- Immunisation is the phenomenon of specific antibody production in an individual against the potential attack of a pathogen. It is carried out through vaccination (active) and inoculation of antiserum (passive).
- The **aim of vaccine** is to provide effective immunity by establishing adequate levels of antibody and a population of memory lymphocytes which can expand rapidly on renewed contact with antigen.
- Live attenuated vaccine are **more potent** (**active**) **than killed vaccine**.
- **Vaccination** is the process of introduction of a preparation of antigenic proteins of pathogens or inactivated weakened pathogens (vaccine) into the human body.
- Vaccination has its origin from the works of Edward Jenner and Louis Pasteur.
- Edward Jenner was able to develop resistance to small pox in a boy by introducing the fluid from sore of a milkmaid who was suffering from cowpox.
- Louis Pasteur observed that, cholera bacteria from ageing cultures, when injected into chickens, they became immune to fowl cholera. Using this method Pasteur **developed vaccine against rabies in 1885**.
- A vaccine consist of a preparation of antigenic proteins of the pathogen or weakened/inactivated pathogen itself.
- **Toxinosis** is a disease or lesion caused by the action of a toxin.
- **Serology** is the study of serum, especially of specific immune or lytic serums (L. *serum* = whey, G. *logos* = study).
- **Antitoxins** are agents which can neutralise the toxins produced by pathogens and the ones present in venoms.

- **Passive immunisation** may be **induced by** – administration of an antibody containing preparation, transfer of maternal antibodies across the placenta; and by transfer of lymphocyte to induce passive cellular immunity.
- The antigenic protein may be prepared from the pathogen, or produced in a transgenic organism, eg. hepatitis B vaccine is produced from transgenic yeast.
- A proper matching of proteins (called human leucocyte antigens or HLA) is essential for a successful organ transplant or skin graft.
- A transplant should be given preference as under. Identical twins > Sibling > Parent > Unrelated donor.
- Passive immunization can be natural or artificial.
- **Natural passive immunization** includes the passage of maternal IgG across the mammalian placenta. In regions with a high incidence of tetanus, immunization of pregnant women with tetanus toxoid results in them making antitetanus IgG which is transmitted across the placenta to the foetus, and can protect the newborn from tetanus. In humans, IgA is transmitted to the baby's gut *via* colostrum and milk.
- **Artificial passive immunization** is effected when immunodeficient patients are given doses of antibodies from a donor; travelers to the tropics may be given 'pooled g-globulins' (antibodies) from donors who live in the visited areas; hopefully, the cocktail of donated antibodies may protect them from endemic diseases.

ORGAN TRANSPLANT

- **Transplantation** involves the removal of damaged/ injured tissues or organs from the body of a person and their substitution by similar tissues/organs from a donor.
- In **autografts** one's own tissue is grafted to another part of the body, *e.g.* skingrafts for burn treatment or plastic surgery. The **most successful transplantation is the autograft**.
- In **isografts** the donor and recipient are genetically identical, *e.g.*, **transplantation from a twin brother or sister**.
- **Allografts** is the transplantation between individuals of same species, but with different genetical background. The success of this transplant is moderate; it is generally **used as temporary measure until the damaged tissue is able to repair itself**.
- **Xenograft** transplant occurs between animals of different species. This type of transplantation is **used primarily as a physiological dressing over serious burn injuries**.
- Transplantation **may result in the rejection of transplanted organs**. The immune system recognizes the protein in the transplanted tissue or organs as foreign and initiates cellular immunity.
- Grafts will not be rejected if the graft is not vascularized, the host and donor have the same genotype and so have the same MHC genes (e.g., identical twins or members of inbred strains of mice), etc.
- **To suppress the immune response during transplantation**, **histocompatibility antigen** and **immunosuppresants** play an important role.
- **Histocompatibility** is the property of having the same, or mostly the same, alleles of a set of genes called the major histocompatibility complex.
- The **Major Histocompatibility Complex (MHC)** is a set of molecules displayed on cell surfaces that are responsible for lymphocyte recognition and "antigen presentation".
- The major histocompatibility complex is encoded by several genes located on human **chromosome 6.**
- Major histocompatibility complex (MHC) also referred to in humans as the **HLA** (**or Human Leucocyte Antigen**) **system**.
- These genes are expressed in most tissues as antigens, to which the immune system makes antibodies. The immune system at first makes antibodies to all sorts of antigens, including those it has never been exposed to, but stops making them to antigens present in the body.
- **Immunosuppressive drugs or immunosuppressants** are drugs, that are **used in the immunosuppressive therapy to inhibit or prevent activity of the immune system**.
- Clinically immunosuppressants are used to prevent the rejection of transplanted organs and tissues (e.g. bone marrow, heart, kidney, liver), treatment of autoimmune diseases or diseases that are most likely of autoimmune origin (e.g. rheumatoid arthritis, Myasthenia gravis, systemic lupus erythematosus, ulcerative colitis).

End of the Chapter

Chapter 72

Common Human Diseases

- Any condition which interferes with the normal structure & function of human body that is manifested by a characteristics sets of symptoms & sign whose etiology, pathology & prognosis may be known or unknown is called **disease**.
- **Terms related to diseases** are –
  - **Infection** : It refers to the entry and development or multiplication of viruses and organisms in the body of larger organisms. It implies body's response to defend itself in some way against the invaders. A disease resulting from an infection is called infectious disease. **Factors influencing infection** are – **number of invading pathogens**, **virulence of pathogens**, **resistance of the body of disease** and **immunity**.
  - **Contamination** : It refers to the presence of disease-causing agents in nonliving materials, such as water, milk, and food, used by the host, without any response to the pathogens.
  - **Infestation** : It refers to the lodgement, development and reproduction of parasites, generally arthropods, on the surface of the body, or in the clothing, *e.g.,* louse infestation.
  - **Incubation period** – It is the time elapsed between exposure to a pathogenic organism and when symptoms and signs are first apparent.
  - **Etiology** : Etiology (alternately aetiology, aitiology) is the study of causation. It is the study of all factors that may be involved in the development of a disease, including the patient's susceptibility, the nature of the disease causing agent, and the way in which the person's body is invaded by the agent.
  - **Epidemiology** : It is the study of the distribution and determinants of disease in human populations, and the application of this study to control of health problems.
  - **Prophylaxis** : It refers to any medical or public health procedure whose purpose is to prevent, rather than treat or cure, disease. Roughly, prophylactic measures are divided between primary prophylaxis (to prevent the development of a disease) and secondary prophylaxis (where the disease has already developed and the patient is protected against worsening of this process).
  - **Reservoir of infection for pathogens** : Every pathogen has some reservoir where it normally lives when it is outside the host susceptible to the disease. The reservoir varies for different pathogens. It may be soil, water, animals, air and other persons called **carriers.** The animals which act as reservoirs do not contract the diseases and are known as **reservoir hosts**.
- On the basis of their occurrence diseases are of **two types** – **congenital** and **acquired disease**.
- **Congenital diseases** are inborn disease **present from the birth**.
- These diseases are generally **inheritable**, **caused by gene or chromosomal mutation**, eg. haemophilia, Down's syndrome, alkaptonuria etc. (*For congenital diseases refer chapter Human Genetics & its Disorders*).
- **Acquired disease** occur only **after birth & are non-inheritable**.
- **Two types** of acquired diseases are – communicable disease & non-communicable disease.

COMMUNICABLE DISEASES

- **Communicable diseases** are infectious diseases and caused by pathogens which spread from infected persons to healthy persons.

- Communicable diseases are of **two types** – **contagious** and **non-contagious disease**.
- **Contagious diseases** are transmitted from infected persons to healthy person through simple contact. Eg. syphilis, chickenpox, measles, leprosy etc.
- **Non-contagious diseases** are transmitted from infected to healthy one **through an agency of water, food or air** (eg. ascariasis, cholera, typhoid) or by **micro-organisms** infected inside the human body by some carrier or vector host (eg. measles, filariasis, plague etc).
- **Depending upon the causative agent** communicable diseases are of following types – viral, bacterial, protozoan, helminthic, mycoplasmal, rickettsial, chlamydial etc.
- Disease caused by mycoplasma are **bronchitis, acute leukaemia** etc.
- Fungi causes **ringworm, thrush, Tinea, pulmonary aspergillosis** & **athelete's foot** diseases etc.

Viral diseases

- Viral diseases are transmitted by **direct contact, fomite** & **droplet method**.
- **Types of viral diseases** are – influenza/flu, small pox, chicken pox, measles, mumps, poliomyelitis, rabies, hepatitis & dengue.

Influenza

- Influenza (also called **flu**) is an **acute respiratory tract infection** caused by influenza virus.
- **Influenza virus**, *Myxovirus influenzae* is a ribovirus (RNA virus) with fragmented genome.
- Influenza is **characterized with** bronchitis, coughing, sneezing, ear infection & pneumonia etc. through inflammation of respiratory tract & eyes.
- Incubation period of influenza virus is **2-3 days**.
- Influenza is epidemic, endemic & pandemic.
- **Endemic influenza** is caused by *Haemophilus infleunzae*, a gram (–) ve bacterium.
- **Asian flu** is viral influenza.
- Influenza virus has **3 forms** – A, B, & C. Vaccine is available against influenza virus A.

Small pox

- Small pox is **highly contagious disease**.
- **Causative agent** for small pox is DNA virus, *Variola virus*.
- Incubation period is **12 days** in case of small pox.
- Small pox is **characterised by** high fever, headache, appearance of rashes followed by papules, vesicles, pustules & finally scabs.
- Permanent pox marks left on skin lead to blindness also.
- First vaccination against small pox was developed by **Edward Jenner in 1796**.
- Small pox has been **eradicated globally**.

Chicken pox

- Chicken pox is **caused by** DNA virus *Varicella zoster* with **14-16 days of incubation period**.
- It is **more common** & **less severe** in children & **severe but rare** in adults.
- Scabs in chicken pox **falls off without leaving any mark**.
- Boric acid, calamine and benzyl benzoate reduces itching and tendency to scratch.
- Passive immunity in chicken pox is possible through **Zoster immunoglobulins (ZIG)**.

Measles

- Measles is **highly infectious eruptive viral disease**.
- It is **caused by** RNA containing *Rubella virus*/ *Polynosa morbillorum*.
- Measles is **also transmitted to developing foetus through placenta**.
- Measles is **accompanied by** coughing, sneezing, skin eruptions of small red spots (rubeola), conjunctivitis etc. with **incubation period** of **10-14 days**.
- **Antibiotics** & **sulpha drugs** are effective in measles.
- **German measles** is caused by *Rubella virus.*
- It is known to cause congenital problems resulting in eye defects, deafness & cardiac problem.

Kyasanur forest disease

Kyasanur forest disease (KFD) is a viral haemorrhagic fever caused by infection with a flavivirus from small wild animals. KFD was first recognised in 1957 during a fatal epizootic of wild monkeys in Mysore (Karnataka), India. Forest workers are particularly at risk, and mortality may reach 10%. The causative virus is a tick-borne virus belonging to the genus Flavivirus of the family Flaviviridae, which has been isolated from ticks, monkeys, and humans. The principal vector appears to be the tick *Haemaphysalis spinigera*, whereas the vertebrate reservoir is uncertain.

Mumps

- Mumps is **caused by** RNA containing *Paramyxo/ mumps virus.*
- It **spreads through droplet infection** or **direct contact with the mucus membranes of mouth**.
- It is **characterised by** swollen parotid gland (hence **infectious parotitis**) due to which patient has difficulty in swallowing & opening of mouth.
- Secondary infections may also cause sterility/ infertility when it involves male & female gonads.
- Incubation period is **12-26 days**.
- **MMR vaccine** is **used against mumps**, **measles** & **rubella**.

Poliomyelitis

- Poliomyelitis is **highly infectious disease of infants & children**.
- **Causative agent** of poliomyelitis is a small RNA containing *Polio virus* or *enterovirus*.
- Poliovirus multiplies in alimentary canal then passes to lymph, blood & finally to CNS in dorsal horn cells of spinal cord & brain stem resulting in paralysis in children. Hence also called **infantile paralysis**.
- Vaccine for polio are **killed Salk's vaccine** & **live Sabin's oral vaccine**.

Rabies

- Rabies or **hydrophobia** is **caused by** RNA virus, *Rabies virus* (*Lassa virus*).
- Rabies is **100% fatal disease** and affects all warm blooded animals and is **exclusively transmitted by the bites of carnivores**.
- It is **transmitted** to human beings **by biting/saliva of rabid dog**, **monkey**, **cats** etc.
- It **leads to** encephalitis, fear of water **(hydrophobia)**, high fever, severe headache, spasm of throat & chest leading to death.
- Characteristic cytoplasmic inclusions called **Negri bodies found in many neurons helps in rapid diagnosis**.
- Rabies virus is **neurotrophic** *i.e.*, damage motor neurons of brains.
- Vaccine against rabies was developed by **Louis Pasteur**.

Hepatitis

- Hepatitis is a **gastroenterological disease** featuring inflammation of liver.
- It is **caused by** the infecton with one of the five viruses called hepatitis A, B, C, D and E.
- **Hepatitis B virus** (HBV) is the **most serious type of viral hepatitis** and the only one causing chronic hepatitis for which vaccine is available.
- In addition to the hepatitis viruses, some other viruses can cause hepatitis including cyto megalovirus, Epstein-Barr virus, yellow fever virus, Rubella virus etc.
- **Hepatitis A virus** (also called **catarrhal jaundice**) causes hepatic anorexia resulting in liver damage or jaundice.
- Its **mode of transmission** is by **faccal-oral route**.
- It is **formerly called infectious hepatitis or epidemic hepatitis**.
- **Hepatitis B**, **popularly called serum hepatitis** or **transfusion hepatitis**, is **caused by** hepatitis B virus. It also called **Dane particle**.
- **Identified methods of transmission of hepatitis B** includes **blood** (blood transfusion, now rare), **tattoos** (both amateur and professionally done), **horizontally** (sexually or through contact with blood and bodily fluids) or **vertically** (from mother to her unborn child).
- **Hepatitis B virus** is **spherical and double shelled**. Genetic material is **circular ds DNA**.
- **Hepatitis C** (originally non A non-B hepatitis) can be **transmitted through** contact with blood (including through sexual contact).
- The HCV (hepatitis C virus) has single stranded positive RNA.
- **Hepatitis D** (Delta hepatitis) is **caused by** simultaneous infection of HBV and delta virus HDV.
- Delta virus has single stranded small circular minus sense RNA. The genome can encode only for its nucleoprotein but not the capsid.
- Hepatitis D virus cannot proliferate without the presence of hepatitis B virus, because its genome lacks certain genes.
- Symptoms are similar to those of hepatitis B but are more severe and cause large scale damage.
- **Hepatitis E** is enterically transmitted non A, non B hepatitis (HNANB). The virus is naked (non-enveloped) and spherical with a diameter of 27-28 nm. It **possesses a single positive stranded RNA**.
- Hepatitis E was first recorded in 1955 in Delhi when some 29000 cases were identified. Like hepatitis A, hepatitis E **spread through faecal** contaminated water and food.

- Incubation period is **5-6 weeks (2-8 weeks)**.
- Symptoms are similar to those of hepatitis A but bilirubin levels are usually higher. Jaundice is deeper and prolonged.
- Personal cleanliness, boiled water, properly heated, cooked and clean food articles and control of files are required in period of epidemic. Vaccine is available.
- **Ethanol**, mostly **in alcoholic beverages**, is an **important cause of hepatitis**. Usually alcoholic hepatitis comes after a period of increased alcohol consumption.
- **Alcoholic hepatitis** is **characterized by** a variable constellation of symptoms, which may include feeling unwell, enlargement of the liver, development of fluid in the abdomen ascites, and modest elevation of liver blood tests.
- Alcoholic hepatitis can vary from mild with only liver test elevation to severe liver inflammation with development of jaundice, prolonged prothrombin time, and liver failure. **Severe cases are characterized by** either obtundation (dulled consciousness) or the combination of elevation bilirubin levels and prolonged prothrombin time; the mortality rate in both categories is 50% within 30 days of onset.
- **Alcoholic hepatitis is distinct from cirrhosis** caused by long term alcohol consumption.
- Alcoholic hepatitis can **occur in patients with chronic alcoholic liver disease** and **alcoholic cirrhosis**. Alcoholic hepatitis by itself does not lead to cirrhosis, but cirrhosis is more common in patients with long term alcohol consumption.

Yellow fever

- Yellow fever **caused by** an arbovirus is a haemorrhagic disease **transmitted by** the infected *Aedes aegypti*.
- **Symptoms** of yellow fever are headache, fever, vomiting, rupture of veins in kidneys, spleen, liver, etc. In severe cases, the skin of the sufferer becomes yellow from jaundice, hence the name yellow fever.
- **Max Theilder** in 1951 **got Nobel Prize for the development of vaccine for yellow fever**.

Dengue

- Dengue fever is **caused by** a RNA containing **arbo virus** (arthropod born virus) of flavi virus group which also causes yellow fever.
- Dengue is caused by viruses DEN-1, DEN-2, DEN-3, DEN-4.
- Dengue virus is spread by a day time biting of female tiger mosquito or *Aedes aegypti.*
- *Aedes aegypti* is primarily a daytime feeder and mainly bites in the morning or late in the afternoon in covered areas.
- **Two types** of dengue fever are – classical dengue fever & dengue haemorrhagic fever.
- **Classical dengue fever** (**break bone fever**) is more severe in adults & **characterised by** mild conjunctivitis, high fever, backache, retro – orbital pain etc.
- **Dengue haemorrhagic fever** is a fatal form with nausea, headache, vomiting, abdominal pain etc.

AIDS

- AIDS (Acquired Immunodeficiency Syndrome) sometimes called **slim disease**.
- AIDS is a chronic life threatening disorder which **damages the human body's immune system**.
- AIDS is caused by **HIV** (Human Immunodeficiency virus) which belongs to retrovirus (group of RNA virus).
- There are **two types of HIV** namely HIV 1 and HIV 2, the most common virus currently associated with AIDS is HIV-1.
- The HIV virus can **only survive in** body fluids like blood, semen, vaginal secretion etc.
- **HIV is transmitted through body fluids by** –
  - Sexual contact with an HIV infected partner (it account for 75% of infection).
  - Infected blood
  - Shared needles, syringes, shaving razors contaminated with infected blood
  - Mother to child (during child birth or breast-feeding)
  - In rare cases the virus may be transmitted through organ or tissue transplants, artificial insemination through donated semen, or un-sterilized dental or surgical equipment.
- HIV is **not transmitted through** – **ordinary contact** (hugging, dancing, sneezing, talking, touching, or shaking hands) **with someone who has HIV or AIDS**; **sweat, tears or saliva,** or **through sharing food, utensils, towels, bedding, a swimming pool, telephone** or **toilet seat** with someone who has AIDS; **bedbugs or mosquitoes.**
- HIV virus, 1st reported in green monkey, was isolated by Monlagnier *et al* (1983) in France and later by Gallo *et al* in USA (1984).

- HIV is a part of family or group of virus called lentivirus (slow acting virus).
- The **major cell affected** by HIV is the **helper T-lymphocyte**.
- The HIV virus multiplies and slowly begins to destroy the CD4 lymphocytes (T-cells or helper T-cells), which are the white bloods cells responsible for the coordination of the entire immune system.
- The length of the time between initial HIV infection and the development of AIDS (called **window period**) varies greatly, and some people may remain without symptoms for years.
- AIDS was **first recognised** in Hatai (USA) in 1981 among a group of young homosexuals who were addicts of heroin and other narcotics and had lost immunity competence to pneumonia and skin cancers.
- **AIDS** is the **end of the disease**.
- A number of infections (called **opportunistic infections**, OIs) commonly occur at this stage and/or cancers that occur in people with otherwise unexplained defects in immunity. Getting on OI is not the same thing as having AIDS. In order for a patient who is infected with HIV to have AIDS, the immune system must be severely damaged. The severity of the immune system damage is measured by a CD4 lymphocyte count. If a person infected with HIV has a CD4 count less that 200/ml, and have one or more of these 'official' OIs then the person is said to have AIDS. (*Normal CD4 lymphocytes count ranges from 600/ml to 1000/ml*). Death is due to uncontrolled or untreatable infection.
- Most serious form of AIDS is known as **AID related complex (ARC)** which is **characterized by** swollen lymph nodes, fever, night sweats and weight loss. 25% ARC patients may develop full blown AIDS.
- HIV antibodies can be detected by the **ELISA test** (enzyme-linked immunosorbent assay).
- **Elisa** is a technique which can detect and even quantitate extremely small amount of a protein, antibodies or antigens with the help of enzymes. The **commonly used enzymes** are **perodixases** and **alkaline phosphatase**.
- A positive ELISA should be confirmed using another test called the **western blot test**. Western blot test is the culturing of blood and testing plasma for virus.
- **Western blot test** will confirm the result of repeated test through the detection of HIV proteins.
  If all three tests are positive a diagnosis of HIV infection will be given.
- **Viral load test** measures the amount of virus in the blood which willl help in determining the probable progression of the disease.
  The currently approved viral load test is called the *Amplicor HIV-1 Monitor Test or PCR* (*Polymerase Chain Reaction*) *test*. Viral load tests are also used in the management of drug treatments.

Bacterial diseases

- **Types of bacterial diseases** are – cholera, pneumonia, plague, tuberculosis (TB), pertussis (whooping cough), tetanus, diphtheria, typhoid, leprosy etc.

Cholera

- Cholera is **highly communicable bacterial disease**.
- Cholera is **caused by** *Vibrio cholerae.*
- Houseflies are the **vectors of cholera**.
- It is an **acute diarrhoeal disease characterised by** vomiting, muscular cramps, anuria (no urine) & rapid dehydration.
- Most **important antibiotic** for cholera are tetracycline & chloramphenicol.
- Cholera is **commonly called** as **Haiza**.
- It is **mainly a water borne diseases** but **also spreads through** contaminated food and drinks or touching by contaminated hands.
- The virus **mainly infects** intestines and parts of digestive tracts.
- *V. cholerae* produces a cholera toxin **enterotoxin** which induces excessive sccretion of an isotonic electrolyte solution by the intact intestinal mucosa. This solution is lost in the shool.
- **To prevent cholera** water must be disinfected with tropical lime of chloride (TLC) or chlorogen (strong chlorine solution).

Pneumonia

- Pneumonia, **a disease of lung,** is **caused by** *Streptococcus* or *Diplococcus pneumoniae.*
- It is of **two types** – **bronchopneumonia** (young children, elderly person) & **lobar pneumonia** (10–50 years).
- Pneumonia is **characterised by** sudden chill, chest pain, cough with rusty mucoid sputum, rapid shallow breathing & high temperature.

- **Important drugs** for pneumonia are **erythromycin, tetracycline & sulphonamide**.

Plague

- Plague is primarily a **disease of rat**.
- It is **caused by** rod shaped non-motile bacterium, *Pasteurella/Yersinea pestis* & **spread through** the bite of infected rat flea (*Xenopsylla cheopsis*) on lower extremities.
- *Pasteurella pestis* is endoparasite of gut of rat flea (which are the ectoparasite of rat & mice).
- Head louse (*Pediculus*) & bedbug (*Cimex*) may also transmit the germ from man to man.
- Plague is also called **black death**. It is of **3 types** – **bubonic plague**, **pneumonic plague** & **septicemic plague**.
- **Bubonic plague** is **characterised by** high fever, weakness, enlargement of lymph nodes (especially of armpit & groin), delerium exhaustion and haemorrhages which turn black. The patients dies there after. Hence plague is also called black death.
- **Pneumonic plague** is **characterised by** haemorrhage of bronchi & lungs.
- Pneumonic plague spreads from human to human (without ratflea) through droplets & fomites.
- **Septicemic plague** is **characterised by** anaemia, fever, chill etc.
- **Streptomycin injection & tetracycline** are **effective drugs** against plague bacilli.

Tuberculosis

- Tuberculosis (TB) is **caused by** rod shaped gram (+) ve bacteria, *Mycobacterium tuberculosis*.
- Disease is **spread by direct contact and droplet method**.
- Koch (1882) discovered *Mycobacterium tuberculosis*.
- During infection bacteria produce a toxin called **tuberculin**.
- TB is of **2 types** – pulmonary & extrapulmonary.
- **Pulmonary TB** is **characterised by** fever, coughing, chest pain, difficult breathing & blood in sputum (haemoptysis) etc.
- **Milk** is a **source of bovine tuberculosis**.
- **BCG** (Bacillus Calmette Guerin) vaccine for TB was **obtained from bovine bacillus** by Calmette & Guerin in 1921.
- **Antituberculosis drugs** are streptomycin, PAS (para amino salicylic acid), rifampicin, ethambutol etc.
- **Sputum, tuberculin, X-ray and gastric analysis** are carried out to diagnose tuberculosis.
- Tuberculin test is also called **mantoux test**.

Pertussis

- Pertussis or **whooping cough** is **caused by bacillus bacterium** *Bordetella pertussis* or *Haemophilus pertussis*.
- It is one of the **most dangerous disease of childhood**.
- It is **spread through droplet infection and direct contact**.
- It is **characterised by** mild fever, vomiting & attack of irritating cough accompanied by inspiratory whoop/gasp (loud crowing inspiration).
- **Most effective antibiotic** for whooping cough are **erythromycin, ampicillin, chloramphenicol** & **streptomycin**.
- **Vaccine** for pertussis is available in the form of **DPT** (*i.e.*, diphtheria, pertussis, tetanus) at monthly interval.

Tetanus

- Tetanus, an incurable bacterial disease, is **caused by** *Clostridium tetani*.
- Its **infection is acquired by** contamination of wounds with tetanus spores as these infected spores are abundant in the soil manured with animal dung.
- Incubation period is **3 to 25 days** during which bacteria secrete a neurotoxin, **tetanospasmin** which is carried to the CNS.
- Tetanus **involves degeneration of motor neurons & characterised by** painful muscular contraction of jaw (lock jaw).
- The **common symptoms** are stiffness of the jaw, difficulty in chewing and swallowing, fever, headache, and spasm of facial muscles.
- **Injection of ATS** (antitetanus serum) **gives passive immunity while TT** (tetanus toxoid) **gives active immunity**.

Diphtheria

- Diphtheria is **caused by** gram (+) ve bacterium, *Corynebacterium diphtheriae*.
- It is **highly infectious** and **spread through droplet infection** and **direct contact**.
- Diphtheria can be **diagnosed by schick test**.
- Endotoxin produced by pathogen causes **nasal diphtheria, pharyngeal diphtheria** & **laryngotracheal diphtheria**.

- **In severe cases**, respiratory tract is blocked causing difficulty in breathing & even death due to choking.
- **Antibiotic** recommended in case of diphtheria are **penicillin** & **erythromycin**.

Typhoid

- Typhoid is **caused by** *Salmonella typhi.*
- Bacteria responsible for typhoid is **commonly found in intestine of man**.
- Typhoid **spreads through** food, milk and water contaminated with intestinal discharges either directly or through flies and personal hygiene.
- It is **characterised by** headache, lesion of intestinal mucosa, haemorrhage, ulceration of intestine, rose coloured rash on chest & upper abdomen.
- Typhoid is **diagnosed by widal test**.
- **Antibiotic** against typhoid are **ampicillin & chloramphenicol**.
- Sometimes cholecystectomy is carried out to remove the source of typhoid infection.
- **TAB vaccine** provide immunity for about 3 years.

Peptic ulcers are eroded areas in the lining of stomach & duodenum. It is caused by **excessive secretion of acid** in gastric juice. According to new findings ulcers occurs due to attack of *Helicobacter pylori.*

Leprosy

- Leprosy (**Hansen's disease**) is **contagious chronic bacterial disease**.
- It is **caused by** *Mycobacterium leprae.*
- *Mycobacterium leprae* was discovered by **Hensens (1973)**.
- **Presence of lepromin** in skin test can indicate the appearance of leprosy.
- Leprosy is of **2 types** – **tuberculoid leprosy** (involves tuberculoid granuloses formed by aggregation of macrophages) & **lepromatous leprosy** (characterised by nodular aggregates of lipid laden macrophages, **lepra cells**).
- Tuberculoid leprosy give **positive test** with lepromin while lepromatous leprosy is **negative** to lepromin test.
- Leprosy is **characterised by** hypopigmentation of skin, thickening of peripheral nerves, numbness in some body parts, rupturing of nodules & formation of ulcers etc.
- Leprosy is a **dreaded disease due to social stigma attached with it**.
- Surgery along with drugs (diaminodiphenyl sulphone or dapsone, ofloxacin, chaulmoogra oil) can cure the disease.

Anthrax

- Anthrax is an **acute infectious disease caused by** spore forming bacterium *Bacillus anthracis*. Anthrax is most common in agricultural regions where it occurs in animals.
- It **most commonly occurs** in wild and domestic lower vertebrates (cattle, sheep, goats, camels, antelopes and other herbivores), **but it can also occur in humans** when they are exposed to infected animals or tissue from infected animals.
- **Anthrax infection** can **occur can three forms** – cutaneous, inhalation and gastrointestinal.
- **Symptoms** are –
  - **Cutaneous** : Itchy bump that resembles an insect bite and develops into a vesicle and then a painless ulcer within 12 days with a characteristic black necrotic area in the centre.
  - **Inhalation** : Common cold which may progress to severe breathing problems and shock. It is usually fatal.
  - **Intestinal** : Acute inflammation of the intestinal tract with initial signs of nausea, loss of appetite, vomiting, fever abdominal pain, severe diarrhoea.
- If left untreated, anthrax in all forms can lead to septicemia and death.
- Anthrax is **considered to be a potential agent for use in biological warfare**.

Diarrhoeal diseases

- Diarrhoeal diseases are group of infections of the intestinal tract.
- It is characterised by food poisoning, abdominal cramps, frequent passage of stool having blood & mucus leading to dehydration.
- **Bacteria causing diarrhoeal diseases** are *E.coli*, *Shigella sp.*, *Campylobacter* & *Salmonella.*
- A protozoan *Giardia* and certain viruses also cause similar conditions.
- **Rotavirus** causes gastroenteritis with acute watery diarrhoea in infants & children.
- **Norwalk viruses** causes gasteroenteritis in all age groups.
- **ORS** is oral rehydration solution used for correcting dehydration caused by diarrhoea in all age groups.

- ORS contains **1.5 gm** glucose, **3.5 gm** NaCl, **2.9 gm** KCl & **2.9 gm** trisodium citrate.

Sexually transmitted diseases

- The sexually transmitted diseases (STD) are transmitted predominantly by sexual contact and caused by a wide range of bacterial, viral, protozoal and fungal agents and ectoparasites.
- **Two types of sexually transmitted diseases** or veneral disease caused by bacteria are **syphilis** & **gonorrhoea**.
- **Syphilis** is **caused by** *Treponema pallidum* with **incubation period of 3-5 week**.
- It is **characterised by** lesion in the mucous membrane of urinogenital tract, ulcers on genitalia & swelling of local lymph nodes.
- Syphilis is **also transmitted to foetus** from infected mother through placenta.
- Appropriate antibiotics recommended for syphilis are **tetracycline** & **penicillin**.
- **Gonorrhoea** is **caused by** diplococcus bacterium, *Neisseria gonorrhoea*.
- It is **characterised by** inflammation of mucous membrane of urinogenital tract resulting in burning sensation during urination.
- **It may also lead** to arthritis & eye infection called **gonococcal ophthalmia** in children of gonorrhoea afflicted mother.
- Antibiotics for gonorrhoea are **penicillin** & **ampicillin**.

Table : Some STD and their pathogens

Disease	Pathogen
Bacterial	
Syphilis	*Treponema pallidum*
Gonorrhoea	*Neisseria gonorrhoea*
Chancroid	*Haemophilus ducreyi*
Vaginitis	*Gardnerella vaginalis*
Viral	
Herpes genitalis	*HSV-2 (DNA) virus*
Condyloma acuminatum	*Papova (DNA) virus*
Molluscum contagiosum	*Pox (DNA) virus*
Protozoal	
Trichomoniasis	*Trichomonas vaginalis*

Chlamydial disease

- **Trachoma** is an eye disease and **caused by** *Chlamydia trachomatis* (a primitive prokaryote).
- *Chlamydia trachomatis* are obligatory intracellular parasite & are larger than virus.
- It is commonly called **Rohe** or **kukre** or kheel.
- It is **transmitted by** direct contact, fomite & flies.
- Trachoma is **characterised by** inflammation & discharge from eyes & ulceration of cornea & conjunctiva resulting in blindness.
- Trachoma is responsible for **5%** of the viral impairment and blindness in India.

Protozoan diseases

Malaria

- Malaria is the **most common protozoan disease of human being**.
- Malaria is **caused by** *Plasmodium* species & **spread through** female *Anopheles*.
- *Plasmodium* is **non-pathogenic** to mosquito host.
- **Laveran (1880)** discovered malarial parasite in blood of malarial patient.
- **Pfeiffer (1892)** proposed that malaria is spread by blood sucking insect.
- Discovery of *Plasmodium* & its transmission by *Anopheles* (female) was confirmed by **Ronald Ross (1897)**.
- Different species of *Plasmodium* causes different types of malaria. The species are – *P. vivax*, *P. falciparum*, *P. malariae* and *P. ovale*.
- **Quotidian malaria** occurs due to secondary complication of malignant tertian or due to multiple or mixed infection **by more than one species** of *Plasmodium*.
- **Quartan malaria** caused by *P. malariae* is characterised by the reccurrence of fever every 4th day *i.e.*, interval of 72 hours.
- *P. ovale* causes **benign tertian malaria**.
- **Tertian malaria** is caused by *P. vivax*, *P. falciparum* & *P. ovale*.
- *P. falciparum* causes **malignant** or **subtertian**, or **aestivo-autumnal** or **pernicious** or **cerebral** or **tropical malaria** resulting in high death rate due to clumping of infected RBC & blocking capillary blood circulation in brain, lung, heart, spleen etc.
- **Black water fever**, caused by infection of *P. falciparum*, resulting in the excretion of haemoglobin in urine.
- Clinical fever in malaria is due to **erythrocytic schizogony**.
- Malaria is **characterised by recurring rigors** lasting 6–10 hours. There are three stages –
  - *Cold stage* : Chill and shivering.

- *Hot stage* : Temperature rise to 100ºC.
- *Sweating stage* : There is perspiration and gradual fall in temperature.

- Malaria **results in** anaemia, toxaemia and splenomegaly (enlarged spleen).
- **Anti-malarial drugs** are **quinine** (extracted from bark of *Cinchona* tree), **chloroquine, paludrine, daraprim** etc.
- Daraprim drug **kills the parasitic stages** present in both liver cells & RBCs of blood.

Amoebiasis

- Amoebiasis (**amoebic dysentry or enteritis**) is **caused by** intestinal endoparasitic protozoan, *Entamoeba histolytica* of man.
- Infection is **transmitted by** contamination.
- *Entamoeba* **secretes cytolysin** that erodes the mucous membane of intestine.
- It is **characterised by** abdominal pain, alternating diarrohea and constipation, stool with blood, mucous and mucous membrane pieces.

Giardiasis

- Giardiasis or **backpacker's disease** is **caused by** *Giardia intestinalis*.
- It **inhabits upper part of small intestine** (duodenum and jejunum).
- Infection is **transmitted by** contamination of cyst with food and drinks.
- It is **characterised by** mild diarrhoea involving passage of pale bulky, foul smelling and greasy stool.

Pyorrhoea or **peridontitis** caused by *E.gingivalis*, is characterised by **bleeding** gums & falling of teeth.

Kala azar

- Kala azar or **Leishmaniasis** is **caused by** *Leishmania donovani* & **spread by** sandfly (*Phlebotamus*).
- Kala azar is **characterised by** fever & enlargement of visceral organs.
- Kala azar is **also known as dum-dum fever**.
- *Leishmania braziliensis* causes **espundia** with ulcers appearing first on legs later on throat, nose etc.
- **Oriental sore** is **caused by** *Leishmania tropica*.

Trypanosomiasis

- **Trypanosoma** is a flagellate protozoan whose different species causes different types of **trypanosomiasis**.
- **Trypanosomiasis** is **characterised by** high fever, swelling of neck & armpit, weakness, anaemia, muscle spasm, lethargy, unconsciousness & death.
- **Gambian fever** or **West African sleeping sickness** caused by *T. gambiense,* is spread by both sexes of tse-tse fly (*Glossina palpalis*).
- **Rhodesian** or **East African sleeping sickness**, caused by *T. rhodesiense*, is spread by *G. morsitans*.
- **Chagas disease** is also called South American sleeping sickness. It is **caused by** *T.cruzi* & spread by *Panstrongilus sp*., and *Triatoma sp*.
- It is **more common in children & young adults**.

Ciliary dysentry (Balantidiasis)

- Ciliary dysentry is **caused by** a ciliated protozoan *Balantidium coli*. The latter **inhabits the human large intestine (colon)**. It is **also seen in pigs** and **monkeys**. In pigs they are non-pathogenic.
- It reproduces asexually by transverse binary fission and sexually by conjugation. The latter is followed by cyst formation. Cysts pass out in the host's faeces.
- **Infection occurs by** ingesting cysts with food and drinks.
- *Balantidium coli* causes ulcers in the colon and invades mucous membrane by secreting an enzyme **hyaluronidase**. This generally results in diarrhoea, but may also lead to severe or fatal dysentry.
- Protection of food articles from dust and files, that may carry cysts, can prevent human infection.
- **Tetracycline** or **iodoquinol** are effective treatments.

Helminthic diseases

- Helminthic diseases are **transmitted through** dirty hand, contaminated soil & food.
- **Helminthes** are multicellular parasites which causes many diseases in man. It consists of roundworm and flatworms.
- **Types of diseases** – are filariasis, taeniasis, ascariasis etc.

Filariasis

- Filariasis is **caused by** *Wuchereria bancrofti*.
- It is also known as **elephantiasis** due to excessive enlargement of body part like legs.
- It is **characterised by** fever, proliferation of endothelial cells & deposition of metabolites in the wall of lymph vessels.
- **Secondary host** of filariasis is *Culex* or *Aedes* mosquitoes.

Taeniasis

- Taeniasis is **caused by** intestinal endoparasite of man called *Taenia solium*.
- The disease **accompanied by** abdominal pain, indigestion, loss of appetite (anorexia), nausea, vomiting etc.
- Cysticerci larva of *Taenia* causes **cysticercosis** which causes damage to different body parts, blindness (in eyes), epilepsy like fits in brain.

Ascariasis

- Ascariases, **caused by** *A.lumbricordes* is more common in children.
- *Ascaris* is **intestinal endoparasite of man**.
- **Vectors** for ascariasis are **flies** & **cockroaches** containing embryonated eggs of *Ascaris* contaminated with food and water.
- Ascariasis is **characterised by** colic pain, indigestion, diarrhoea, vomiting, weakness, retarded physical or mental efficiency etc.
- **Scratch test**, **dermal test** & **stool test** can be done to detect the roundworm infection (*Ascaris*).

Other diseases

- **Enterobiasis, ancylostomiasis, trichinosis,** & **schistosomiasis** (also called **bilharzia**) are caused by *Enterobius vermicularia* (pin or seat worm), *Ancylostoma duodenale* (hook worm), *Trichinella spiralis* (trichina worm) & *Schistostoma haematobium* (blood fluke) respectively.
- *Enterobius vermicularis* (**Oxyuris**) is found in large intestine and appendix, causes anal itching, appendicitis, nervous problem. No intermediate host. **Transmission is direct by** contaminated food.
- *Trichinella spirillis* is found in the human intestine, causes muscular pains and pneumonia or **Trichiniasis**. It is transmitted by eating infected pork.
- *Schistosoma haematobium* is **transmitted by** snail. It is found in urinary baldder, blood vessels and caused itching rashes aches, fever and eosinophilia.
- *Dracunculus medinensis* (Guinea worm) are found in the subcutaneous tissues of body. It causes **Guinea worm disease**, characterised by blisters on skin. Like small pox it is considered to be an extinct disease in India.
- *Loa Loa* (The eye worm) is found in the subcutaneous tissues of eyes, causes **conjunctivitis**.
- *Trichuris trichura* (whip worm) is found in the caecum and appendix, cuases **anaemia**, bloody stools and pain.

Table : Some diseases and their confirmatory immunological tests

Test	Disease
Ames test	Carcinogenicity
Dick test	Scarlet fever
Mantoux text	Tuberculosis
Rose-Waaler test	Rheumatoid fever
Schick test	Diphtheria
Wassermann test	Syphilis
Widal test	Typhoid
Wayson stain test	Plague
Tourniquet test	Dengue fever
Presence of lepromin in skin	Leprosy

NON-COMMUNICABLE DISEASES

- **Non-communicable diseases** develops in persons suffering from them.
- These diseases are **non-infectious** as these do not spread from infected persons to healthy one.
- **On the basis of their causative agent** non-communicable diseases are of the following types – **deficiency**, **degenerative**, **cancerous** and **allergy**.
- **Deficiency diseases** occur due to absence of those factors which are important in body growth and development.
- These are of two types - **hormonal** and **nutritional**.
- **Hormonal diseases** occur due to hypoactivity or damage to endocrine gland, e.g. *diabetes insipidus* caused due to hyposecretion of vasopressin secreted by posterior lobe of pituitary gland and *diabetes mellitus* caused by hyposecretion of insulin secreted by pancreas.
- **Nutritional deficiency** diseases are kwashiorkar (protein deficiency) and pellagra (vitamin B_5-niacin deficiency).
- **Degenerative diseases** occur due to degenerative changes in some vital organs of the body. These are of following types – like cardiovascular disease, brain disease and arthritis.
- **Allergies** are caused when the body which has become hypersensitive to certain foreign substance, comes in contact with that substance. Hay fever is an allergic disease.

Cardiovasular diseases

- **Cardiovascular diseases** are degenerative diseases of heart and blood vessels of the body.
- **Heart diseases** are the most common cause of deaths in human beings in the present century.

- **Arteriosclerosis** is the **most common type of cardiovascular disease**.
- It occurs in elderly person whereby the arteries thicken and lose their elasticity due to hardening and thickening of fibrous tissue which lead to **hypertension causing cerebral or visceral haemorrhage**.
- **Atherosclerosis** is narrowing of arteries and arterioles due to insolubilisation and deposition of cholesterol inside and over the intima.
- Enzyme **paraoxonase** present in blood **checks cholesterol deposition**.
- **Rheumatoid heart disease** (RHD) is caused by the toxins produced due to repeated attack of rheumatic fever (due to *Streptococcal* infection of throat).
- RHD is **characterised by** damaged heart walls, heart muscles, scarring and malfunctioning of heart valves especially **atrio-ventricular** one.
- **Hypertensive heart disease** are caused by increased blood pressure (continuous hypertension) which may lead to heart attack.
- **Hypertension** and **hypotension** is characterised by persistent high and low blood pressure respectively.
- Main **cause of hypertension** is obesity, arteriosclerosis, mental and emotional stress etc resulting in nephritis, stroke etc.
- **Heart attack** is failure in working of heart due to valvular obstruction or degeneration, blood insufficiency or myocardial infarction.
- It involves the **irregular pulse**, **pain in chest** in the area of heart, **murmur**, **constant high/low blood pressure** etc.
- **Myocardial infarction** is necrosis or death of a part of myocardial tissue/middle layer of heart wall, due to reduced blood supply.
- **Coronary heart disease** are characterised by impaired heart function due to reduced blood flow to the heart.
- Blood flow may be reduced to heart due to **hardening and narrowing of coronary arteries** and **coronary thrombosis**.
- **Thrombosis** is the appearance of blood clot causing vascular obstruction at the point of its formation.
- Thrombosis occur in coronary arteries is called **coronary thrombosis** & if it occurs in brain, it is called **cerebral thrombosis**.
- **Coronary thrombosis** is occulsion of coronary vessel by a clot of blood, stoppage of blood supply, causing cardiac tissue necrosis leading to heart attack.
- Anticoagulant drugs like TPA **(tissue plasminogen activator)** and **streptokinase** are effective if given within 4 hours of attack. Disprin is also used on regular bases.
- **Angina pectoris** is a severe temporary cardiac pain due to decreased blood supply at the time of stress.
- The pain arise as a result of cramp may spread out from the centre of the chest to the neck, jaws, arms (especially left) & back.
- Angina **occurs when heart needs more blood**.
- Vasodilator drugs like **nitroglycerin** are effective to give immediate relief from angina pain.
- Heart disease and heart attacks **can be reduced by taking low cholesterol diet**, **avoiding smoking**, **alcohol**, **becoming obese**, **overwork, tension free work** etc.
- **Arrhythmia** is **irregular heart beat** due to atrial fibrillation, atrial flutter, heart block etc.
- **Atrial fibrillition** means **rapid random atrial contraction causing irregular ventricular beats**.
- **Atrial flutter's** is **regular rapid contraction** but submultiple ventricular contraction. Atrial rate is 200-300/min.
- In flutter (as compared) to fibrillation the frequency of irregular heart beat is much higher **(about 300-500 per min)** and is more difficult to treat and hence more dangerous.
- **Varicose vein** are unusually distended vein which **develops due to excessive stretching and inflammation of vein wall**. The causes for this conditions are **heredity, obesity, excessive sitting, standing** etc.

Stroke

- Stroke [cerebrovascular (brain blood vessel) accident or CVA] is the **most common degenerative disease in man**.
- Stroke is a **brain damage** due to stoppage of blood supply resulting from cerebral thrombosis, cerebral haemorrhage, cerebral embolism and sustained contraction or spasm of an artery.
- **Cerebral haemorrhage** is rupturing of an artery due to weakening of its wall & hypertension (high blood pressure).

- **Embolism** is the sudden blocking of an artery by a clot or foreign materials like air, fat etc. which has been brought by the blood from another vessels & forced into a smaller one.
- Stroke is **characterised by degeneration of motor neurons of brain** due to reduced supply of oxygen resulting in paralytic attack of some body part especially limb, loss of memory, speech, hearing and even death.

Arthritis

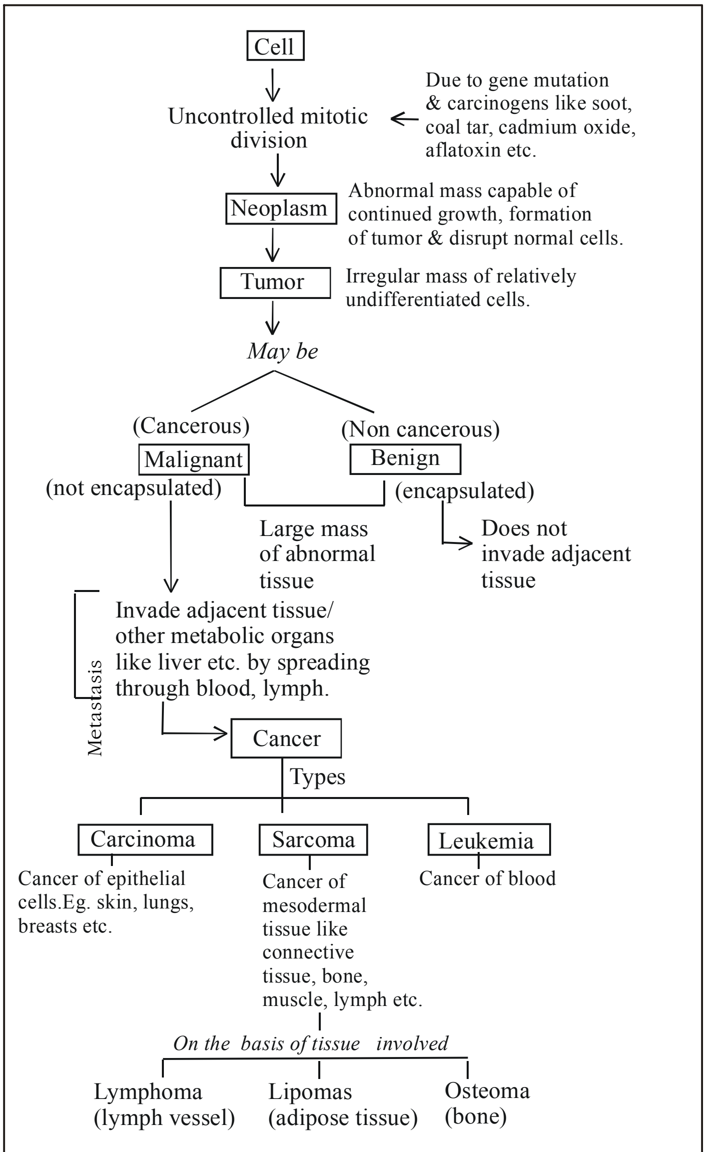
- Arthritis is a **common disease of** old age in which inflammation of the joints occurs.
- Arthritis is of several types **- rheumatoid arthritis**, **osteroarthritis** and **gout**.
- **Rheumatoid arthritis** generally attack woman (between 20-40 years).
- It generally involves the chronic **painful inflammation of the synovial membrane of the joints** resulting in stiffening of joint and painful movements. In severe cases, it eventually results in crippling deformalities.
- Rheumatoid arthritis is **believed to be caused by bacterial infection** that provides an antibody called **rheumatoid factor** or **macro-gammaglobulin**.
- **Osteoarthritis** is **degenerative arthritis** where **secretion of synovial fluid decreases** and bone head develops excrescences (bony/fibrous extensions) that limit movements causing joint fixation (**ankylosis**).
- It is **common in old persons**, mainly affecting weight bearing joints.
- **Gout** is a diet related disease. Person suffering from gout should avoid meat which are a rich source of nucleic acids including purines.
- Gout is an **inherited disorder of purine metabolism**, occurring especially in men.
- Gout develops when **no uric acid is excreted** from the body.
- It occurs due to **accumulation of uric acid crystals in the synovial joints**. (especially joint of great toe).
- It is **characterised by** sudden acute pain especially in **great toe** accompanied by swelling, chill, fever, headache, tachycardia.

Cancer

- A group of diseases characterised by uncontrolled mitotic division of cells having ability to invade other tissues or parts of body is called **cancer**.
- Cancer is **not a contagious disease**.
- Cancerous cells have **high invasiveness** (ability to rapidly grow, infiltrate into blood vessels and subsequently spread to other parts of the body especially to metabolic organs like liver).
- **Neoplasm** (also called **tumor**) is a new abnormal tissue which is capable of continued growth, formation of tumor and disruption of normal cells.
- All tumors are **not cancerous**.
- **Tumors** may be **benign** and **malignant**.
- **Benign tumor** is a large localised mass of abnormal tissue enclosed in connective tissue which does not invade adjacent tissue.
- **Malignant tumor** is not encapsulated and is capable of invading adjacent tissues and distant sites.
- **Metastasis** is a spread of cancerous cells from one part of the body to other part through blood, lymph and secondary form of malignant tumor.
- **Symptoms of cancer** are –
  - Thickening or lump in the breast or any other part of the body
  - Changes in bowel or bladder habits
  - Obvious change in a wart or mole
  - A sore that does not heal
  - Nagging cough or hoarseness
  - Indigestion or difficulty in swallowing
  - Unexplained changes in weight
  - Unusual bleeding or discharged.
- Types of cancers are **carcinoma**, **sarcoma**, **leukemia** and **lymphoma**.
- **Carcinoma** is a **cancer of epithelial tissue** and their derivatives like mucous membrane, skin, lungs, breast etc.
- **Sarcoma** is a **cancer of primitive mesodermal tissue** like connective tissue, bone, muscle, lymph nodes etc.
- Depending upon the tissue involved, sarcoma is of **following type** –
  - *Fibrosarcoma* – fibrous connective tissue
  - *Liposarcoma* – adipose tissue
  - *Chondrosarcoma* – cartilage cells
  - *Osteosarcoma* – bone
  - *Leiomyosarcoma* – smooth muscles
  - *Rhabdomyosarcoma* – stripped muscles
- Ewing sarcoma (family of tumors) and Kaposi's sarcoma are the **common types of sarcomas**.
- **Leukemia** is a **blood cancer**. It involves the

increased WBC count (200,000-1000,000/mm^3) of blood due to increased formation in the blood marrow **resulting in decreased erythropoiesis and RBC count**.

- In **myelocytic leukemia** (9th and 22nd chromosomes bring their jumping genes together) erythroblastic tissue of bone marrow degenerates followed by bleeding at different places with enlarged tonsils and cervical glands.
- **Vincristin** and **vinblastin drugs** obtained from *Catharanthus rosesus* are effective in controlling leukemia.
- **Bone marrow grafting** is **used for the treatment of leukemia**.
- **Lymphomas** affect the lymphatic system, a network of vessels and nodes that acts the body's filter.
- **Proto-oncogenes** are inactive cancer genes.
- **Oncogenes** (active forms of proto-oncogenes) are **cancer causing genes**.
- **Carcinogens** are factors or physical or chemical agents which induces the cancer growth, e.g. coal tar, asbestos, cadmium oxide, aflatoxin etc.
- **Anticarcinogens** occurring in green yellow vegetables, fruits and milk **prevent the action of carcinogens**.
- **Some viruses, parasites and excessive secretion of hormones** are believed to produce cancer. Eg.- cervix cancer is caused by virus.
- The **carcinogens are of following three types** –
  – Agents causing alterations in the genetic material (*DNA*), resulting in oncogenic transformation, e.g., radiations and certain chemicals.
  – Tumor promoters that promote proliferation of cells, which have already undergone genetic alterations, e.g., some growth factors and hormones.
  – Cancer causing DNA and RNA viruses (*tumor viruses*).



Flow chart : Cancer at a glance

- **Cancer-associated genes** can be **divided into the following three categories** –
  – Genes that induce cellular proliferation, e.g., genes encoding growth factors, growth factor receptors, transcription factors etc.
  – Genes that inhibit cellular proliferation (*tumor suppressor cells*).
  – Genes that regulate programmed cell death **(apoptosis)**.

- **Apoptosis**, referred to as programmed cell death is another intricate piece of the cell cycle. Apoptosis is a distinct form of death that is a programmed event and occurs in response to certain stimuli. Apoptosis is essential for normal tissue development. In addition, this system allows cells to self-destruct after detecting DNA damage rather than perpetuating mutations that might be lethal to the whole organism.
- **Examples of tumor supressor genes** are –
  - **Wilms Tumor** – Involved in Wilms tumor of the kidneys (nephroblastoma). Appears to shut down division of a small subset of kidney cells during development.
  - **BRCA1** - Inheritable **breast cancer** (5%) & **ovarian cancer**. Codes for a protein that binds strongly to DNA, inhibiting an enzyme involved in DNA breakage.
  - **p53**; a transcription factor that blocks entry into S phase if there is DNA damage. If there is too much damage to repair, it causes apoptosis.
- **Other cancer genes** includes –
  - *Telomerase* : Activation of telomerase is necessary for immortality
  - *Angiogensis genes* : Tumors need to promote the growth of new blood vessels to support their growth
  - *Metastasis genes* : Proteinases to cut through the extracellular matrix, etc.
- **Cancer of stomach** is the **most common cancer in both male & female human beings**.

Table : Some cancer-causing agents and their targets

Carcinogen	Target tissue
Soot	Skin and lungs
Coal tar (3, 4-benzopyrene)	Skin and lungs
Cigarette smoke (N-nitrosodimethylene)	Lungs
Cadmium oxide	Prostate gland
Aflatoxin (a mold metabolite)	Liver
Mustard gas	Lungs
Nickel and chromium compounds	Lungs
Asbestos	Lungs
Diethylstibestrol (DES)	Vagina
Vinylchloride	Liver

- The most common cancers in India are **mouth-throat cancer in men** and **uterine-cervical cancer in women**.
- Cancer can be diagnosed by **biopsy of tissue**, **endoscopy** (gastroscope for stomach and laproscope for pelvic region), **X-rays, ultrasound**.
- Therapy used in the treatment of cancer are **radiotherapy**, **chemotherapy** and **hormonal therapy**.
- In **radiotherapy** cancerous parts of body is exposed to radioactive isotopes.
- The biological effect of radiation **depends on the amount of energy absorbed per unit mass**.
- **Chemotherapy** involves the use of chemicals/drugs which are more toxic to cancer cells than normal cells.
- Chemotherapy have **many side effects** like vomiting, nausea, loss of hair, shortness of breath, constantly tired, feeling anxious or tense, loss of weight etc.
- **Taxol** is anticancer drug obtained from *Taxus baccata.*
- In **hormonal therapy** hormone causing cancer is treated with another hormone which neutralizes the carcinogenic hormone. Eg.- breast cancer can be controlled by testosterone.
- The **major advantage of hormonal therapy over chemotherapy** is the **less severe side effects** than those associated with cytotoxic drugs.
- **Pap's test** is originally developed to detect the cancer of cervix and **barium test** is performed for alimentary canal.
- **Ames test** is a routine screening test developed by Bruce Ames **to know the mutagenicity and carcinogenic nature of substance**.
- Most cancers are treated by combination of surgery, drugs & radiation therapy.

Occupational diseases

- Occupational diseases arises among those people who are exposed to air pollutants generated from the industries where they are working.
- **Types of occupational disease** are: asbestosis, silicosis, byssinosis, bagassosis, anthracosis.
- **Asbestosis** is characterised by pulmonary fibrosis leading to respiratory unsufficiency & death, carcinoma of bronchus & gastro-intestinal tract etc.
- **Silicosis** is characterised by dense nodular fibrosis, impart of total living component etc.

- **Byssinosis** is characterised by chronic cough, progressive dyspnoea, ending in chronic bronchitis & emphysema.
- **Bagassosis** is characterised by breathlessness, cough, haemoptysis & slight fever.
- **Anthracosis** is characterised with little ventilatory impairment, progressive massive fibrosis causes severe respiratory disability & results in premature death.
- All these diseases are caused by dust, called **pneumoconiosis**.
- Pneumoconiosis may gradually cripple a man by reducing his working capacity due to lung fibrosis and other complication.
- Oxides of sulphur & its hydrates, H_2SO_4 in moderate concentration cause suffocation & irritation in the upper respiratory tract & continuous exposure causes lung diseases like chronic asthma, bronchitis etc.
- Carbon dioxide causes headache, dizziness, palpitation, tickering before eyes & finally it may lead to collapse, unconsciousness & even death.

Some other Animal Diseases

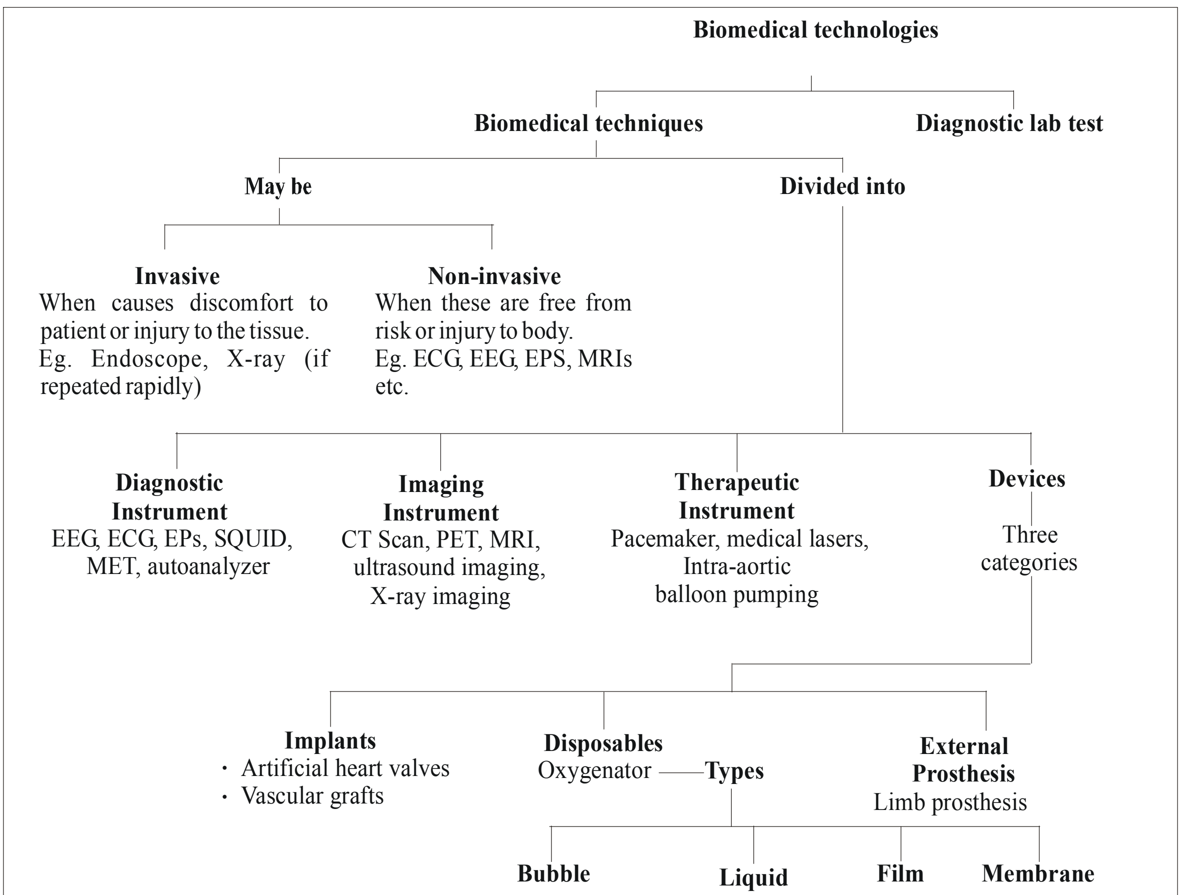
- **Rinderpest**
  Rinderpest is an acute, usually fatal, contagious viral disease principally of cattle. The disease affects the gastrointestinal and respiratory systems. It is a devastating disease of cattle and some wild artiodactyls (African buffalo, giraffe, eland and kudu) with death rates during outbreaks approaching 100%. Rinderpest is caused by a virus (a single stranded RNA virus), belonging to the family paramyxoviridae, genus morbilli virus. Virus is found in expired air, eye and nose discharges, saliva, faeces, urine and milk. Transmission is mainly through aerosols. Rinderpest virus is a relatively fragile virus. Sunlight is lethal, and the vaccine must therefore be kept in a brown bottle and protected from light; virus in a thin layer of blood is inactivated in 2 hours. Moderate relative humidity inactivates the virus more quickly than either high or low humidity. The virus is very sensitive to heat, and both lyophilised and reconstituted virus should therefore be kept cold; lyophilized virus stored at –20°C is viable for years. Rinderpest virus is rapidly inactivated at pH 2 and 12 (10 minutes); optimal for survival is a pH of 6.5 - 7. The virus is inactivated by glycerol and lipid solvents.
- **Foot and mouth disease**
  Foot and mouth disease (FMD) is an acute, highly contagious *picornavirus* infection of cloven animals (pigs, sheep, cattle, goats, deer etc). The virus (FMDV) is sensitive to environmental influences, such as pH less than 5, sunlight and dessication, however it can survive for long period of time at freezing temperatures. The disease is highly contagious and may spread over great distances with movement of infected or contaminated animals, products, objects and people. It causes vesicles or blisters on the feet and in the mouth and on the nose. The animals become sick (fever, loss of appetite, salivation, depression and young animals can die) and lose productivity.
- **Cowpox**
  Cowpox is a contagious viral disease of cows and is mild form of smallpox. Cowpox virus is related to the virus of smallpox. Also called variola, it is characterised by pustular lesions on the teats and udder. Cowpox is transmitted by contact, inducing a mild infection of the hands in persons who milked infected cows
- **Coccidiosis**
  Coccidiosis is an infection caused by a protozoan (one-celled organism) called coccidia. Unlike most reptile endoparasites (those that live inside the host), coccidia are not worms; but live in the actual cells of the intestine walls. A bad infestation of coccidia can cause diarrhoea and for this reason may be mistakenly identified as a worm problem.
- **Tick Fever**
  Tick Fever is an illness caused by a virus carried by small mammals, such as ground squirrels, porcupines, and chipmunks, and by ticks. Tick fever (babesiosis) is an important disease of cattle. The disease was probably introduced as early as 1829 with cattle from Indonesia infested with the cattle tick *Boophilus microplus*.Babesiosis is caused by two organisms : Babesia bovis and *Babesia bigemina*. Of the two species, *B bovis* is by far the most important, causing about 80 per cent of outbreaks and an even higher percentage of deaths. Both Babesia species are single cell organisms that develop in the red blood cells of cattle and are transmitted in Australia by the cattle tick *Boophilus microplus*. Transmission of *B bovis* takes place when engorging adult female ticks pick up the infection, pass it on to their progeny (larval or seed ticks) which, in turn, pass it on when feeding on another animal. Transmission of *B bigemina* is also from one generation of ticks to the next but with engorging adult ticks picking up the infection and nymphal and adult stages of the next generation passing it on to other cattle.

End of the Chapter

Chapter 73

Biomedical Technologies

- Biomedical technology **involves the application of engineering and technology principles** to the domain of living or biological systems.
- Usually biomedical denotes a greater stress on problems related to human health and diseases.
- Biomedical engineering combined with biotechnology is often called **biomedical technology or bioengineering**.
- Examples of concrete applications of biomedical engineering are the development and manufacture of biocompatible prosthesis, medical devices, diagnostic devices and imaging equipment such as MRIs and EEGs, and pharmaceutical drugs.
- With the advancement in the field of science and technology a number of new techniques and sophisticated instruments have come to help in accurate diagnosis of diseases.
- Techniques and instruments which are **free from**



risk of injury to body are called **noninvasive**, eg. ECG, EEG etc.

- Instruments which **causes discomfort to the patient** are called **invasive**, eg. endoscope etc.

DIVISION OF BIOMEDICAL TECHNIQUES

- Biomedical techniques are divided into **diagnostic instruments**, **imaging instruments**, **therapeutic instruments** and **devices**.

Diagnostic instruments

Electroencephalogram (EEG)

- **Electroencephalograph** is an electricity operated instrument having electrodes which when attached to scalp gives information about the electric waves emanating from different parts of brain.
- **Electroencephalogram** is recording of electrical potentials originating from different parts of the brain in the form of waves.
- The electrical activity of the exposed animal brain was discovered by **Satton** in 1875.
- This device is used to assess brain damage, epilepsy and other problems. EEG can also be used in conjunction with other type of brain imaging.
- This test is only one part of the investigation into diagnosing epilepsy. Further information on how epilepsy is diagnosed can be obtained through epilepsy action.
- Neuroscientists and biological psychiatrists use EEGs to study the function of the brain by recording brain waves during controlled behaviour of human volunteers and animals in lab experiments. Theories to explain sleep often rely on EEG patterns recorded during sleep sessions.
- Historically **four major types of brainwaves** are recognized – alpha, beta, delta and theta.
- **Alpha is the frequency range from 8.5 Hz to 12 Hz**. It's often **associated with an alert adult and is present by the age of two years**. Alpha rhythms are **best seen with the eyes closed**. It attenuates with drowsiness and eyes open.
- **Beta** is the frequency range above 12 Hz. It's often **associated with active, busy or anxious thinking and active concentration**. It is a smaller and faster wave.
- **Theta** is the frequency range from 4.5 Hz to 8 Hz and is **associated with drowsiness, childhood, adolescence and young adulthood**. Theta can also be produced by hyperventilation in people without it being an abnormal phenomena.
- **Delta** is the frequency range up to 4 Hz and is often **associated with the very young and certain encephalopathies and underlying lesions**. It is **seen in sleep**, but generally is associated with other frequencies to become waveforms such as vertex sharp waves.
- Delta waves **indicates brain disorders**.
- **Significance of EEG**
  - EEG is used to diagnose epilepsy and other seizure disorders. In epilepsy abnormal discharges of certain neurons cause excessive electrical activity that interferes with the normal functioning of brain. EEG helps to detect and locate the specific regions.
  - EEG is used to study normal brain activity as well as to diagnose brain infections, metabolic and drug effects, sleep disorders, degenerative diseases, hematoma, trauma, brain tumors, drug induced hypothermic necrotic and periods of unconsciousness and confusion.
  - EEG is used to determine the brain death also. When there is complete absence of brain waves in two EEGs taken 24 hours apart, it is considered as brain death.

Evoked potentials

- Evoked potentials (EPs) is a measure of the brains electrical activity in response to sensory stimuli.
- EPs is obtained by placing electrodes on the surface of the scalp, repeatedly administering a stimulus and then using a computer to average the results.
- It is a diagnostic tool **used to evaluate the function of the central nervous system**.
- An evoked potential is **also known as an evoked response**.
- An evoked potential test measures the electrical signals sent by the brain when nerves are stimulated. These are called **evoked responses**.
- The most common types of evoked potential tests are visual, auditory (hearing), and somatosensory, which refers to the pathway of nerve impulses between the limbs and the brain.
- Evoked potential tests can be **used to diagnose diseases of the nervous system**, such as multiple sclerosis, that affect the patient's response time

because of damage to the nerves. They are also used to diagnose hearing loss, vision loss caused by optic nerve damage, and to test brain response in infants and abnormal electrical discharges in people with epilepsy.

Electrocardiogram

- **Electrocardiograph (ECG)** is a non-invasive instrument employed to **record myoelectrical changes during cardiac cycle**.
- **Electrocardiogram** is the **recording of electrical potential produced during cardiac cycle** from initiation and spread of cardiac impulse from SA node to AV node.
- The waves produced in ECG are known as P, Q, R, S and T.
  - **P wave** : Represents **depolarization of the atria**.
  - **PR interval** : Interval from first atrial depolarization to the beginning of the Q wave. It decreases when heart rate increases and *vice versa*. A longer PR interval may indicate that conduction velocity through the AV node is slowed (e.g., heart block).
  - **QRS** : **Represents depolarization of the ventricles**. Note that there is no wave that represents repolarization of the atria; atrial repolarization is masked by the large QRS complex.
  - **QT interval** : QT interval is measured from the beginning of the Q wave to the end of the T wave. It **represents the entire period of depolarization and repolarization of the ventricles**.
  - **ST segment** : This is the segment from the end of the S wave to the beginning of the T wave. It **represents the period when the entire ventricles are depolarized**.
  - **T** : Represents repolarization of the ventricles.
- This method **causes no discomfort to a patient** and is often **used for diagnosing heart disorders** such as coronary heart disease, pericarditis or inflammation of the membrane around the heart, cardiomyopathy or heart muscle disease, arrhythmia (heart rhythm problems), changes in the electrical activity of the heart caused by an electrolyte imbalance in the body and coronary thrombosis.
- The electrocardiography is a **painless and quick procedure**.
- **Einthoven** is **father of electrocardiography**.
- **Echocardiography** is sonographic (ultrasound) imaging of heart, great vessels like aorta, heart valves, heart wall etc. to know any abnormality. It is also used to record blood flow velocity and blood turbulence.
- **Multi-channel monitor** measure and display the ECG, blood pressures in various heart chambers and other physiological data.
- **Doppler echocardiography** is a technique which allows the indirect measurement of the flow of velocity as it passes through the heart.
- **Vector-cardiography** is employed for **analysis of Q wave** and **intra-ventricular conduction abnormalities**.

SQUID and Autoanalyser

- **SQUID** is super-conducting quantum interference device, e.g. magnetoencephalograph.
- SQUID and MET (magnetoencephalographic technique) **give information about the health of various parts of the brain**.
- **Autoanalyser** is a fully automatic, computerised instrument which can **analyse qualitatively and quantitatively various biochemicals present in body fluids** like urea, uric acid, ketones, cholesterol, glucose, proteins, enzymes etc.

> The abbreviation EMG is for **electromyogram**, a recording of electrical activity in muscle. In case of nerve injury, with the help of EMG the actual site of nerve damage can often be located.

Imaging instruments

Ultrasound imaging or sonography

- Sonography is a noninasive technique which **uses ultrasound for producing images of internal body parts**.
- Ultrasound is **sound beyond human hearing power or above 20,000 Hz or 20 kHz**.
- Diagnostic ultrasound used in sonography has a frequency of **1 – 15 MHz** (MHz = 1 million oscillations/sec).
- Ultrasound is produced through **piezoelectric effect**. It is based on the principle when an electric potential is applied to crystals of lead zirconate, they get excited and start vibrating. These vibrations are the source of the production of ultrasound.
- Sonography is **also known as ecography**. The visual record is known as **echogram or sonogram**.

- Ultrasound **has wide applications in medicine and is especially useful in obstetrics**.
- In obstetrics it is **used to the study the age, sex and level of development of the foetus and to determine the presence of birth defects or other potential problems**.
- **Sex determination of foetus** by sonography is now banned under prenatal diagnostic techniques act, 1994.
- **Doppler ultrasound scanning** is used in scanning blood flow in vessels, blood clots and heart abnormalities.

X-ray imaging

- X-rays are **highly penetrating electromagnetic radiation of extremely short wavelengths or high frequency** (*i.e.* high energy). It is because of their high energy, X-rays can penetrate through many objects.
- When a beam of X-rays is directed at a part of the body such as chest, the rays are absorbed more by dense structures such as the ribs or heart muscles than by less dense structures such as the skin or lungs.
- X-ray imaging is **commonly employed for diagnosing diseases of the heart, lungs and detection of bone and joint injuries**.
- X-ray imaging is the oldest and perhaps also the most common medical imaging method which began with the accidental discovery of X-ray by **William Kornad Roentgen**, a German Physicist in 1895.
- The branch of science that deals with the study of X-rays for detection and treatment of diseases is called **radiology**.
- However there are differences in penetration through different materials due to the differences in the material densities. For example, X-rays can penetrate through fat/muscle/soft tissues of the body easier than through bone, which is the basis for imaging the body with X-rays. X-ray imaging is usually applied in detecting bone factures and dislocations.
- The X-ray imaging technique **has some drawbacks**, *e.g.*, the plain X-ray images fail to differentiate soft tissues and superimpose a number of structures from front to back on the image. Moreover, the images are not sharp to study the internal organs in detail. X-ray imaging is potentially harmful specially when the body is repeatedly exposed to it. Therefore, this technique is **invasive**.
- The introduction of contrast X-ray imaging techniques increases the usefulness of X-rays.
- Most commonly used contrast X-ray techniques are **urography**, **barium X-ray examinations** and **angiography**.
- **Urography** is performed to obtain X-ray pictures of the urinary system.
- **Barium X-ray examination** is useful to investigate the digestive tract.

CT-scanning

- CT scanning (**Computerised / Computed Tomographic Scanning**) is an invasive radiographic technique which passes short X-rays through the patient's body.
- **CAT** (Computerised axial tomography) scanner is specialised radiological technique (X-ray) for **study of various parts inside the skull**.
- Now **CAT** is **replaced by CT scanning**.
- CT scanning employs **more than 30,000**, **2 - 4 mm beams of X-rays** falling into different horizontal planes and the images picked up by special X-ray detectors.
- It uses **low level of radiations** so that radiation damage is little.
- The technique is **useful in diagnosis of disorders in any body part like abdomen, chest, spinal cord, brain, tumors, oedema etc**. It is **commonly used to investigate the brain following a stroke**.
- CT scan is **advantageous than simple X-rays studies** as it provides more detailed information. CT scan uses X-rays but the images are stored in a computer. The computer is used for constructing the 3 - d images instead of directly recording them on a photographic paper as in X-rays.
- CT was **first developed by** a scientist **Godfey Hounsfield in 1968 who got a Nobel prize in 1979**.

PET

- PET (**Positron Emission Tomography or Positron Emission Tomographic Scanning**) is a diagnostic technique **based on detection of positrons** (positively charged electrons) **emitted by radio isotopes** such as ^{11}C, ^{13}N, ^{15}O and ^{18}F generated by the **cyclotron**.
- These radio isotopes are then incorporated by chemical

methods into biological molecules such as glucose, amino acids, carbon dioxide and ammonia and then injected in very small amounts into or inhaled by the experimental animals or human subjects.

- These positron emitting compounds are injected into the blood-stream and are taken up in greater concentration by areas of tissues that are more metabolically active.
- Specific centres in brain, like colour processing in visual cortex of humans can be detected by PET.
- PET is **useful in measuring**
  - Metabolic rates
  - Regional blood volume and blood flow
  - Area of abnormalities like disease and defects
  - Identification of specific centres in brain like colour processing in visual cortex of humans.
- PET scanning **provides three-dimensional images** that reflect the metabolic and chemical activity of tissues being studied.
- PET scanning is **used for detecting tumors**, for locating the origin of epileptic activity within brain and for examining brain function in various mental illnesses. It is **used to study epilepsy, schizophrenia, Parkinson's disease and drug addiction**.
- PET scanning was developed by Louis Soko Loff of USA in 1985.

MRI

- MRI (**Magnetic Resonance Imaging**) is a non-invasive technique which **uses strong magnetic field for generating resonance and low radio frequency in protons present in the body**.
- The **most common protons are ^{1}H nuclei of water molecules** that form 70 – 80% of body.
- Nuclei of carbon, phosphorus and sodium can also produce magnetic resonance.
- MRI **detects water** because it focuses on the behaviour of hydrogen atoms in water molecules. This allows MRI to distinguish between water poor and water rich tissues. Therefore, tissues surrounded by bones (*water poor*), such as spinal cord (*water rich*) are readily observable in MRI.
- MRI is used to detect tiny lesions of multiple sclerosis on brain and spinal tissue, joint injuries, slipped disc in the spinal column and minute cancerous tumors.
- MRI can map internal tissues, highlight pathological changes and study tissue metabolism with the help of spectroscopy.
- MRI is **superior to CT and PET** because (i) No ionising radiations are employed. (ii) MRI **gives 2- and 3- dimensional pictures**. (iii) Images can be obtained from any plane instead of only cross-sectional area. (iv) Study of tissue metabolism (PET gives information of regional metabolism rate, CT only static anatomic images), brain and heart functions. (v) It gives a better contrast of soft tissues. (vi) MRI can be used to study blood flow. (vii) It provides better information about infections, cancers and tumors.
- However, **MRI cannot be used in patients fitted with pacemakers and metal implants**.
- **Functional magnetic resonance imaging (fMRI)** is used to visualize brain function, by visualizing changes in chemical composition of brain areas or changes in the flow of fluids that occur over timespans of seconds to minutes.
- Patients with **internal ferromagnetic (metallic iron) devices** such as a pacemaker, metal cardiac valve or metal in the area of the examination **cannot be scanned**. The powerful **MRI magnets** would interfere with these metal devices. **In this patient CT scan is performed**.
- Medical use of MRI was first reported by **Raymond Damadian**.

NMR

- NMR (**Nuclear Magnetic Resonance Imaging**) was **first discovered by Purcell and Bloch** working independently in 1952.
- The **basis of this technique** is that the magnetic resonance generated by the nuclei of hydrogen atoms is subjected to an external magnetic field. (The hydrogen atoms are present in abundance in all the biological tissues).
- The external strong magnetic fields required for NMR are obtained by using either large water cooled resistive magnets or superconductive magnets using liquid helium.
- The imaging NMR technique is **superior to CT-scanning technique** in two ways –
  - It does not use iodised radiations and so free from all hazards
  - It can obtain images in any plane unlike CT-scanning which is more or less restricted to cross-sectional imaging.
- NMR-technique is also **useful in the study of tissue metabolism by spectroscopy**. Instead of using

hydrogen nuclei, other nuclei of carbon, phosphorus and sodium can also be used to understand metabolic activities at the tissue level.

Endoscopy

Endoscopy is a technique which enables a doctor to view directly and/or indirectly the body parts like bronchus, stomach, colon, urinary bladder etc. Using an endoscope a surgeon is able to carry out minor operations without cutting through overlying tissues.

Endoscopes are named after the part of the body they are designed to view. For instance a **gastroscope** is used to examine the stomach for an ulcer, a **laparoscope** to detect cysts or infections of uterus, fallopian tube and ovaries, and so on.

Therapeutic instruments

Pacemaker

- Pace maker is an electric device, first developed by **Greatbach** and **Chardack** (1960).
- A pacemaker has a **pulse generator** having long lasting lithium halide cells.
- It is a device implanted in the heart of patients so that the heart beat is generated by them. Therefore, its function is to pace the heart on a long term basis.
- Pacemaker is used when the heart beat drops to about 30 to 40 per minute due to any reason. So it is a life saving device.
- Pacemaker may be of **various types** - external pacemaker (worn on belt), epicardial pacemaker, endocardial pacemaker, permanent pacemaker etc.
- Anyone fitted with a pacemaker **should avoid powerful radio or radar transmitters and should not pass through security screens at airports**.
- An **artificial pacemaker** (introduced by Chardack, 1960) is implanted when a person's **sinu-atrial node** is not functioning properly.
- Demand pacemaker discharges impulses only when the heart-rate slows or a beat is missed. A normal heart-rate and beat suppresses the pacemaker.

Medical lasers

- Laser is a beam of very high energy particles.
- Laser is an acronym for **light amplification by stimulated emission of radiation**.
- Lasers are also **used for** sealing of bleeding arteries in peptic ulcers, the destruction of abnormal cells in various parts of the body such as the cervix and treatment of endometriosis.
- **Gall bladder stone** and **kidney stones** can be treated (by making it into fine powder) **by using laser**.
- Laser is also used in breaking of chromosomes at specific points for genetic engineering.
- Depending upon the source of elements or compound used, different types of lasers can be generated like arson laser, neon laser and carbon dioxide laser.
- By using a technique called **laser photo bleaching technique**, the fate of a hormone bound to the specific receptor on the cell surface can be known.

Intra-aortic balloon pump

- Intra-aortic is **meant for improving blood supply to heart walls and other organs**.
- A small balloon is positioned in the descending thoracic aorta. It is connected to an external machine which can inflate (with helium) and deflate it rhythmically.
- The intra-aortic balloon is **inflated during diastole or relaxation phase of ventricle**. This pushes some blood into coronary arteries. The balloon is **deflated during systole**. The process is continued for hours/days till normal functioning of the organ is restored.

Angioplasty

- Angioplasty is a technique of opening a blocked coronary artery through **ballooning**. The process is called **percutaneous transluminal coronary angioplasty** (PTCA).
- Coronary artery-bypass surgery (CAS) is resorted to when the main left coronary artery or three-vessel coronary artery is blocked.
- **PTCA** was **first applied by Gruentzigin in 1977**.
- PTCA literally means repairing of the coronary artery (coronary angioplasty) by passing a catheter through the skin (percutaneous) and reaching the coronary artery *via* the lumen of the intervening arteries (transluminal).
- A deflated dilation catheter and a guiding catheter are advanced over a guide wire into the blocked segment of coronary artery.
- The balloon is inflated with several atmospheres of pressure for 30-40 sec for two or more times till the blockage is removed. The same is confirmed through coronary angiography.

- **Angiography** is special X-ray procedure that takes pictures of blood vessels. It is usually done by inserting a catheter into an artery or vein in groin. It is radiography in which a radio-opaque contrast medium or fluoroscopic chemical is passed through catheter into the various parts of the heart to study health of walls, valves, atria, ventricles, coronary arteries, etc.
- For study of coronary arteries (coronary angiography), the chemical is injected directly into each coronary artery orifice and filming the progress of chemical 30-60 times per second.

Devices

Implants

- Implants are devices used for replacing a diseased organs or tissue within the body.
- **Artificial heart valves may be** either **mechanical** or **made of human or animal tissues**.
- **Mechanical valves** are made of special biocompatible plastics, metal alloys and ceramics, having ball/disc occluder. Mechanical valves develop tendency of blood coagulation. Hence, blood anticoagulants are required.
- **Tissue valves** are obtained directly from pigs, cadavers, (corpses) or made from pericardium of animals. The valves have the tendency to calcify with time, especially in young.
- **Artificial arteries** or **vascular grafts** are pliable tubes generally **made of fibrous plastic of dacron** (terylene) **or teflon** (polytetra fluoro ethylene).

Disposables

- Disposables are **devices used only once and then thrown away. They prevent spread of diseases from one person to another**. It includes syringes, needle, blood bags, oxygenators, blood dialysers etc.
- **Blood bag** is **used in storing blood**, **separation of components** (through centrifugation) and **transfusion of blood**.
- Disposable blood bags **decrease chances of spreading diseases**. Substitute of blood is also being found. Perfluorocarbon can function as artificial blood.
- **Oxygenator** is used in open-heart surgery to oxygenate the blood passing through the heart-lung machine.
- The first open heart surgery was performed in 1953 by the use of the technique called "heart-lung bypass". In this technique, the heart and lung of the patient are bypassed and their vital functions' *i.e.,* circulation and respiration are carried out by a "heart-lung machine". The function of the heart is carried out by a roller-pump and the oxygenation of blood is done by an "oxygenator".
- Oxygenator can be called as an **artificial lung**.
- **Common types** of oxygenators are **bubble oxygenator**, **film oxygenator**, **membrane oxygenator** and **liquid liquid oxygenator**.
- **Bubble oxygenators** are used for short term operations whereas **membrane oxygenators** are more suitable but damages RBCs in long term operation for longer operations and for operation of infants.
- The main function of kidney in the body is to remove the metabolic wastes from the body in the form of urine. If, due to some reasons, kidneys do not function properly then the metabolic wastes are to be eliminated from the body by artificial means. This is known as **blood dialysis or artificial kidney**.
- Artificial kidney can do only the passive filtration process.
- The **function of an artificial kidney is based on the physicial laws of diffusion and osmosis**.
- **Various components of an artificial kidney** are –
  - A **blood dialyser** having the membrane and a rinsing fluid.
  - A **pumping system** to pump the blood into the body.
  - The **heating equipment with thermostat**.
  - **Dialysing fluid**, having same constitution as that of blood plasma but deficient in nitrogenous waste products, phosphates and sulphates with slight excess of glucose to make it isotonic.
  - The **oxygen supply system** to supply oxygen to the blood.
  - An **arrangement to prevent the clotting of blood** (heparin and antiheparin).

Prosthesis

- External prosthesis are devices that are attached to our body externally like an externally arm, leg or denture (artificial teeth) so they help the body to function normally.
- A myoelectric arm has also been developed which can move prosthetic wrist and fingers to hold objects.

- **Great achievement in this field have been obtained by Dr. P.K. Sethi of Jaipur**, India who has evolved a prosthesis foot very similar to the natural foot. It is very light in weight and can be moved in all directions with great ease.
- Even a "denture" can also be regarded as an external prosthesis as it remains in the mouth and not strictly within the body.

Biotechnology applications

- Biotechnology (technology involving living beings or their products for formation of useful materials) is being increasingly used in reconstructive surgery, early diagnosis of various diseases, treatment of hormonal, metabolic and genetic disorders etc.

Diagnostic kits

- The kits are based on recombinant DNA and immunological tests involving specific antibodies for different antigens. For examples, malaria can be tested even without seeing parasite in RBC through precipitation of specific antibodies.
- Other tests available with the help of kits are hepatitis, pregnancy, allergies, blood sugar, blood urea and other biochemicals, urine tests, test of cerebrospinal fluid, etc. In some cases colour reactions are used for the tests.

Cryopreservation of tissues and organs

- This involves the use of natural tissues taken from humans and other animals of the reconstructive surgery.
- In this technique, cornea transplantation has been done with great success. It is because of the fact that cornea is not difficult to preserve, it also does not link up with the blood supply and the immune system of the recipient and the donor is also not complicated.
- However, the preservation of other organs like kidney, liver and heart is very complicated and may evoke immune rejection.
- In case of skin transplant or graft, patient's own skin can be from an undamaged part (**autograft**) or may be taken from another organism of the same species (**allograft**) or of another species (**heterograft**). In allografts or heterografts, there are more chances of skin rejection by the recipient because of high immunogenicity property of the skin. For this purpose the skin removed is subjected to special treatment to neutralise immune specific proteins and then cryopreserved for emergency use. This can later be used at any time. However, it should be noted that these transplants are not permanent.

Hormones and enzymes by recombinant DNA technology

- Discrete genes, *m*RNAs, proteins, hormones and enzymes can be obtained in sufficient quantity through *r*DNA technology for treating different diseases.
- Plasmids carrying DNA sequences for A and B insulin chains have been successfully introduced in *Escherichia coli* for production of humulin (human insulin). Gene for human growth hormone *c*DIVA has been integrated with 'trp' gene of plasmid to form the biochemical.
- Cultured leucocytes/lymphocytes/fibroblasts can be used to produce interferons.
- Plasminogen activator produce enzyme plasmin in the blood plasma to dissolve clots inside the arteries. Gene therapy involves introducing genes through specific vectors like disabled viruses to overcome genetic deficiency.
  [*For more on biotechnology application refer chapter - Biotechnology and Genetic engineering*]

Diagnostic laboratory test

- Laboratory tests are tools helpful in evaluating the health status of an individual.
- The **basic test** is a **screening test of blood and urine**.
- The tests are **carried out for the following reasons** –
  - Presence, excess or deficiency of various biochemicals for knowing the state of metabolism.
  - Diagnose a disease (like anaemia, leukemia, bleeding disorders, neutropenias etc)
  - Confirm an early diagnosis.
  - To know the stage of the disease.
  - To screen individuals for diseases which are yet to show their symptoms.
  - For prognosis or forecasting sequence of events of a disease.
- There are **several types of test** – haematology, immunology, biochemistry, microbiology and the emerging area of molecular diagnostics.

Table : Blood test with their applications

	Blood tests	Medical applications
1.	**Total Leucocyte Count (TLC)**	**Increased** leucocyte count (*leucocytosis*) occurs during Burns, Haemorrhage, Leukemia and acute infections such as Appendicitis, Pneumonia, Tonsillitis, Ulcers, Diphtheria, etc. **Decreased** leucocyte count (*leucopenia*) occurs during Typhoid, Measles, Influenza, Liver cirrhosis, Dengue, Hepatitis, etc.
2.	**Differential Leucocyte Count (DLC)**	DLC is important to diagnose the type of infection. For example—(i) Neutrophils rise in neutrophilia; (ii) Eosinophils rise in allergies; (iii) Basophils increase in Leukemia; (iv) Lymphocytes increase in chronic infections; (v) Monocytes increase in chronic inflammatory conditions.
3.	**Erythrocyte Sedimentation Rate (ESR)**	Increased ESR is observed during Pregnancy, Rheumatoid Arthritis, Tumor formation, Chronic infections and in Tuberculosis.
4.	**Lipid profile** (Estimation of cholesterol)	Evaluation of risk of heart disease. **Increased levels** of serum cholesterol is observed during atherosclerosis (hardening of blood vessels), Nephrosis (a disease of kidney), Diabetes, Jaundice and Myxoedema. A **decreased level** of cholesterol is observed during hyperthyroidism, nutritional malabsorption and anaemia.
5.	**Haemoglobin Estimation**	Deficiency in haemoglobin is called *anaemia*.
6.	**Blood Sugar Estimation**	Level of blood sugar is increased in *diabetes mellitus*.
7.	**Blood Urea Estimation**	Increase in blood urea occurs with *loss of body fluids* and *Renal failure*. Blood urea is decreased under *normal pregnancy*.
8.	**ELISA Test** (Enzyme linked immunosorbent Assay)	Used for the diagnosis of *Hepatitis*, *AIDS* (caused by HIV), *thyroid disorder,* and *sexually transmitted diseases*.
9.	**Widal Test**	Applied for the detection of *typhoid*.

- **Haematology** is the study of blood formation and the diseases which occur when the process goes wrong.
- **Routine blood test** is also called as the **complete blood count** or **CBC.**
- **Blood tests** are laboratory tests done on blood to gain an appreciation of disease states and the function of organs.
- Blood for laboratory tests can be **capillary or venous blood**.
- **Capillary blood** is **obtained from the tip of a finger** while **venous blood** from the **upper part of the arm**.
- Blood obtained is to be mixed with the anticoagulants which could be oxalates, EDTA, or heparin. **EDTA** is the **most abundant used anticoagulant**.
- The **haematocrit** (**Ht**) or **packed cell volume** (**PCV**) is the proportion of blood volume that is occupied by red blood cells.
- The length of the tube containing blood cells, divided by the length containing cells or plasma gives the PCV.
- The packed cell volume can be determined by centrifuging the blood in a capillary tube (a haematocrit tube), which forces the cells to one end.

- A **significant drop** in the value of PCV **means anaemia** while a **higher value means polycythemia**.
- The number of RBC/ L **gives an indirect estimate of the haemoglobin content of blood**.
- Amount of haemoglobin per 100 ml of blood is called **haemoglobin count** and is measured by an instrument called **haemometer**.
- The **mean corpuscular volume** (or **MCV**) is a measure of the average red blood cell volume that is reported as part of a standard complete blood count.
- **In patients with anaemia**, it is the **MCV measurement that allows classification as either a microcytic anaemia** (MCV below normal range) or **macrocytic anaemia** (MCV above normal range).
- MCV can be **calculated by** multiplying the haematocrit percentage by ten, and dividing the product by the RBC (red blood cell) count. The **result is typically reported in femtoliters**.
- Haemoglobin concentration can be estimated by the oxyhaemoglobin method, cyanmethaemoglobin method, by specific gravity method or by chemical method.
- **TLC** gives the **total leucocyte count per cubic millimetre of blood**. The **counting is done by hemocytometer** also called counting chamber.
- **Increased TLC** means leucocytosis while **abnormal low count** means **leukopenia**.
- **Normal value of TLC**

Adults	– $7.5 \pm 3.5 \times 10^3/mm^3$;
New born	– $18 \pm 8 \times 10^3/mm^3$;
Full term pregnant woman	– $15 \pm 3 \times 10^3/mm^3$;
Infant (1 year)	– $12 \pm 6 \times 10^3/mm^3$;
Children (4-7 years)	– $11 \pm 5 \times 10^3/mm^3$;
Children (8-12 years)	– $9 \pm 4.5 \times 10^3/mm^3$;

  It is, therefore clear that TLC value slowly declines from birth to adulthood.
- **DLC** (Differential leucocyte count) gives the percentage of different types of leucocytes.
- A change in the percentage of a specific leucocyte indicates a specific disorder or disease. For example, high neutrophil count indicates bacterial infection while high eosinophil count indicates allergic reaction.
- The **erythrocyte sedimentation rate** (**ESR**), also called a **sedimentation rate** is a non-specific measure of inflammation that is commonly used as a medical screening test.
- ESR is the rate of sedimentation of RBC's in a given period of time. It helps in differentiating between the degenerative disease and functional disease.
- It is **most commonly done** by **westergren pepette or wintrobe tube**.
- Factors like anaemia, increased level of fibrinogen, globulins and cholesterol **increase ESR** while removal of fibrinogen, increased albumin and sickle shaped RBC **decrease ESR**.
- **Lipid profile** of blood is done on blood plasma. Generally it **measures total cholesterol**, **HDL cholesterol** and **triglycerides**.
- **Value of serum cholesterol**
  Normal value. 150-250 mg/dl. Increase with age and pregnancy are to be taken into consideration. The value is lower in neonates, infants and children.
- **Value of HDL cholesterol**
  Normal value. (i) **Men.** 35-55 gm/dl, average 44 mg/dl (ii) **Women.** 45-64 mg/100 ml, average 55 mg/dl.
- **Value of LDL**
  Normal value. 62-185 mg/dl. **Average.** 150 mg/dl.
- **Normal value** of serum triglyceride is 80-150 mg/dl
- **Increase in glucose level** is called **hyperglycaemia while decrease in glucose level** in blood is called **hypoglycaemia**.
- Blood glucose level increases in diabetes mellitus and stress and decreases in Addison's disease.
- **Normal values of sugar**.
  - *Whole blood sugar* (Fasting) 90 - 120 mg/100 ml. It includes 20 - 30 mg/dl non-glucose saccharoid fraction.
  - *Plasma/Serum Sugar* (Fasting) : 70 - 110 mg/dl.
  - *Plasma/Sugar Post Prandial Sugar* : 100 - 140 mg/dl.
  - *Whole Blood Post Prandial Sugar* : 140 - 180 mg/dl.
- **Blood urea level** may vary with the protein intake of individual. It may increase during kidney disease and decrease during liver failure.
- Concentration of blood urea indicates the health of excretory system. There are two methods for estimating the same – **Nessler's reaction** and **Berthelot's reaction**. In both cases, urea is broken down by enzyme urease to liberate ammonia.
- **Nessler reagent** is aqueous solution of 5% potassium iodide, 2.5% mercuric chloride and 16% potassium hydroxide. In **Berthelot's reaction,**

ammonia reacts with phenol and hypochlorite to produce blue-coloured indophenol.

- **Normal value blood urea** is 30-40 mg/dl.
- **ELISA test** (enzyme-linked immunosorbent assay test) is based on the detection of specific antigens or antibodies of patient's blood with the help of enzyme-linked antibodies or antigens respectively in the ELISA wells of a polystyrene or polyvinyl chloride microtitre plate.
- ELISA is very quick diagnostic technique for detection of a wide variety of pathogens, disorders, allergens and hormones, *e.g.,* (i) Pregnancy test through presence of human chorionic gonadotropin in urine or blood. (ii) AIDS or HIV infection. (iii) Hepatitis. (iv) STD or sexually transmitted disease. (v) Rubella virus. (vi) Thyroid disorder.
- **Widal test** helps to diagnose typhoid or enteric fever. A **positive test indicates the presence of gram negative bacteria** *Salmonella* found in the human intestine.
- A **urinalysis** (or "UA") is an array of tests performed on urine.

Biopsy

A biopsy is a small sample of tissue taken for microscopic examination so that the nature of a disease process can be accurately determined. The word 'biopsy' literally means 'taking a look at life'.

Biopsy is a valuable and accurate way of finding out exactly what is wrong with a person and by establishing an important diagnosis at an early stage, it is often life-saving. Biopsies, especially from the skin, may often be taken after a simple injection of local anaesthetic, the skin opening then being closed with one or two stitches.

Types of biopsies –

– **Excisional biopsy :** The entire lump or tumor is removed (excised).

– **Incisional biopsy :** A portion of the lump is removed surgically. This type of biopsy is most commonly used for tumors of the skin to distinguish benign conditions and diagnose cancers and other tumors. This can be done by 'shave', 'curette' or 'punch' methods.

– **Fine needle aspiration:** A needle no wider than that typically used to give injections is inserted into a lump (tumor), and a few cells are drawn up (aspirated) into a syringe.

End of the Chapter

Chapter 74

Domestication & Improvement of Animals

- Domestication of animals started during the "hunting and gathering phase" of human civilization. When man realised the utility of domestic animal, he began improving them by selective breeding.
- **Animal husbandry** is the science of rearing, feeding, caring, breeding improvement and utilization of domesticated animals.
- One the **earliest animals to be domesticated was dog**. Dogs are represented in Egyptian monuments as far back as 3400 BC and various breeds of dogs existed during the height of the roman civilization.
- The cattle (cows, buffaloes and goat) were domesticated during the New Stone Age in both Europe and Asia. These provide milk to be taken as such or in the form of butter, curd and ghee.
- Domestication perhaps began when these animals were used as draft animals, probably in the first steps of the tillage of the soil. As civilization developed, feed became more abundant, methods of caring for livestock improved, and the latent possibilities for rapid growth, fat storage, and milk production began to be realised under man's selection.

LIVESTOCK

- Livestock are those domesticated animals, or farm animals who are kept for use or profit. On the basis of the utility the livestock can be put into the following categories –
  - **Milk giving animals** – Cows, buffaloes and goats provide us with milk which provide animal protein and serve as a perfect natural diet. Milk is also used in preparing curd, butter, ghee, cheese etc.
  - **Meat and egg giving animals** – A large number of animals such as sheep, goat, pigs, ducks and fowls provide us meat and eggs.
  - **Animals utilized as motive power** – Buffaloes, horses, donkeys, bullocks, camels and elephants are used in transport and ploughing the fields.
  - **Wool giving animals** – Sheep are reared for obtaining wool from their hide.
  - **Miscellaneous uses** – The hides of cattle are used for making a variety of leather goods. Horns of animals and feathers of birds are used for making a variety of goods and articles of decoration. India is the largest exporter of hides and skin in the world. Dung is used for maintaining the soil fertility and also as fuel.
- The **most important livestocks of India** are cattle and buffaloes which yield milk and help in agriculture.

Zebu cattle or cow

- Cow (*Bos indicus*) is **raised for milk**. Bullocks have been used in agricultural operations and drawing carts. Hides are used for preparing leather goods. Droppings yield gas and manure. Meat, bone metal, glue and gelatin are other articles.
- A cow produces 8 – 10 calves during its reproductive period.
- Breeding is of two types : natural and artificial. **Natural breeding** can be random or controlled (= selective). **Artificial breeding** is through **artificial insemination**. It involves introduction of semen of selected bull artificially when the cow is in heat.
- The **method is superior** because –
  - It prevents spread of infection.
  - The bull is not required at the time of heat.
  - Exotic superior quality bulls can be kept far away in environment suitable for them.

- A single bull can inseminate a large number of females.
- **Superovulation** (more ova and hence more embryos), **embryo transplantation** and **surrogate mothers** also **help improve breeds. Deep freezing** (–190°C) is used for keeping seven day old embryos for several years. They can be transplanted when required.

Exotic breeds are foreign breeds of animals which are introduced in a country and require special environment, e.g., Friesian, Holstein, Brown Swiss, Jersey. They have been hybridized with Indian cows to develop locally acclimatized high performance cattle, e.g., Karanswiss, Sunandini, Jersey-Sindhi, Brown Swiss-Sahiwal, Ayreshire-Sahiwal.

Buffalo

(Water buffalo, Indian buffalo, *Bubalus bubalus* = *Bos bubalus*)

- Buffalo population in India is about 83.5 million (1992 census). It is **raised for milk**. Buffalo bull is used for agricultural operations and driving carts. Number of buffaloes is one third of cows but their milk yield and hardness is better.
- Buffalo is **better than cow** in many respects –
  - The average annual milk yield of a buffalo is 491 litres as against 173 litres of a cow in India.
  - Buffalo's milk has about 50% more fat content than cow's milk.
  - Buffalo milk also has higher mineral contents than cow's milk.
  - Buffalo has better adaptability and disease resistance.
  - Buffalo lives longer than cow.
  - The buffalo-bullock is an animal of strength. It moves slowly but can draw very heavy loads over long distances.
- Breeding season of buffalo extends from September to February. **Average lactation period for a milch** buffalo is about **281 days**. Buffalo has lower heat tolerance than a cow.
- Infertility in local breeds of cattle has been overcome through the use of pregnant mare serum gonadotropin. **Sterile and immature cows** can be **induced to lactate through stilbesterol**.

Table : Breeds of Indian cattle

Milch breeds	
Sahiwal	Punjab, Haryana and U.P.
Deoni	Andhra Pradesh and Tamilnadu
Gir	Gujarat and Rajasthan
Red Sindhi	Andhra Pradesh
General utility breeds	
Ongole	Andhra Pradesh
Haryana	Haryana, Punjab, Bihar, M.P.
Tharparkar	Andhra Pradesh and Gujarat
Kankrej	Gujarat
Draught breeds	
Nageri	Delhi, Haryana, U.P.
Kangayam	South India
Malvi	Rajasthan, M.P.
Hallilkar	Karnataka

Table : Breeds of buffaloes

Nili and Ravi	Punjab, Haryana
Nagpuri	Central and South India
Mehsana	Gujarat
Surti	Rajasthan, Gujarat
Jaffarabadi	Gujarat
Bhadawari	U.P. and M.P.
Murrah	Punjab, Haryana, U.P.

Sheep

- Sheeps (*Ovis aries*) are **reared for wool and mutton**, mostly in hilly tracts. Sheep graze on grass and herbs. Farm waste, mineral mixture, oil cake and other cattle feeds can also be given.
- **Deccani and nellore** breeds are **raised only for mutton**. **Patanwadi provides wool** for army hosiery while **narwari yields coarse wool**.
- **Four breeds** yields good wool : Rampur - Bushair (brown fleece for superior cloth), lohi (quality wool, also milk), bakharwal (undercoat for shawls) and nali (carpet wool).
- Exotic breeds include merino, dorset horn, and suffolk correidale. They have been crossed with Indian breeds to improve the quality of the latter.
- **Advantages of sheep farming :** Sheep farming is more economical than raising other kinds of livestock.
  - A simple open pen with a fence of dried, thorny

babul branches is enough for keeping sheep. Expensive sheds are not required.
- Sheep do not need special care and facilities.
- Establishing of the foundation stock of sheep is cheap and the flock swells up rapidly.
- Sheep can thrive on natural grasses, weeds and farm wastes.
- Sheep **give 4 products : milk, wool, skin** and **lambs**.
- Sheep do not damage trees unlike goats.
- Sheep are **excellent weed destroyers**.
- Sheep **droppings form excellent manure**.
- Mutton eating is not forbidden in any community.Thus,there is a great scope for raising mutton producing sheep.

Goat

- Goat (*Capra capra* = *C. hircus*) is **called poor-man's cow** because it yields a small quantity of milk. However,the milk carries protein lectoperoxide (LP) which is effective against a number of disease causing bacteria.
- Goat feeds on a variety of wild plants, even prickly ones.
- Goat **also yields meat, skin and pashmina** in case of Kashmiri goats.
- **Common breeds of goats** are – malabari (Kerala), berari (Maharashtra), bengal (Bihar, Orissa), marwari (Rajasthan) , beetal (Punjab), jamunapuri (U.P., M.P.), gaddi and chamba (Himachal Pradesh), and kashmiri and pashmina (Himachal Pradesh, Kashmir and Tibet).

Pigs

- In India, pigs (*Sus scrofa*) raising and pork production are in a primitive state.
- Pig (also called **hog** or **swine**) rearing is almost entirely in the hands of poor people with little resources, who continue to follow old and primitive methods.
- The common village pig in India, is a scrub animal and has no definite characteristics. It is a slow grower and the pork is of poor quality. It is small-sized and produces small litters.
- **Uses of pig**
  - Pig meat is called pork. It is inexpensive and is taken by the poor.
  - Hide of the pig is used as leather and its bristles for making brushes.
  - The fat obtained is used for soap manufacture.
  - Pig droppings are a good source of nitrogen, phosphorus and potassium for agriculture.
  - Ham, bacon and sausages are prepared from pig meat.
- Pig is harmful too. Pork may contain encysted larvae of the tapeworm *Taenia solium*. Therefore, pork should be well cooked to avoid tapeworm infection.

Table : Important breeds of pigs

Native pigs	
Desi	Uttar Pradesh, Bihar, Punjab, Madhya Pradesh
Ghori	Manipur, Assam, Meghalaya, Arunachal Pradesh
Exotic pigs	
Berkshire	U.K.
Large white Yorkshire	U.K.
Landrace	Switzerland, Denmark.

Horse

- Horses are **intelligent** and are **known for their robust common sense**. For thousands of years horses have been used to carry man on their back, pulled the carts and chariots both in peace and war.
- The horses are **fast learners and loyal friends**. They adopt themselves to all kinds of climates.
- They are used by the armed forces and police and are used for transport at high altitudes. They are used for riding, race and polo.

Table : Important breeds of Indian horse

	Name	Regions
1.	Kathiawari	Rajasthan and Gujarat
2.	Marwari	Rajasthan
3.	Bhutia	Punjab and Bhutan
4.	Manipuri	North-eastern mountains
5.	Spiti	Himachal pradesh
6.	Zanshari	Ladakh

- Horses should be kept in hygenic and comfortable stables. Stables should be able to provide sufficient protection from inclement weather, excessive heat, cold and rain. Cool places with good ventilation are preferable to warm, close stables.
- Horses, as compared to other animals, **have a low**

reproductive rate. They are **more difficult to breed** and **have a long gestation period**. Horse breeding by controlled natural mating has been in practice for long time in our country.

Donkeys

- Donkeys are **smaller than horses** but **have larger head, longer pinnae and narrower hoofs**. There mane is erect and tail has a tuft of hair at the tip. Donkey is the most simple and unselfish animal. It can withstand adverse weather conditions. It is a hardy animal and can work incessantly (continual) without rest on poor forage.
- Donkeys are used for riding and transport , mainly of clothes, earth, bricks, etc. They are also employed for pulling carts in some regions.
- There are two breeds of donkeys in our country : small, dark grey; and large, light grey to almost white. The grey donkey occurs in most parts of the country. The **white donkey, also called wild ass**, occurs in Rann of Kutch.
- Donkeys have descended from the wild ass *Equus asinus* of Abyssinia. They were domesticated around 4,000 B. C. in Mesopotamia and Egypt.
- The donkeys are **generally bred at the age of 2.5 to 3 years**. They can breed throughout the year, there being no particular breeding season.
- The **gestation period is 11.5 to 12 months**. The optimum time for mating is the third day of heat. Usually one young is born at a time.

Mules

- A mule is **a hybrid of a male donkey and a female horse**.
- The hybrid from a reciprocal cross is called hinny.
- Mules show hybrid vigour. They are sturdier than the horse and larger than the donkeys. Both male and female mules are infertile.
- Indian army has imported male donkeys from Europe for breeding mules. Army uses two types of mules : (i) general service type, and (ii) mountain artillery type. The latter are firm footed and can carry heavy loads on steep terrain.

Elephant

- Elephant is the largest land animal. It was used in war, for religious purposes and in royal processions.
- It is regarded in India as a remover of obstacles and a symbol of good fortune.

Camels

- Camel has been aptly **described as the ship of the desert**. It is the valuable beast of burden and transport in the hot and arid desert regions.
- There are **two species of camels**. The *Bactrian* **camel is an inhabitant of Central Asia**. It has two humps. The second is *Arabian* or *Dromedary* camel with one hump. In India, only the one-humped camels are found. The Arabian camels is less heavily built and longer in the hind. Its skin is soft and comparatively thin.
- **Adaptations for desert life** –
  - Extraordinary power to resist thirst and hunger.
  - It can live on thorny shrubs.
  - Long neck and thick foot pads for movement on loose hot sands.
  - Thick skin over the body to prevent water loss.
  - Long eye lashes to prevent the eyes from sand.
  - Hard lips to browse thorny bushes.
  - **Hump acts as an emergency food-store** in the form of fatty tissues to enable it to live under drought conditions.
- Camel is **used for** riding, carrying loads, ploughing and threshing grains. It is also used for pulling carts, drawing water from wells. It is used as a motive power in surgarcane and oil seed crushing mills. Hair of camel are used for making garments, brushes and cords. Its dung is used as fuel. Hide provides leather for making saddles. Camel's milk and meat are taken by the desert dwellers.

POULTRY

- **Poultry** is a rearing of domesticated fowls (chicken), ducks, geese, turkeys, guinea fowls and pigeons, but it is more often used for fowls.
- Keeping fowls for eggs, raising browlers (table birds) for meat, poultry-breeding and hatcheries are the common poultry enterprises. Other allied professions are egg and meat processing, egg and poultry marketing processing and sale of food poultry equipment.
- Poultry farming has now become popular, and many of the farms have several thousands layers. The **factors favourable for the growth of poultry farming** are : small initial investment, quick return, requirement of small area and use of various kinds of food stuffs.

- **Domestic fowl** (*Gallus domesticus*) **constitutes the major poultry bird**.
- Poultry birds exclusively grown for meat are called **broilers** (eg. plymouth rock), **layers** are for egg production, **cockerel** are young male fowls and **rooster** are mature male fowls.
- **Pullet** is young hen of less than one year.
- **Broilers** are **generally quick growing birds** which are generally males but can also be female. They are grown for 8-10 weeks when they attain a weight of 1.5-2.0 kg. Broilers are **sold in fresh or frozen form** after dressing (removal of feathers, head and feet).
- **Layers** are females which have a high rate of egg production. They are **debeaked** twice (21st day and after 4 months). Debeaking is removal of tip of beak. It reduces chances of injury when birds fight amongst themselves. Birds are given fresh balanced diet everytime. Extra care is required for young birds. It is called **brooding period**. It lasts for 6-8 weeks. **Dubbing** is removal of wettles and combs of young birds. Females start laying eggs in about 22 weeks. It continues for 12-15 months. When egg production becomes uneconomical, the layers are sold for slaughtering.
- **Breeds of fowls** are –
  – **Indigenous breeds** (**desi breed**) : Chittagong, Punjab brown, Aseel, Bursa, Danki, Tellicherry, Karaknath etc. **Aseel** is one the **best table bird** but it can not be raised on commercial purpose because of its poor growth and low fertility.
  – **American breeds** : Polymouth Rock (most popular breed of USA), wyandotte, Rhode Island Red, New Hampshire.
  – **Asiatic breeds** : Brahma, Langshan, Cochin.
  – *English breeds* : Sussex, Orpington, Australorp, Cornish, Dorking, Red cap.
  – **Mediterranean breeds** : Leghorn, Minorca, Ancona, Spanish, Andalusian and Buttercup.
- The **largest and the most healthy fowls** are Brahma, Australops, Orpington, Langshan, Sussex. Monarcha is the best layer of lange sized eggs.
- **Aseel is one of the best table birds** with plenty of flavoured flesh.
- The desi birds **(indigenous breeds)** generally have poor egg laying capacity.
- For poultry breeding two aspects are kept in mind (i) improving the birds for poultry meat, and (ii) improving the birds for more eggs. For meat fast growing chickens are selected. When the production of eggs is the prime consideration, the high egg laying varieties of chickens are selected. The hens with characters for high egg production give better results.
- Cross breeding is done between the males and females of desired characters. Cross breeding has resulted in higher rate of hatching of eggs, more efficient and faster gains in weight and lower rate of chick mortality.
- Some of the **important diseases of poultry** are given below :
  – *Viral diseases*, these are Fowl fox and Ranikhet or New castle disease.
  – *Bacterial disease*, these include fowl cholera, salmonellosis and coryza.
  – *Fungal disease*, Aspergillosis.
  – *Parasitic diseases*, the parasites are of two types – *internal parasites* (roundworms, tapeworms and thread worms) and *external parasites* (fowl mite, chicken-mite, fleas, ticks, lice, etc).
- **Ducks** form only 6% of our country's poultry population. They are **commonly raised in the southern and eastern regions of the country**. There are 20 breeds of ducks, the **native ones** include Indian Runner and Syhlet meta, and the **exotic ones** include Muscori, Pekin, Aylesbury and Campbell. Domesticated ducks have been derived from the wild duck named mallard (*Anas boscas*).
- **Brown and white geese** *(Anser)* are common in India.
- **Turkey** (*Meleagris*) was **domesticated in Mexico** in the 16th century. It is **highly esteemed as a table bird**. It is **associated with Christmas festivities** in U.K. and with those of Thanks giving in U.S.A. The turkey breeds in demand at these occasions include Narfold, British white, Broad Beasted Bronze and Beltsville Small White.

FISHERIES

- Fisheries is a water body having fishes and other aquatic animals which are reared and caught for food which is rich in protein, vitamins A and D. Marine animals are also richer in iodine. Shark liver oil and Cod liver oil are very good source of vitamin A and D.

- **Aquaculture** is rearing and management of useful aquatic plants and animals like fishes, oysters, mussels, prawns, etc.
- **Pisciculture** is rearing, catching and management of catching of fish.

Types of fisheries

Fresh water fisheries or Inland fishery

- They are small scale fisheries found inland. Inland fisheries are of further **two types**– **brackish water** and **fresh water**.
- **Brackish water fisheries (estuarine fisheries)** develop in lagoons, mangroves, estuaries, back waters, etc. Prawn **(***Penaeus*, *Metapenaeus***)**, Mullet (Mugil), Perch **(***Lates***)**, *Chanos* and Ladyfish **(***Sillago***)** are some eg's.
- **Fresh water fisheries** : India has a large area of 1-6 million hectares under fresh water in the from of rivers, canals, irrigation channels, reservoirs, lakes, tanks, ponds and pools. Important products of inland fisheries are fresh water prawns (*Palaeomon*, *Macrobrachium*) and fish like *Labeo rohita* (Rohu), *Labeo calbasu* (Calbasu), *Catla catla* (Catla), *Wallago altu* (Malli), *Clarias betrachus* (Magar), *Msytus singhala* (Singhara), *Heteropneustes heteropneustes* (singhi).
- **Capture** and **culture fisheries** are two types of inland fisheries.
- **Capture fishery** is practice of only catching the fish available naturally as in large water bodies of lakes, reservoirs, tanks, etc. Marine fisheries are also capture fisheries.
- **Culture fisheries** is the type of fishery found in small water bodies where fish is first reared and then harvested. Culture fishery of **three types** –
  – **Monoculture :** Growing of only one type of fish, eg. cat fish.
  – **Polyculture :** Growing of two or more types of fish in the same water body, e.g., Tilapia and Carp.
  – **Composite culture :** It is rearing of food fish and other food animals in the same water because they do not harm one another but reside and feed at different levels like surface, middle and bottom.

Marine fishery

- Marine fishery deals with the fishery aspects of the sea water or ocean. Some of the important marine fishes are – *Hilsa* (Hilsa), *Aluitheronema* (Salmon), *Sardinella* (Sardine), *Harpodon* (Bombay duck), *Stomateus* (Pomphret).
- **Crustacean fisheries constitute the most important class of marine fisheries** of the country. They include prawns, lobsters and the crabs. Indian prawn industry constitutes 18 per cent of the world production. The annual catch is about one lakh tonnes and is second only to the U.S.A. Prawn pulp is exported to several countries.

Molluscan fishery

- The commercial culture of molluscs such as edible oysters and mussels had been old practice in European countries and Japan.
- The bivalves, gastropods and cephalopods are the molluscs of economics importance. This group constitutes a good percentage of sea food. Pearls and shells are also very important articles of trade.

Fish farming

- Fish farming **(pisciculture)** aims at the cultivation of selected varieties of fishes in ponds by providing them suitable physico-chemical and biological conditions. Cultivation is done in a manner that a maximum amount of fish is produced within a short period of time, and in a limited amount of water.
- **Various techniques of fish farmings** have been successfully developed in the country and may be classified as – complete fish farming, restricted fish farming, extensive fish farming, intensive fish farming, depending on natural habitat of fish, monoculture, polyculture, monosex culture and integrated fish farming etc.
- **Complete fish farming :** This technique began with the production of eggs and culminates in the formation of full size fishes, which may be utilized as food, for marketing or as breeding stocks. The farm must therefore have the necessary types of ponds and facilities required for feeding, breeding and growth of fish.
- **Restricted fish farming :** This type of fish culture is restricted to one or more stages of fish growth. Fish seeds, fry or fingerlings may be produced and allowed to grow in the ponds of the farm. Hatcheries may also be established where, after induced spawning the collected fishes may be sold to fisherman for restocking their ponds.
- **Extensive fish farming :** Here the fishes are

cultivated on the natural food available in the pond and their productivity corresponds to natural productivity.

- **Intensive farming :** This cultivation is based on artificial feeding, so that the production is a maximum quantity of fish in minimum quantity of water. A semi-intensive farming of fish is a transitional phase between extensive and intensive fish farming.
- **Depending on natural habitat of fish :** Fish farming may be done in cold water, warm water, fresh water or brackish water depending on the habitat of the fish selected for cultivation.
- **Monoculture :** It is the culture of only a single type of fish species in a pond. It may be *Tilapsia* of one species or common carp or any other species.
- **Polyculture :** Here two or more species of fishes are cultivated together in a pond, e.g. a mixture of Chinese carp, grass carp and big head carps are cultured together. It is also sometimes called **composite culture**.
- **Mono sex culture :** It is the culture of only one sex of a species of fish in a pond.
- **Integrated fish farming :** In this type of fish farming, the culture of fish is done along with the agricultural crops such as paddy and banana.
- Also fish culture may be carried out by placing the fishes in a cage and suspending it in water, released from the farmers house and animal shelter **(cage culture)**.

By products of fishing industry

- **Fish oil** *:* It is extracted from adipose tissue of fish. It is a mixture of triglycerides, cholesterols, alcohols, pigments, vitamins etc. Fish oil is grouped into body oil and liver oil. Body oil is generally used in lubricants, cosmetics, paints etc. Liver oil is extracted from liver of fishes and is of pharmaceutical value as it is main source of vitamins A, C, D and E. Liver oil of hammer headed fish and sharks has highest percentage of vitamin *A*.
- **Fish meal** : It is prepared from the wastes of fish oil or from the whole fish. It is used as major food of domestic animals like pigs, poultry etc.
- **Fish flour** : It is highly nutritive food for infants of 3 to 4 months as it is easily digested.
- **Fish roes** : It is rich source of thymine, ichthulin, creatine, tyrosine, xanthine, hypoxanthine, vitamin B, C, D and E etc. It is widely used because of its easily digestibility and high nutritional value.
- **Fish selage** : It contains high percentage of unaffected vitamins. It is semi solid material prepared from fresh pieces of fish treated with sulphuric acid, formic acid and molasses.
- **Fish fertilizer** : The wastes obtained during the preparation of fish meal is widely used as manure for coffee, tea and tobacco plantation. It is of 3 types :
  - *Dry fish manure* : Whale fish is dried in sunlight and used as manure.
  - *Pit fish* : It is obtained by burning the fish waste into pits.
  - *Fish guana* : The refuse of cooked fish body obtained after proper pressing during the extraction of oil is fish guana.
- **Fish skin** : The skin of some fishes like sharks and rays are used for making jewel boxes, purses and several other ornamental purposes.
- **Fish glue** : It is prepared from skin and bones of fishes.
- **Chum** : The residue obtained during extraction of glue after proper drying is used as poultry feed or fertilizer.
- **Isinglass** : It is produced from air bladder of cat fishes and carps. It is used for preparation of purse, book and ribbon etc.
- **Squalene** : It is a constituent of the unsaponifiable fraction of fish oil. It is used as a mordant in the dyeing of synthetic fibres.

Induced Breeding

Induced breeding is a technique whereby ripe fish breeders are stimulated by pituitary hormone injection to breed in captivity. The stimulation promotes a timely release of eggs and sperms from ripe gonads. The hormone is the gonadotropin playing a role in bringing about spawning. A substitute of the pituitary hormone, natural or synthetic may be equally effective and is preferred for commercial usage because of the difficulty of obtaining large quantities of pituitary hormones for large scale usage, which in turn would mean a larger number of fish donors. The mammalian chorionic gonadotropin (CG), synahorrin (combination of CG and pituitary extract) and SZK (from pregnant mare serum) are some of the tested substitutes.

SERICULTURE

- **Sericulture** is the breeding and management of silkworm and the raw silk they produce. Depending upon the number of crops of silkworm cocoons raised per year.
- Sericulture is **univoltine**, **bivoltine or multivoltine**.
- **Silk** is a natural fibrous secretion which is **secreted by caterpillar over it during cocoon formation**. Cocoons are dipped in hot water to kill the pupa and separate the fibres.
- **India ranks third in the production of silk**. Karnataka ranks first in production of raw silk.
- Fine texture silk is the product of the domesticated type or mulberry-feeding silkworms belonging to the family *Bombycidae*, whereas silk of other varieties *Eri*, *Muga*, *Tasar*, are products of the larvae of wild or semi wild types of moths belonging to the family *Saturniidae*.

Silk

- Silk is a natural fibrous substance obtained in the form of a long, continuous filament from cocoons (pupal nests) spun by a large variety of moth caterpillars, known as silkworms. At the end of the fifth or last stage in the growth and development of these caterpillars, silk is exuded from the silk glands present inside their body (*i.e.*, located on the ventro-lateral sides of the body cavity, which is extended from the 4^{th} to the 8^{th} segment of the abdominal part of the body) through the spinneret to spin the cocoons. Silk filaments from these cocoons are reeled out after proper treatment into raw silk, made of usually 8-10 filaments.
- Silk is tough and bright but at the same time it is soft, light and elastic. The silk fibre never creates any reaction on the skin and can be used in all season. Hence **silk**, the most beautiful of all textile fibre, is acclaimed as the queen of textiles.
- Silk is **composed of two kinds of very large molecular weighted amphoteric colloidal proteins – fibroin** and **sericin**. Fibroin ($C_{15}H_{26}N_5O_6$) **constitute about 75%** and sericin ($C_{15}H_{25}N_5O_8$) the remaining **25%** of the silk thread.

Structure of silk gland

- Each gland is divided into **three regions**, *viz.* anterior, middle and posterior regions.
- The anterior sections of both the sides of the glands are narrow and united near the mouth to form the spinneret.
- The middle part is broad and is termed as **reservoir** where as the posterior section is long, narrow and coiled.
- The **posterior region produces the inner core** (**fibroin**) and the **middle part secretes three kinds** of **sericin**.
- A pair of Lyonet's glands or De Filippis gland is located near the spinneret. The secretion of those glands mixes with the silk thread and lubricates it.

Species of silkworm

Mulberry silkworm

- *Bombyx mori* belongs to the family Bombycidae. China is the native place of this silkworm but it has now been introduced in India, Japan, Korea, Russia and France.
- The natural food of this worm is mulberry leaf.
- The silk produced by this moth is white or yellow in colour, called **mulberry silk**.
- Mulberry specially grown for silkworm is called **moriculture**.

Tasar silkworm

- *Antheraea paphia* belongs to the family Saturniidae are common in India, China and Sri Lanka.
- The caterpillar feeds on ber, oak, sal and fig plants. The moths do not breed easily in captivity.
- The silk produced by them is called **tasar silk**.

Muga silkworm

- *Antheraea assama* also belonging to family Saturniidae are semi-domesticated in nature.
- The native place of this species is Assam.
- The caterpillars of this worm feed on *Machilus* plant and the silk produced by this moth is known as **muga silk**.

Eri silkworm

- *Attacus ricinii* belongs to the family Saturniidae.
- It feeds on castor leaf and cocoons cannot be reeled but have to be spun.

Oak silkworm

- *Antheraea pernyi* produces good quality silk.

Giant silkworm

- *Attacus attas* belongs to family Saturniidae. It is the **largest of the living insects reaching upto 11 inch in wing span**.

Life history of mulberry silkworm

- Silkworm is dioecious *i.e.*, sexes are separate. Fertilization is internal, preceeded by copulation.
- Development includes complete metamorphosis.
- Life history of silkworm includes eggs, caterpillar, or larva, pupa, imago.

Eggs

- After fertilization each female lays about 300-500 eggs in clusters upon leaves of mulberry trees.
- The egg of *Bombyx mori* is a very small and hard structure whose shell provides a protective covering for embryonic development. Female covers the eggs by a gelatinous secretion.
- After laying the eggs the female does not take food and dies within 4-5 days.
- In India, and other tropical countries, the silkmoth lays non-diapause eggs with continuous growth and development, which enables to raise 2 to 7 generations within a year. In temperate (cold) countries, diapause eggs are laid which rest until spring when growth is resumed, so that a single generation is produced per year.

Caterpillar or larva

- The larva which hatches from egg in about 10 days is known as caterpillar. During growth the larva will moult 4 times.
- The period between successive moults is called an *instar*. The I instar larva moves about in a characteristic looping manner. Its head bears mandibulate mouthparts with which it at once starts feeding on mulberry leaves and grows very quickly. After 4-5 days it stops feeding and becomes inactive after which moulting or ecdysis takes place. The earlier skin bursts and a new caterpillar emerges out. It starts eating voraciously and then moults again. This process is **repeated four times**.
- A full grown V instar caterpillar has biting and chewing mouthparts and 3 pairs of true legs. A pair of salivary glands develop in the lateral sides of its body.

Pupa or chrysalis

- Mature caterpillar stops feeding and returns to a corner among the leaves. Its salivary glands now secrete a sticky fluid through a narrow pore of the spinneret situated on the hypopharynx (lower lip of its mouth). This sticky substance turns into a fine, long, solid thread of silk in contact with air. The saliva is continuously poured out for three or four days.
- Silk thread is composed of 5 filaments stuck together by sericin secreted by two other glands. It becomes wrapped around the body of caterpillar forming a pupal case known as cocoon.
- The silkworm transforms inside cocoon into a tubular pupa or chrysalis.

Imago

- Active metamorphic changes take place during pupation. Unsegmented abdominal legs (prolegs) disappear. Thorax develops two pairs of wings. The pupa finally metamorphosis into the imago. It secretes an alkaline fluid to moisten one end of cocoon and then escapes by forcing it way out of the softened silk. After emergence the male and female moths mate, lay eggs and die within 3 to 4 days.
- Life history of a silk moth illustrates a type of complete metamorphosis (holometaboly) among insects. Eggs of this moth hatch out into larvae which differ greatly in appearance and food habits from the adults.
- Silkworm seeds or eggs are usually of two kinds – hibernating and non-hibernating.
- **Hibernating or annuals eggs** which are deposited by the moth in spring, undergo a diapause (*aestivation* during summer and autumn, *hibernation* during winter) and hatch out only in the next spring. **Non-hibernating eggs** are those derived from successive generations without any pause in a year.
- Laying of hibernating or non-hibernating eggs depends upon the voltine character of the silkworm race *i.e.*, univoltine worms lay hibernating eggs hence from them only one crop is taken in one year. Multivoltine worms lay non-hibernating eggs. Some races are also bivoltine, trivoltine etc. depending upon the number of generations produced in a year.
- **Voltinism** is a specific characteristic and is hereditary but can be radically influenced by factors like temperature, light, humidity, etc.
- **Darkness favours laying of non-hibernating eggs**. Light favours the deposition of hibernating eggs. Hibernating eggs are usually coloured bluish grey, whereas non hibernating eggs are either pale yellow or cream coloured.

- Silk spinning activity of the silkworms is a physiological function by which the larvae probably get rid of excess of protein acquired from the mulberry leaves during the period of their growth.

Rearing of silkworm

- It is the **most important aspect of sericulture** requiring great skill, care and patience, constant vigilance and cleanliness. In India, sericulture is a subsidiary industry, carried on without much cost of labour in different parts of the country.
- The **most important appliances used for rearing silkworms** in India **include** bamboo trays, mounting or spinning trays (chandrikas), nets for transferring worms from one tray to another, knife or bonti for cutting leaves into chips etc.
- **Two methods of rearing silkworms** practiced in India are –
  - **Cellular rearing** which means rearing of individual layings separately, and
  - **Mass rearing** meaning rearing of worms in bulk for production of cocoons for reeling purpose.

Steps of rearing operations

- **Grainage management**
  - The aim of the establishment of grainage is to provide good quality of seed to rearers and maintenance of original quality of races. Proper nutrition and protection from the attack of diseases should be provided right from the caterpillar stage.
  - After final selection of good quality of "crop of silkworm", the cocoons are kept for mass emergence.
  - Males and females just after emergence have to be separated. Female of one lot is kept with the males of the other lot and copulation is allowed.
  - Fertilized females are subjected to egg laying.
- **Egg laying**
  - Within 24 hours the females complete egg laying process after which they will die. The eggs are called as **seed** and are kept in sterilized trays and stored at 4°C under laboratory conditions. One female may lay 400 to 500 eggs depending on the race.
  - This commercial seed is supplied to the rearers.
- **Hatching**
  This is an **important phase of sericulture industry** since as soon as the larvae are hatched they start feeding voraciously. So sericulturists should be able to supply sufficient amounts of fresh mulberry leaves to the young hatched larvae.
- **Supply of seed to rearers and commercial rearing**
  - Next step involves the supply of seed or caterpillars to the farmers.
  - The old rearers well versed with the rearing technique may purchase eggs for rearing but new and untrained rearers should always be given II instar caterpillars for this purpose.
  - Fully grown fifth instar larva stops feeding.
- **Spinning of coccons**
  - This is the **period when the caterpillar stops feeding and starts secreting a pasty substance from the silk gland.**
  - In this condition worms should be picked up and transferred to the spinning trays and kept in a position of slope to the sun for a short period.
  - Within three days spinning is over and the cocoon is formed and this is the **last phase of the rearing of the silkworm**.
- **Post cocoon processing** is the method of obtaining silk thread from cocoon. This **includes stifling and reeling**.
- **Stifling** is the process of killing the cocoons. Selected good sized cocoons are dropped into hot water. The killing of the cocoon in boiling water helps in softening the adhesion of the silk threads among themselves and loosening of the outer threads to separate freely, facilitating the unbinding of silk threads.
- **Reeling and spinning** : The process of removing the threads from the killed cocoon and combining them together to make a thread of raw silk is called **reeling**. 4 or 5 free ends of the threads of these cocoons are passed through eyelets and guides to twist into one thread and wound round a large wheel from which it is transferred to spools. The silk obtained on the spool is known as **raw silk or reeled silk**. The waste outer layer or damaged cocoons and threads are separated, teased and then the filaments are spun. This silk is called as "**spun silk**".
- The raw silk is further boiled, stretched and purified

by acid or by fermentation and then carefully washed over again and again to bring about the well known lustre on the thread.

Diseases

- The common diseases of silkworm are –
  - **Pebrine or pepper disease** by protozoan *Nosema bombycis*. Parasite infects eggs and is, therefore, transmitted to next generation. It kills caterpillars.
  - **Flacherie** is an infectious viral disease marked by body flaccidity and digestive disorders.
  - **Muscaridine** is caused by a fungus, *Spicaria* or *Botrytis*.
  - **Grasserie** is caused by *Borrelina* virus *bombycis*

Economic Importance

- Silk is the finest textile fibre which is known for its softness, lustre and durability.
- It is mixed with other textile fibres to produce terisilk and cotsilk.
- Because of its strength and durability, it is used in the manufacture of parachutes, filter cloth, fishing fibres, insulation coils, etc.
- It earns a lot of foreign exchange for India.
- It is cottage industry and can be undertaken by villagers on a large scale.

APICULTURE

- Apiculture or bee keeping is care and management of honey bees. Honey bees give us honey and wax. They are also good pollinators.
- Honey bees are these days raised in apiaries. **Apiary** is the place where bees are cultured and bred to get commercial products.
- **Common breeds of honey bee** are –
  - *Apis dorsata* (Rock bee) : Largest bee. Due to its ferocious and irritable nature, specific hive and migratory habit it is very difficult, rather practically impossible to domesticate them for bee keeping industry.
  - *Apis indica* : Indian bee, commonly found in forest & plain regions of India. This species is very gentle in nature & so can be domesticated easily.
  - *Apis florea* : Little bee. Due to its docile nature & rare stinging behaviour the combs can be removed easily for the honey.
  - *Apis mellifera* : European bee. Due to its docile nature they can be domesticated easily and can be improved by breeding for several hundred years. Out of its several variety, the Italian variety is reared every where in Europe & America in artificial hives for honey.

Honey bee

- Honey bees are highly specialized insects, both in structure and habits. Sense organs, mouthparts, wings, legs and many internal organs are more diversified and specialized than in cockroach or grasshopper.
- They are **social insects** living in colonies and **exhibiting polymorphism** and **division of labour**.
- The nests **(or beehives)** of honey bees, harbouring thousands of individuals, are seen hanging down the tree branches or ceilings of houses and old buildings. These are built by their cooperative efforts and manifest a spectacular engineering feat.
- Behive are formed of a secretion from the wax glands of workers. It consists of two layers of hexagonal chambers of cells. Some chambers are packed with honey and pollen. They are called the **storage cells** and are closed with a lid of wax. In other chambers, young ones are brought up. These are known as the **brood cells.** The latter are of different sizes to accommodate different castes.
- Honey bees feed on pollen and nectar of flowers. They communicate with each other through a sign language. **Mating occurs in a nuptial flight** and **development includes metamorphosis**.
- Three types of individuals (castes) found in the colony of honey bees are – **queen**, **drones** and **workers**.

Queen

- Queen (2-5) is the **only fertile female** which lays eggs continuously for 2-5 years.
- Normally one queen is found in one nest. It is 15 to 20 mm in length and can be easily distinguished by her long tapering abdomen, short legs and wings. Structurally it is unable to produce wax or honey and gather pollen nector.
- **Egg laying** is the **only function of queen**.

Drones

- Drones (45 days of life span or five weeks) are males which mate with queen. Their number in the colony is not much. The sting and wax gland are absent.

- Drones are **smaller but stouter than queen** with broader abdomen, longer appendages and larger wings.

Workers

- Workers (3-12 months) are **sterile females** and performs various duties of the colony.
- The queens and drones are fed by the workers.
- The worker bees are **darker and smallest members of the colony**. They have chewing and lapping type of mouth parts, modified for collecting nectar and pollen of the flowers.
- The abdomen contains the wax glands and the sting.
- **Wax glands** are the glandular area secreting wax lies on the ventral surface of the last 4 visible segments of abdomen. Wax is secreted through minute pores in the form of flat scales. It is masticated by the mandibles before its use for building the "cells" of the honeycomb.
- **Sting** is the **modified ovipositor of the insect** and is **used for injecting poison for protection**. It is composed of two straight grooved *stylets* or *lancets*. Their distal free ends are provided with many anteriorly-pointed spines or *barbs* which prevent the removal of sting. The muscles associated with the sting help in the operation of lancets. A set of 3 chitinous plates on either side act as levers to move the barbs. A pair of filiform *poison glands* secrete the acidic material that is stored in a sac-like storage *poison sac* located at the base of the sting. Associated with it is an elongated *alkaline gland* that secretes an alkaline material. The two materials mix to form the poison or **been venom** that flows down the sting into the wound of the victim. After stinging, the worker bee leaves the sting apparatus and dies. Sting of queen bee is longer but less barbed and can be withdrawn without injury to her own body. Males do not have a sting because they have a copulatory apparatus instead of an ovipositor.
- The worker bees of a hive fall into **three major age groups or cases**. These are–
  - **Scavenger** (or **Sanitary) bees :** For the first three days each worker bee acts a scavenger.
  - **House** (or **Nurse) bees :** From the fourth day onwards, each worker been feeds like a foster mother, with a mixture of honey and pollen. From the seventh day, the **maxillary glands** of a worker bee secrete **"royal jelly"** to feed young larvae, the queen and those older larvae which are destinated to develop into future queens. From the twelfth to the eighteenth day, each worker bee develops wax glands. Wax is secreted in the form of thin scales.
  - **Foraging** (or **Field) Bees :** When a worker bee is about 15 days old, it takes up the job of foraging. It means they explore new sources of nectar and pollen and collect these and water. These bees are also called **scout bees.** Worker bees live for a few weeks only.

Life history

- When the colony becomes overcrowded, the old queen leaves the hive along with some workers and drones. They fly to a new place to establish another colony. This is called **swarming**.
- **Swarming takes place during the spring or early summer**. New queen is then formed in the old colony. She soon undertakes a **marriage**, or **nuptial flight** with the drones. **Mating occurs in the air**.
- Drones **dies during the course of copulation**. The queen mates only once in a life time.
- The queen, after mating, returns to the hive, it stores the sperms in its spermatheca, which suffice to fertilize all the eggs laid by her and wards off the drones after copulation. She does not leave again till she becomes old when swarming occurs.
- Queen lays **2 types of eggs** – fertilized [diploid (32 chromosomes)] and unfertilized [haploid (16 chromosomes)].

Queen lays
- **Unfertilized eggs** (n) → Natural parthenogenesis (arrhenotoky) → **Drone**
- **Fertilized eggs** (2n)
  - Larva fed on royal jelly → **Queen**
  - Larvae fed on honey → **Worker** (sterile female)

- The life cycle includes **complete metamorphosis or holometabolic development**.
- Larvae emerge out from fertilized as well as unfertilized eggs which are completely different in external structure, many internal organs and mode of living from adult.
- The **drones are developed parthenogenetically**

(called **arrhenotoky**) from unfertilized egg, whereas **workers develop from fertilized eggs**.

- The **worker bees have a pollen collecting apparatus**, **honey storing mechanism and wax secreting glands**. Queen from its mandibular glands secrete a queen substance which inhibits the worker bees from building the brood chamber for future queen bees.
- Drones take 24 days to develop from egg to the adult stage.
- Larvae from fertilized eggs if fed upon royal jelly, develop into queen whereas if fed upon honey, develop into workers. Thus workers are **sterile females**.
- The royal jelly consists of digested honey and pollen mixed with glandular secretion into mouth of workers. After 5 days of feeding the cell is sealed and larvae undergo pupation.
- Queen takes about 15 days whereas workers take about 21 days to complete their development.
- Life span of queen, drone and worker is 2 to 5 years, 57 days and 3 to 12 months respectively.

Communication

- **Ernest Spytzner** (1788) was the first to draw attention to the fact that bees communicate by means of definite movements now called **"bee dances".**
- **Prof Karl von Frisch** (1946 to 1969) got **Nobel Prize** for decoding the language of "bee dances".
- He discovered that scout bees perform two types of dances for communication –
  - **Round dance** is performed when a newly discovered food source is close (less than 75 metres) to the hive.
  - **Tail wagging dance** is performed for long distance food source (farther than 75 m).

Diseases

- Two common diseases are (i) **Nosema disease** by protozoan *Nosema apis*; and (ii) **Acarine disease** by parasitic mite *Acarpis woodi*.
- A number of animals feed on honey bees or attack their hives for honey. They include wax moth (*Galleria mellonella*), bear, monkey, lizard, spider, wasp, kingcrow, black ant, etc.

Economic importance

Honey

- It is a near neutral aromatic sweet syruph having 17-25% water, 70-80% sugars, 3.3% minerals and vitamins (B_1, B_6, C and D). Sugars include laevulose (L-fructose, 41%), glucose (35%), sucrose (1.9%) and dextrin (1.5%).
- Honey is a natural sweetener.
- It is laxative, expectorant and blood purifier.
- Honey is a tonic and immediate source of energy. It is good for children and convalescing persons.
- It is used in preparation of honey biscuits and honey bread.

Bees wax

- It is a yellowish brown and insoluble in water but soluble in ether. It is secretion of worker bees from their wax glands. Bees wax is **used in cosmetics**, **creams**, **ointments**, **paints and polishes**.
- Candles are only occasionally produced because bees wax tends to crack in cold. The candles are, however, smokeless.

Bees venom

- Venom from sting is used in the treatment of rheumatoid arthritis.

Propolis

- It is resin derived from plants (auxiliary buds). Propolis has **antiseptic and antibiotic properties**.

Pollination

- The biggest use of honey bee is that it is the **major pollinator of many crop plants**.

LAC CULTURE

- Lac is the resinous secretion produced by lac insect as protective covering around its body. It belongs to genera *Laccifera* or Tachardia.
- Lac is a complex substance having large amount of resins, together with sugar, water and other alkaline substances. The **percentage of various constituents** are – **resin** - 68 to 90%, dye - 2 to 10%, wax - 6%, **albuminous matter** - 5 to 10%, **mineral matter** - 3 to 7%, **water** - 3%.
- *Laccifera lacca* is the common Indian lac insect.
- Lac insects and their products have been known to naturalists since very early times. The first scientific reference regarding the lac and the lac insect is the report of **Kerr** and **Glover** in 1782.
- Three products from the lac insects *viz,* the **lac dye**, **lac wax** and **lac (resin)** have been items of trade and commerce.
- The lac insects have more than one host plant. Common host plants are given in the table.

Host Plants

Kusum	..	*Schleichera oleasa*
Babul	..	*Acacia nilotica*
Ber	..	*Zizyphus lylopyra*
Palas	..	*Butea monospema*
Peepal	..	*Ficus religiosa*
Gular	..	*F. glomerata*
Mango	..	*Mangifera indica*
Shisham	..	*Dalbergia sisso*
Fig	..	*Ficus carica*

Life history

- The lac insect (*Tachardia lacca*) is a minute, resinous insect which inserts its beak into plant tissue, sucks juices and grows. It secretes lac from the hind end of the body and ultimately gets covered with lac in the "cell". Lac is actually secreted for its protection and not for the food of the insect.
- Male is red in colour and secretes bright creamy lac. Female is larger than male. The female after fertilization lays about 200-500 eggs in a cell in which it is enclosed. After 6 weeks of laying, the eggs are hatched into first instar nymphs. The nymphs emerge in large number and this mass emergence of nymph is called **"swarming"**. These nymph suck the sap from host plant and grow in size. Various morphological changes occur and after a period of 6 to 8 weeks they are metamorphosed as a result of which about 30% active winged males and 70% wingless females emerge. The females get fixed on the host plant in a resinous mass. The males walk over the encrustation of females and fertilize them.
- Due to short life period males do not take major part in the secretion of lac but **female secretes lac throughout her life** and **its life span is larger than males**. Thus major quantity of lac is secreted by females.

Lac cultivation

- In order to obtain lac, lac insects cultured and the technique of lac production is known as the *lac culture*.
- For the purpose of propagation the older branches containing crusts are tied with new branches and this method is called **oculation**.
- When new crusts are formed, the old twigs are removed (approximately 20 – 30 cm long) and this is known as **harvesting**.

Processing of lac

- When the crop matures fully most of the lac is harvested and some part is left on the host plant.
- The twig bearing the lac along with eggs is called a "**brood lac stick**" and lac is known as "**brood or stick lac**". The processing starts with scraping of the stick lac from the twig. Brood lac is subjected to various processing steps to obtain purest form of lac, called **"shell lac"**.
- The **quality of lac depends upon the host plant**.
- Palas and Ber produce the best quality lac known as **kusumi lac** while **Dhak lac** is supposed to be the worst and cheapest one.

Economic importance of lac

- It is used as filling material in gold jwellery.
- It is used in making polishes, paints and varnishes.
- It is utilized for preparation of toys, buttons in pottery and artificial leather.
- It is used as an insulating material for electric goods.
- It is used as sealing wax.
- It is used in the manufacture of photographic material and lithographic ink.

Lac industry in India

- India has monopoly on the production of lac. Other countries like Africa, Australia, Brazil, China, Thailand, Japan etc. also produce lac.
- About 50% of the total lac produced in India is obtained from chhotanagpur region. 'India Lac Research Institute' Namkum, Ranchi had been established in 1925 which is producing good quality of white lac.

SNAKE VENOM AND ANTIVENIN

- There are two biting teeth in poisonous snakes called fangs (modified maxillary teeth). The fangs are connected to poison gland which are modified salivary glands (parotid and labial).
- The snake poison is of **two types** – **neurotoxic** which causes respiratory arrest due to neuromuscular paralysis, eg. – cobra, krait, sea snake and **hematoxic** which causes wide spread haemorrhage and destruction of body tissues, e.g. – viper.
- **Antivenin** is prepared by immunising horses against common poisonous snakes. For this purpose the horse is given frequent and increasing doses of

toxin (venom) injection that the animal can tolerate the toxicity. The blood from such immunized horses is taken out and allowed to clot. Serum is separated from clotted blood which is now called as '**antivenin**'. Antivenin is packed in phials for commercial purpose.

- Antivenin is **prepared at Haffkine institute**, **Mumbai**.
- The **snake venom is used in the treatment of a number of diseases** like arthritis, epilepsy, neuritis, migraine, asthma, insomnia etc. *Russell viper's* venom is used in treatment of haemophilia as it has coagulating property.

IMPROVEMENT OF ANIMALS

- The improvements of animals is brought about by selection for desirable tracts by –
  - Inbreeding and selection.
  - Outbreeding or hybridization and selection.
  - Artificial insemination.

Inbreeding & Selection

- The process of mating among closely related individuals is known as **inbreeding**. Inbreeding combined with selection over a period of time has resulted in many valuable breeds of domestics animals. For example –
  - Merino sheep known for producing fine wool are developed in Spain as a result of inbreeding and selection conducted for about 170 years. Rambouillet sheep were developed in France from Merino breed.
  - Modern race of horses are the descendents of three Arabian stallions imported into England between 1686 and 1730 and mated with several local mares of the slow and heavy horse type.

Hybridization

- It is practised for creating new breeds. Some examples of hybridization or controlled breeding are –
  - A cross breeding between white short horn and the black Angus cattle produces a Blue roan hybrid which had the vigour, rapid growth, economical utilization of food and high quality of beef.
  - A cross between Brahman Bull, a race found in India with domestic cattle of European origin produced hybrids which showed greater adaptability to warm and humid climate.

Artificial insemination

- In India, artificial insemination was first exercised in 1944 at Indian Veterinary Institute, Izatnagar. In this method the semen from the better quality bulls is collected, stored and artificially introduced into the oviducts of females. The semen can be preserved for long time and can also be transported to different places.

Advantages of artificial insemination

- It is very economical and makes possible a wider use of superior bulls. A bull normally produces 50 to 60 calves per year by natural mating. By restoring to artificial insemination it is possible to produce about 1000 calves in a year from one bull.
- The semen can be collected from the bull and used at distant places, while transportation of bull is not practicable.
- The spread of diseases can be controlled. A large number of foreign breeds of cows, bulls, buffaloes and other animals have been introduced in India. Some of these are : Jersey (England), Ayrshire (Scotland), Brown Swiss (Switzerland), Holstein, Freisian (Holland) etc. By cross breeding with Indian varieties following hybrid varieties have been developed : Jersey-Sindhi, Ayrshire-Sahiwal, Brown Swiss-Sahiwal etc. Animals like chicken, ducks, pigs, boars, etc. have also been improved by introduction. Boars of foreign breed like Large White Yorkshire, Middle White Yorkshire and Berkshire have been introduced in India for improving Indian pigs.

End of the Chapter

Chapter 75

Animal Behaviour

- **Behaviour** can be defined as the way an organism responds to stimuli in its environment.
- The **ethology** (Gr. *ethos*, habit; *logos*, study) deals with the study of animal behaviour and is one of the recent branches of zoology.
- Ethology is **concerned primarily with natural behaviour exhibited by a wide variety of animals** living under natural and seminatural conditions.
- **Kandel** (1976) **defines animal behaviour** as all observable muscular and secretory responses to changes in an animal's internal and external environment.

Branches of ethology

Ecothology	– Relationships between behaviour of a species and its environment.
Ethophysiology	– Physiological basis of behaviour.
Neuroethology	– Sensory process and central nervous system that underline a particular behaviour.
Ethoendocrinology	– Relations between hormones and behaviour.
Ethogenetics	– Genetic basis of behaviour.
Behavioural embryology	– Prenatal development of behaviour pattern.
Human ethology	– Study of human behaviour

- The scientific study of animal behaviour has its origins in the work of **Gilbert White** (1720-1793) and **Charles Leroy** (1723-1789).
- The most significant starting point in the understanding animal behaviour came from the works of **Charles Darwin** (1809-1882). He is **regarded as the father of the scientific study of animal behaviour**.
- Two important works of Darwin with reference to animal behaviour are: '**The Expression of the Emotions in Man and the Animals**' (1873) and '**The Descent of Man in Relation to Sex**' (1871).
- The work of **Charles Whitman** (1842-1910), **Wallace Craig** (1876-1954) and **Oskar Heinroth** (1871-1945) provided further basis for future development of ethology.
- **Konrad Zacharius Lorenz** (1903-1989) from Vienna, **Karl Von Frisch** (1886-1983) from Germany and **Nikolaus Tinbergen** (1907-1988) from Holland are generally regarded as the **founders of modern ethology**. In 1973, all the three were awarded the **Nobel Prize** in Physiology and Medicine for their pathbreaking contributions to behavioural science.
- **Karl Von Frisch's** greatest material contribution was his work on honey bee communication (1943) and sensory biology.

INNATE AND LEARNED BEHAVIOUR

- Animal behaviour may be broadly classified into two types – **innate** and **learned behaviour**.

Innate behaviour

- The term innate **refers to the activities characteristic of the species**.
- Innate behaviours are also called **inherited, inherent, inborn, stereotyped** or **instinctive behaviours**.
- In this behaviour, the **organism is** to a large extent **stimulus bound** where a pattern of stimuli trigger a sequence of responses.
- Innate behaviour is an outcome of inherited properties of the nervous system of the organism.

The animal behaves in a stereotyped and predictable manner.

- Innate behaviour is **independent of the experience** of the individual; it is **determined by heredity and is a part of the animal's original makeup**.
- Innate behaviours are **modified by natural selection** and **also by genetic factors and the experience of the individual**.
- Innate behaviour is of **three types** – **taxes**, **reflexes** and **instincts**.
- **Taxes** means the **orientation of the body with respect to the source of stimulation**.
- The animal's body takes up a particular direction which may be combined with locomotion.

Types of taxes

Klinotaxis	– Receptor incapable to discriminate the source of stimulation.
Trophotaxis	– Simultaneous comparison of stimulation by bilaterally symmetrical receptors.
Telotaxis	– Taxis without simple balance between two sources of stimulation.
Menotaxis	– Also known as light compass response, involve orientation at a constant angle.
Mnemotaxis	– Taxes without involvement of configuration stimuli.
Phototaxis	– Locomotory movement caused by light.
Thermotaxis	– Response to temperature.
Chemotaxis	– Response to chemical stimuli.
Geotaxis	– Response to gravity.
Rheotaxis	– Response to current of water.
Thigmotaxis	– Response to contact.
Galvanotaxis	– Response to electric current.

- **Reflexes**, like taxes are relatively stereotyped behaviours controlled by inherited neural mechanisms.
- There are **two types of reflexes** namely **tonic reflexes** and **phasic reflexes**.
- Tonic reflexes are slow, long lasting adjustments like muscle tone, posture and equilibrium.
- Phasic reflexes are quick, short lived adjustment as found in the flexure response.
- The reflex response is one of the major modes of adaptation in animals.
- **Instinct** is the most controversial term in ethology and is frequently understood as an innate behaviour mechanism expressed in ordered movement sequences.
- Instincts involve complex and often highly rigid pattern of behaviour.
- A **fixed action pattern** (FAP) is a type of instinct found to be same in all members of a species (stereotype).
- The notion of the fixed action pattern was formulated by **Konrad Lorenz**.
- A fixed action pattern is a specific and stereotyped sequence of activities that is triggered by a specific stimulus called a **sign stimulus** or **releaser**.
- Fixed action pattern sequences are inherited; they require no previous experience and are characteristic of the species.
- FAP **cannot be influenced in performance by external stimuli**.
- A **classic example of FAP** is provided by the study of **egg-rolling behaviour of the greylag goose** (*Anseranser*).
- Occasionally responses (FAPs) occur in the absence of the appropriate stimulus called **vacuum behaviours**.
- Insectivorous birds deprived of flying insects, for example, may fly out and go through all the motions of catching, killing and eating an imaginary insect.
- Some artificial stimuli were found to elicit responses more effectively than the natural, normal stimuli.
- Exaggerated form of stimulus which releases a particular behaviour pattern more effectively than the appropriate natural stimulus is called **supernormal releaser**.
- The building of a web by a spider is an example of a fixed action pattern.

Learned behaviour

- In addition to innate (inherited) behaviours, most animals develop **learned behaviour** (**acquired behaviour**) patterns from interacting with their environment.
- The modification of a behaviour as a result of experience is called **learning**.
- During learning, new relationships develop among neurons in the nervous system, allowing the animal to acquire new behaviours and modify inherited responses.

- **Non-associative learning** is the simplest type of learning which does not require an animal to form an association between two stimuli or between a stimulus and a response.
- Simple non-associative learning involves **habituation** and **sensitization**.
- Habituation can be **defined as a decrease in response to a repeated stimulus that has no positive or negative consequences**.
- Sensitization is **characterized by an increased responsiveness to a stimulus**.
- **Associative learning** is a behavioural alternation that involves an association between two stimuli or between a stimulus and a response.
- The behaviour is modified or conditioned, through the association.
- This form of learning is **more complex than habituation or sensitization**.
- **Two main types of associative learning** are – **classical conditioning** and **operant conditioning**.
- In **classical conditioning**, an association is formed between a previously neutral stimulus and a physiological response controlled by the autonomic nervous system.
- Classical conditioning is also called **Pavlovian conditioning**, after the Russian physiologist **Ivan Pavlov** (1849-1936) who first described it.
- Pavlov worked on the **condition reflex** and showed that if the presentation of food to a **dog** was repeatedly accompanied by the sound of a bell, then the dog would come to respond to the bell as if it was food.
- Pavlov **regarded the salivation of the food as an unconditional response** and the subsequent salivation to the bell alone as a conditional response.
- Pavlov is responsible for many of the basic concepts and can be regarded as the **founder of the experimental study of animal learning**.
- Pavlov received a **Nobel Prize** in 1904 but it was **for his work on digestive physiology rather than for his work on conditioning**.
- In **operant conditioning**, associations are formed between a completely voluntary response and the stimulus associated with the consequences of the response.
- Animal training in which behaviour is "shaped" by rewarding or punishing acts, is **an example of operant conditioning**.
- **Imprinting** is **another kind of learned behaviour**.
- It is the imposition of a stable behaviour pattern in a young animal by exposure to particular stimuli during a critical period in the animal's development.
- Imprinting was observed at least as early as the first century AD. by the Roman naturalist **Pliny**.
- **Konrad Lorenz** was **first to study imprint objectively and systematically** and given credit for developing the concept of imprinting in 1937.
- Imprinting is genetically programmed to take place during specific, sensitive periods, lasting only a few hours or days.
- Although imprinting typically occurs in the very young, it can also occur at any point during an animals life.
- Imprinting is found to influence the associations of young with their parents, mate selection, choice of habitat and a variety of social behaviours including parental care.
- **Maximum work on imprinting is carried out** in groundnesting birds, but it also has been observed in other vertebrates ranging from hoofed mammals to domestic dogs.
- **Osker Heinroth** (1871- 1945), a German zoologist, is often given the credit for being the first to use the term '**imprinting**'.
- Imprinting is a rapid form of learning and is critical to normal behavioural development.

ANIMAL COMMUNICATION

- Communication is the passage of information from one animal to another through messages or signals.
- Many signals are simple and direct, whereas others are extremely complex, involving complex interaction among animals.
- "Communication" is usually treated equivalent to "**social behaviour**".
- Most examples of communication are intraspecific social interactions.
- The basic general characteristic of the common concept of communication include a **signal** (coded information or message), a **sender** and a **receiver**.
- Both sender and receiver, but not always, belong to the same species.
- Animals **communicate through the use of chemical**, **visual**, **auditory**, **tactile** and **electrical signals** that can be perceived by other individuals.

Chemical communication

- Molecules used for chemical communication between individual animals are called **pheromones**.
- Pheromones can communicate very specific messages that contain a great deal of information.
- Pheromone message **last a long time**, **but they cannot be changed quickly**.
- An important feature of pheromones is that once **they are released**, **they remain in the environment for a long time**.
- When a female **gypsy moth** is ready to inseminated, she releases a pheromone called **gyplure**.
- Pheromone-producing glands are found in **black-tailed deer**. They include metatarsal, tarsal, anal, interdigital and forehead glands.
- Scents from the metatarsal are rubbed onto other regions of the body such as the forehead, which in turn, is rubbed on twigs.

Visual communication

- Many species use visual communication which is transmitted instantaneously and can carry a large amount of information.
- **Visual signals** are known as displays, often include specific movements and postures.
- A display or signal is a behaviour that has evolved to influence the behaviour of other individuals.
- **Visual signals are easy to produce**, **can be changed rapidly** and **clearly indicate** the position of the signaler.
- Most animals are sensitive to light and can therefore receive visual signals.
- Birds are **highly visual** and have evolved a vast diversity of patterns of coloured feathers used in communication.
- Because visual communication requires light, it is not useful for many species at night.
- Visual communication **cannot be used over great distance**.
- It is **blocked easily** by obstacles so that the sender and receiver must be in direct line of sight.
- **Fireflies use an enzymatic mechanism** to create flashes of light.
- By emitting flashes in species-specific patterns, fireflies can advertise for mates at night by sending visual signals.

Auditory communication

- Humans are very familiar with communicating by sound.
- Compared to visual communication, auditory communication has several advantages and disadvantages.
- Sound can go around obstacles that would interfere with visual signals.
- Sound is **better than visual signal** at getting the attention of a receiver.
- Sound is good for communicating over long distance. The humpback whales use their complex song to locate each other over vast areas of ocean.
- Most invertebrates do not produce loud sound, **cicadas** and **crickets** are marvelous **exceptions**.
- Sound may be transmitted by the air or water or *via* the substrate. Many spiders, for example, communicate by vibrations of the web.

Tactile communication

- Tactile communication is generally found in situations of close bodily contact between individuals.
- This communication **occurs in combination with olfactory**, **visual or auditory signals**.
- Communication by touch is **extremely common in social insects** such as ants, termites or honeybees.
- One of the most remarkable and best studied uses of tactile communication is the **dance of honeybee** to convey information about distance and direction of the food source.
- Dancing bees also make sounds and carry odours on their bodies.

Electric communication

- In addition to being used for sensing objects in the immediate surrounding, **electric signals** are **used to communicate messages in fishes**.
- Some fish use electrosensors to gather information about their murkey environment.
- **Glass knife fish** (*Eigenmannia*) males emit lower frequencies than females.
- The most dominant male has the lowest frequency and the most dominant female has the highest frequency.

HUMAN BEHAVIOUR

- Like all other animal behaviour, human behaviour consists of genetically determined and learned components.
- An **important characteristic of human behaviour** is the extent to which it can be modified by the experience.

- The transmission of learned behaviour from generation to generation-culture-is the hallmark of humans.
- The structure and many functions of our brain are coded in our genome.
- Biological drives such as hunger, thirst, sexual desire and sleepiness are inherent to our nervous system
- The emotions such as anger, aggression, fear, love, hate and jealousy may not be solely the consequences of learning.
- Human sensory systems enable him to use certain subsets of information from the environment.
- The structure of human nervous system makes it more or less possible to process certain types of information.
- Humans possess the most highly advanced communication ability of any living species.
- The capacity of human language is familiar to all.
- Language is a major and every day of human life.
- Verbal communication is deeply rooted in the human evolution.
- Reading and writing are relatively recent products of human culture.
- The chemical senses including taste and olfaction, are perhaps the most universal among animals.
- Human chemical sense appears to be crude and insensitive.
- The simple four-class taste system (salt, bitter, sour and sweet) is applicable to humans, certainly does not apply to all animals.
- Sleep is the most extreme state of inactivity. It has been studied and described most extensively in humans.
- Some motor patterns are programmed into our nervous system.
- Basic similarities of facial expression and body language in human population have little or no contact with one another.
- Infants born blind smile, and show other facial expression at appropriate times, even though they have never observed such expressions in others.

End of the Chapter

Chapter 76

Bioenergy

- **Bioenergy** is stored energy from the sun contained in materials such as plant matter & animal wastes, known as biomass.
- **Biomass** is actually a product of solar energy that has been stored by the photosynthetic activity of plants.
- Biomass is present in many common waste, such as agricultural waste, forest waste, municipal waste food processing waste, pulp and paper mill residue, urban wood waste, energy crops, landfills methane and animal waste.
- Biomass does not add carbon dioxide to the atmosphere as it absorbs the same amount of carbon in growing as it releases when consumed as a fuel. Its advantages is that it can be used to generate electricity with the same equipment or power plants that are now burning fossil fuels.
- Biomass is an **important source of energy and the most important fuel worldwide after coal, oil & natural gas**.
- **Biomass is essentially a renewable energy source** because it replenish more quickly without permanently depleting the Earth's natural resources and **helps to conserve soil and water.**
- About **0.2 percent of the solar energy** which reaches the earth's surface is converted into biomass.
- Biomass can be **used to generate producer gas** to run irrigation pumps, to replace petrol, to get alcohol, to generate biogas or to generate electricity.
- The total quantity of matter (dry mass) in the organisms forming a trophic level or population or inhabiting a given region is called **biomass**.
- Most of energy which mankind has been using or which mankind still uses, is derived directly or indirectly from sun.
- **Bioenergy** is obtained from following types of biological sources: **animal energy, biofuels and fossil fuels.**
- **Animal energy** can be classified into **human muscle power (HMP)** and **draught animal power (DAP)**.
- Energy used by labourers, farmers, and household working women is **human muscle power**.
- Energy used by animals in agriculture and transport is called **draught animal power**.
- DAP is of significant importance in the rural and hilly areas, where most of the work is done by draught animals.
- **Biofuels** are the combustible bodies of plants or combustible product derived from biomass.
- Biofuels are **renewable**. If they are used properly and efficiently they can help overcome energy problems of India.
- **Major sources of biofuels** are – **wood, agro-industrial residues** and **petroleum** and **oil producing plants**.
- **Wood** is defined as the main strengthening and water conducting vascular tissues in stems & roots of plants.
- **Good firewoods** must be highly combustible; should produce high calories on burning; when burnt, it should not split; can be dried easily; should be non-resinous and should not produce smoke, and should not release offensive smell.
- **Dicotyledonous woods** (called **hard woods**) are considered **better than gymnospermous woods** (called **softwoods**) because these burn for a longer time and provide uniform heat.
- **Good fire woods** are – *Acacia senegal* (Gum Arabic), *Acacia nilotica* (Kikar), *Albizzia* (Siris), *Azadirachta indica* (Neem), *Quercus* (Oak), *Casurina* (Jhau), *Adina cordifolia* (Yellow teak), *Hopea* (Dammar tree), *Dalbergia sisso* (Shisham), etc.

- **Bad fire woods** are – *Pinus roxburghii* (Chir pine); *Mangifera indica* (Mango); *Madhuca indica* (Mahua); *Bauhinia racemosa* (Kachnar) etc.
- **Fuel-wood** constitutes **the most important source of energy** in developing countries of the world.
- Fuelwood consumption provides almost **43% of the total energy** consumed in developing countries and amounts to about **14% of the total world's energy production**.
- Coal, oil and natural gas represent the photosynthetic output of green plants which occurred millions of years ago.
- **Forms of energy obtained from wood** are carbonisation, gasification, pyrolysis etc.
- **Carbonisation** of wood is heating of wood till it gets converted into charcoal/carbon.
- **Gasification** is the process in which the wood is heated and air/steam is allowed to pass over incandescent coke to produce the **producer gas**.
- **Pyrolysis** is the heating of wood & waste wood to high temperature to produce charcoal, pyroligenous acid, tar, oil etc.
- **Producer gas** is mixture of approximately 25% carbon monoxide, 55% nitrogen, 13% hydrogen & 7% other gases.
- Producer gas is cheap & used as a fuel mainly in glass furnaces & metallurgical furnaces. It also serves as a fuel in gas engines to operates tractors, motor cars etc.
- The following **three methods have been suggested to overcome fuel wood crisis–**
  - Growing of energy plantations with fuel wood efficiency.
  - Improved chullahs should be used. The present day chullahs have a very low efficiency resulting in loss of useful energy.
  - Processes like carbonisation (conversion of wood into carbon), gasification (conversion into gas) and pyrolysis (thermochemical conversion) are being used.
- **Energy plantations** are the plantations where fuel wood trees are grown. Such plantations would ensure the supply of firewood to nearby areas.
- **Coppicing** means thick growth of branches from the stump after the aerial branches have been removed.
- **Afforestation** of all available lands (not held by the forest department) by communities of people to obtain ecological and environmental security, fodder, fuel wood, fibre, fruits etc., is called **social forestry**.
- **Direct combustion** is the simplest, cheapest and most common method of obtaining energy from biomass.
- **Global warming** is an increase in the average temperature world wide believed to be caused by green house effect.
- **Biogas**, also called **digester**, typically refers to methane produced by the fermentation of organic matter including manure, waste water sludge, municipal solid waste, or any other biodegradable feedstock, under anaerobic condition.
- Biogas is also called **swamp gas**, **landfill gas** & **marsh gas** depending on where it is produced.
- Biogas contains 50-70% methane, 30-40% CO_2, traces of hydrogen, hydrogen sulphide and nitrogen.
- **Stages in anaerobic digestion during biogas formation** are –
  - The facultative anaerobic micro-organisms break down the polymers into soluble monomers with the help of enzymatic hydrolysis. Lignin cannot be broken down by micro-organism, so it remains as residue along with inorganic salts.
  - The monomers become the substrate for micro-organisms. These are then converted into organic acids.
  - In this stage, soluble organic acids (acetic acid) are formed for the substrates of the last stage.
  - Finally **methanogenic anaerobic bacteria** produce methane (biogas).
- Scarcity of firewood, indoor health problems with cooking on firewood or cow-dung fire, and loss of fertilizer from burning cow-dung are the problems of biogas plants in India.
- Biogas can be easily stored to provide more efficient source of energy which has wider uses than the traditional energy sources.
- The production of biogas **results in the formation of a stabilised residue that acts as the fertilizer**.
- **Petroleum plants** or **Petro-crops** are plants which can yield large amount of latex having long chained liquid hydrocarbons, e.g., *Jatropha, Euphorbia lathyris* (family Euphorbiaceae), *Brickellia* (family compositae), and other members of euphorbiaceae, compositae, asclepiadaceae and apocynaceae.

- The product can be used directly or broken through cracking to yield a number of petroleum products.
- Utilising petroleum plants for energy cropping was first suggested by **Melvin Calvin**.
- **Latex** is fluid product of laticiferous plants that exudes from the cut surfaces as a milky juice. It contains long chained liquid hydrocarbons. The latex can be used directly or broken through cracking to yield petroleum products.
- **Alcohol** can be used as a fuel for automobiles either or as 10-15 per cent blend with petrol or as entire fuel, the mixture is called **gasohol**.
- **Pro-alcohol** programme of Brazil is aimed at completely replacing petrol with alcohol for running automobiles.
- The crops which can be used for the production of alcohol are called **energy crops**. Some energy crops are maize, sugarcane, sugarbeet, tapioca and molasses.

Table : Application of bioenergy

Bioenergy applications	**Potential users**	**Sources of bioenergy**
Process heat and/or electricity	**Industrial**	Pulping liquor and wood residues are burnt in large boilers. Wood residues are processed using **gasification** to produce fuel gas. Forestry and agricultural residues are processed using liquifaction pyrolysis to produce bio-oils.
	Municipal	Municipal solid waste is burnt directly or digested in a landfill to produce landfill gas. Municipal sewage is processed biologically in anaerobic digesters to producer biogas.
Space and water heat	**Residential**	Chunk wood or pellets are burnt in high-efficiency enclosed fireplaces, box-stoves, furnaces and cook stoves.
	Commercial	Wood or agricultural residues are burnt in furnaces to produce direct heat or to heat water in boilers. The biomass can be made into a more efficient fuel by transforming it into pellets, briquettes and logs.
Automobile fuel	**General public**	Straw and corn stover are converted to sugars that are fermented to produce ethanol.
Heavy vehicle fuel	**Trucking industry**	Oilseed is processed using extraction to produce bio-diesel fuel.

End of the Chapter

Chapter 77

Growth of Human Population

- **Clark (1954) defined population** as a group of individuals of a species occupying a definite geographic area at a given time.
- Human population all over the world belongs to single species *i.e. Homo sapiens*.
- The scientific study of human population is called **demography**. It involves three major phenomenon – **changes in population size; the composition of population; the distribution of population**.
- There are **five** "**demographic processes**", namely **fertility, mortality, marriage, migration and social mobility**. These five processes **determine size**, **composition and distribution**.
- Population growth is determined by biotic potential and environmental resistance.
- **Biotic potential** is the capacity of organisms to produce offspring.
- The environmental factors which can check the growth of population size constitute **environmental resistance**. The factors include non-availability of food and shelter; drought, cloud burst etc. and certain biotic factors like pathogens, parasites, predators etc. Thus environmental resistance does not allow population growth to soar towards infinity.
- **Population grows** when the number of births is greater than the number of deaths.
- Population size may change when individuals enter or leave the population.
- If more individuals **enter** then population **will grow** and if more individuals **leave** the population, the population **will shrink**.
- The rapid increase in human population size over a relatively short period is called **human population explosion**.
- Human population growth rate is measured as the '**annual average growth rate**'. It is calculated as follows:

Average annual growth rate (in %)

$$= \left(\frac{p_2 - p_1}{p_1 \times N} \right) \times 100.$$

where, P_1 = Population size in the previous census, P_2 = population size in the present census.
N = Number of years between the two census.

- The time required for a population to double itself is called the **doubling time**.
- Population growth rate **depends on factors like fertility, mortality, migration, age and sex structure**.
- **Fertility** is the ability of reproductively active individuals to produce babies.
- The number of babies produced per thousand individuals is called **birth rate** (natality). The birth rates do not indicate the current fertility pattern. It increases the population size and population density.
- **Total fertility rate** (TFR) is the average number of children that would be born to a woman during her life time, assuming the age-specific birth rate of a given year.
- **Replacement level** (RL) is the number of children a couple must produce to replace them. The actual RL is always slightly higher than 2.0 since some children will die before reaching reproductive age. In developed countries, RL is attained at 2.1, where as in developing countries, it is around 2.7 due to a higher death rate at immature age, and shorter life expectancy.
- **Mortality** is the death rate per thousand individuals.
- The death rate has dropped mainly due to improved personal hygiene, sanitation and modern medicines. A **decrease in death rate** results in **increased population growth rate**.
- The difference between the number of births and that of deaths is the **rate of natural increase**. If birth and death rates are equal a zero population growth rate will result, which is called

demographic transition.

- **Migration** refers to the movement of individuals between different places. The movement of individuals into a place/country is called **immigration**, while the migration out of a place/country is called **emigration**. Migration between the countries influences a nation's population.
- The movement of individuals into a place/country is called **immigration**, while the migration out of a place/country is called **emigration**.
- Migration emigration and immigration are three types of population dispersal. **Population dispersal** is the movement of individuals or propagules into or out of population for preventing overcrowding, obtaining food, avoiding predators and other adverse conditions.
- The population of individuals of different ages within a particular population is called its **age structure**, while the population of male and female individuals in a population is called its **sex structure**.
- The proportion of reproductively active males and females in a population influence the population growth. Most of the developing countries like India have larger number of young people and represent rapidly growing populations.
- **Age composition** or **age ratio** is relative abundance of pre-reproductive, reproductive and post-reproductive individuals in a given population.
- **Pre-reproductive** is before the age of child bearing. It is 14-18 years in human beings; **reproductive** have individuals in the age group of child bearing, 14-45 years in woman and 18-59 years for men and **post-reproductive** have individuals after the age of 45-59 years when they are not able to bear children.
- **Age pyramid** is graphic representation of abundance of individuals of different age groups with per-reproductive at the base, reproductive in the middle and post-reproductive at the top.
- Age pyramids are of **three types** – **triangular age pyramids**, **bell shaped age pyramid** and **urnshaped age pyramid**.
- **Triangular age pyramid** has high proportion of pre-reproductive individuals, moderate number of reproductive individuals, and fewer post-reproductive individuals. It represents **young** or rapidly **growing population**.
- In **bell-shaped age pyramid** the number of pre-reproductive and reproductive individuals is almost equal. Post reproductive individuals are comparatively fewer. It represents stable or **stationary population** where growth rate is near zero.
- In **urn-shaped age pyramid** the number of reproductive individuals is higher than the number of pre-reproductive individuals. It represents **declining** or **diminishing population**.
- **Growth of a population** can be **expressed by a** mathematical expression, called **growth curve** in which logarithm of total number of individuals in a population is plotted against the time factor.
- Growth curves **represent interaction between biotic potential and the environmental resistance**.
- Population growth curves are of **two major types**: the **J-shaped curve** and the **S-shaped curve**.
- The **J-shaped curve** shows **three stages**: lag phase, exponential phase and crash phase.
- The J-shaped curve is a biopotential curve when environmental resistance is zero; it is produced because larger populations increase more rapidly than smaller ones.
- **J-shaped growth curve** is shown by small population of reindeer experimentally reared in a natural environment with plenty of food but no predators.
- **Lag phase** is period of adaptation of animals to new environment so is characterised by slow or no growth in population.
- **Logarithmic or exponential phase** is characterised by rapid growth in population which continues till enough food is available. But with the increase in reindeer population, there is corresponding decrease in the availability of food which finally becomes exhausted, which leads to mass starvation and mortality. This **sudded increase in mortality is called populatio crash** or **crash phase**.
- The **S-shaped curve (sigmoid curve)** is generated when a population approaches the environment's carrying capacity.
- Carrying capacity is defined as the feeding capacity of an environmet of a ecosystem for a population of a species under provided set of conditions. The limit beyond which no major increase can occur is represented by K. **When population reaches the carrying capacity of its evironment, the population has zero growth rate**.
- The S-shaped curve shows three phases –
  – **Early phase** (**Lag phase**): Little or no growth takes place due to small size of population and lack of adaptation.

- **Middle phase** (**Log phase or exponential phase**): There is geometrical increase in population size owing to abundance of food and other favourable conditions.
- **Stationary phase** (**Zero growth or Plateau rate**): Birth and death rates are equal, the population stabilizes around the carrying capacity of the environment. So there is zero growth phase.

- S-shaped growth is **shown by yeast cells and most of organisms**. Sigmoid growth curve was described by **Verhulst** (1839).
- In 1798, T.R. Malthus, a British economist, **put forward a theory of human population growth**.
  - He stated that population grows geometrically when unchecked, whereas the means of its subsistence like food grow only arithmetically.
  - Naturally, after some time an imbalance would occur in the population and the environment.
  - When the imbalance reaches a certain value, some factors like hunger, epidemics, floods, earthquakes, war etc, will bring the population to desired level. Such a population crash is called **catastrophic control of population**. These factors were called positive checks by Malthus.
- **Causes of icrease in human population** are –
  - **Control of disease** (**decline in death-rate**) : In old days, people used to die in thousands because of illness. But the development of medical sciences has protected them from such unnatural deaths. So there is decrease in death rate and not the increase in birth rate that has led to the increase in population.
  - **Development of agriculture** : Man needs food for all his body requirements. For this he developed the techniques to grow more food. Thus he could afford food for more people on this earth. Not only agriculture, but other animals that are used as food by man were also reproduced successfully using scientific methods.
  - **Storage conditions** : Food is not available at all the times. So people used to die of starvation when food was not available. With the better storage conditions, the food could be made available at all times.
  - **Transport** : With the development of means to go from one place to another safely, the population also increased. Food growth in one region could be transported to another region where it could not be grown. Thus people living in remote places were also fed.
  - **Protection from nature** : Man formed houses so that he can protect himself from wild animals and enviornmental calamities. He then formed villages, cities and countries.
- **Consequences of over population** leads to a number of not only national but also individual family problems. Some of them are described below–
  - **Poverty** : If in a family there are more persons and the income is less, so naturally it becomes poor. With the addition of evey child, the poverty increases.
  - **Food supply** : If the population increases and the production of food does not increase, this will lead to a shortage of food supply.
  - **Hygenic condition** : More people in a small area generally make the hygenic conditions bad. There will be an accumulation of waste material as it is not removed that early.
  - **Unemployment** : More number of people means more jobs and if sufficient number of jobs are not available, it leads to unemployment.
  - **Housing problem** : For more people, more houses are required and the houses are not built at high rate.
  - **Pollution** : There will be an added problem of population. As every thing is taken from environment in excess, so it will result in pollution.
  - **Education problem** : It becomes difficult for the government to provide education to all.
- **Measures to control over population** are – (i) **Education** : People, particularly those in the reproductive age group, should be educated about the advantages of a small family. Mass media and educational institutions can play an important role in this campaign. (ii) **Age of marriage :** Raising the age of marriage is more effective means to control the population. (iii) **Family planning :** There are many birth control measures which can check birth rate.

BIRTH CONTROL

- The regulation of conception by preventive methods or devices to limit the number of offspring is called **birth control.**

- A variety of methods are known for birth control. The birth control methods which deliberately prevent fertilization are referred to as **contraception.**
- **Contraceptive methods** are preventive methods to help woman avoid unwanted pregnancies. These methods are of 2 main types: **temporary** and **permanent**.
- Temporary methods includes **natural methods** (safe period, coitus interruptus, abstinence), **chemical method, mechanical means** and **physiological (oral) devices (hormonal)**.
- A week before and a week after menses is considered the **safe period (rhythm method)** for sexual intercourse. The idea is based on the following facts: (i) ovulation occurs on the 14th day (may be 13th to 16th day) of menstruation; (ii) ovum survives for about 2 days; (iii) sperms remain alive for about 3 days. This method may reduce the chances of pregnancy by about 80 percent. It has certain drawbacks also.
- **Coitus Interruptus** is the oldest method of birth control. It involves withdrawal of the penis by the male before ejaculation so that semen is not deposited in the vagina and there is no fertilization. This method also has some drawbacks. Male produces some lubricating fluid from his Cowper's glands before ejaculation. This fluid contains many sperms.
- **Abstinence** is the best and 100% reliable way to avoid conception is to abstain from sexual intercourse. It is an unnatural mode of birth control, and seems impracticable. Some couples practice abstinence at certain times with success.
- **Chemical means** (**Spermicides**) : Foam tablets, jellis, pastes and creams, if introduced into the vagina before sexual intercourse, adhere to the mucous membrance and immobilise and kill the sperms by inhibiting oxygen uptake. These contain spermicides such as lactic acid, citric acid, boric acid, potassium permanganate and zinc sulphate.
- **Mechanical means** are of **3 types** – condom; **diaphragm and cervical cap;** and **intrauterine devices**.
- **Condom** (Nirodh) is a rubber sheath to cover the erect penis. It is the most widely used contraceptive by males in India as it is cheap and easily available. It is also given free by government. It is a simple but effective method and has no side effect. It checks pregnancy by preventing deposition of semen in the vagina. Condom should be used regularly and put on before starting coital activity, otherwise sperm-containing lubricating fluid may be left in the vagina. Condom should be discarded after a single use. Condom is also a safeguard against AIDS and sexual diseases.
- **Diaphragm and cervical cap** are rubber plastic covers that are fitted on the cervix in the female's vagina, and check the entry of sperms into the uterus. These must be kept fitted for at least six hours after sexual intercourse. They are smeared with a spermicidal jelly or cream cap and is the counterpart of condoms in the female.
- **Intrauterine devices** (IUDs) are plastic or metal objects placed in the uterus by a doctor. These include loop, copper-T , spiral, ring, bow, shield, etc. They prevent the fertilization of the egg or implantation of the embryo. Their presence perhaps acts as a minor irritant and this makes the egg to move down the fallopian tubes and uterus rather quickly before fertilization or implantation. Hormone releasing devices increases the viscosity of the cervical mucus and thereby prevent sperm from entering the cervix. They also maintain high levels of progesterone in the endometrium and thus, releasing low levels of estrogen, thereby sustaining an endometrium unfavourable to implantation.
- Commonly used IUDS are **plastic loop** and **copper T**.
  - **Copper T** releases Cu^{2+} which prevents implantation of fertilized eggs. Copper seems to enhance the cellular response in the endometrium. It also affects the enzymes in the uterus. By altering the biochemical composition of cervical mucus, copper ions may affect sperm motility, capaciation and survival.
  - **Plastic loop** (especially **Lippes loop**) is double S-shaped device made of polyethylene that is non-toxic, non tissue reactive material. The larger sized loop usually has a greater anti fertility effect and a lower expulsion rate but a high removal rate because of side effects such as pain and bleedings.
- **Drawbacks of IUDs** include their spontaneous expulsion, even without the woman's knowledge, occasional haemorrhage; and chance of infection.
- **Physiological (Oral) Devices (Hormonal)** includes birth control pills.

- **Birth control pills (oral contraceptives)** check ovulation by inhibiting the secretion of follicle-stimulating hormone (FSH) and luteinizing hormone (LH) that are necessary for ovulation. High (but not too high) levels of these hormones prevent follicle development (high estrogen/progesterone from the pill inhibits GnRH release from the anterior pituitary) and hence inhibits FSH (estrogen effect) and LH (progesterone effect) release so follicle does not rupture. The low LH prevents the follicle from rupturing so there is no ovulation. Hence, no eggs are released in a woman on the pill and conception cannot occur.
- The **birth control pills have side effects** such as nausea, breast tenderness, weight gain and break through bleeding (slight blood loss between menstrual periods) and high blood pressure. On the other hand, the oral contraceptives reduce the chances of certain types of cancer to occur in their users.
- A **combined pill** is the most commonly used birth control pill. It contains synthetic progesterone and estrogen in doses high enough to check ovulation. Pill Mala D is taken daily, and the pill Saheli is taken weekly.

I. Combined oral pill (containing both estrogen and progestin) → prevent the release of ovum from the ovary

↓ achieved by

Blocking the pituitary secretion of gonadotropin (necessary for ovulation to occur)

II. **Progesterone** only preparations $\xrightarrow{\text{renders}}$ Cervical mucus thick and scanty

↓ thereby inhibit

Sperm penetration

Also inhibit tubal motility and delay the transport of the sperm and of the ovum to the uterine cavity

Flow chart : Mechanism of action of oral pills

- **Abortion** is the medical termination of pregnancy (MTP) before the foetus becomes viable. It is one of the most widely used methods of fertility control in the world. Certain pills act as abortants. They function by inducing menstruation which checks the implantation of the zygote or detaches the implanted egg.
- **Permanent method** includes **sterilization**.
- **Sterilization** provides a permanent and sure birth control. It is called **vasectomy in man** and **tubectomy in woman**.
- **Vasectomy** involves a cut in the scrotal sac, cutting or burning of the vas deferens (tubes that carry sperm), and blocking both cut ends. Vasectomy **prevents the passage of sperm into seminal fluid by blocking the vas deferens**.
- Following vasectomy, sperm production and hormone output are not affected. Production of testosterone continues and its distribution does not need the ducts. The sperm produced are destroyed intraluminally by phagocytosis. This is a normal process in the male genital tract, but the rate of destruction is greatly increased after vasectomy. Vasectomy is a simpler, faster and less expensive operation than tubectomy.
- **Female sterilization** prevents fertilization by interrupting the passage through fallopian tube. Eggs continue to be produced because the ovaries are intact, but they fail to pass into the uterus and sperms fail to reach the eggs for fertilization.
- Female sterilization can be done as an interval procedure, postpartum or at the time of abortion. Two procedures have become most common, namely laparoscopy and minilaparotomy.
- **Laparoscopy** is a technique of female sterilization through abdominal approach with a specialized instrument called "laparoscope". The abdomen is inflated with gas (carbon dioxide, nitrous oxide or air) and the instrument is introduced into the abdominal cavity to visualise the tubes. Once the tubes are accessible, the Falope rings (or clips) are applied to occlude the tubes. Laparoscopy is not advisable for postpartum patients for 6 weeks following delivery. Haemoglobin per cent should not be less than 8. There should be no associated medical disorders such as heart disease, respiratory disease, diabetes and hypertension.
- **Minilaparotomy** (**minilap operation**) is a modification of abdominal tubectomy. It is a much simpler procedure requiring a smaller abdominal incision of only 2.5 to 3 cm conducted under local anaesthesia. The minilap/Pomeroy technique is considered a revolutionary procedure for female sterilization. It has the advantage over other methods with regard to safety, efficiency and ease in dealing with complications. Minilap operation is suitable for postpartum tubal sterilization.

End of the Chapter