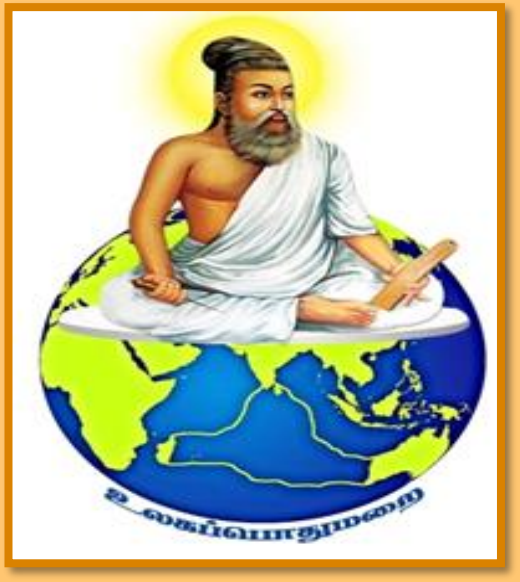
HIGHER SECONDARY
SECOND YEAR

PHYSICS



UNIT -5

ELECTROMAGNETIC WAVES

PROBLEMS AND SOLUTIONS

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EXAMPLE PROBLEMS

1. Consider a parallel plate capacitor which is connected to an 230 V RMS value and 50 Hz frequency. If the separation distance between the plates of the capacitor and area of the plates are 1 mm and 20 cm² respectively. Calculate the displacement current at t = 1 s.

Solution :- $V_{RMS} = 230\ V$; $d = 1\ mm = 1\ X\ 10^{-3}\ m$; $A = 20\ cm^2 = 20\ X\ 10^{-4} m^2$

$f = 50 Hz$; $t = 1\ s$; $I_d = ?$

No	Log
8.85	0. 9469
20	1. 3010
325	2. 5119
314	2. 4969
(+) ALog	7. 2567 1. 806 X 10 ^{7}

❖ Potential difference between the plates ;

$$V = V_m \sin \omega t = V_{RMS}\sqrt{2} \sin 2\pi f t$$
$$V = 230\ X1.414\ X \sin(2\pi\ X\ 50\ t)$$
$$V = 325 \sin(100\ \pi\ t)$$

❖ Hence the displacement current,

$$I_d = \varepsilon_o \frac{d\Phi_E}{dt} = \varepsilon_o \frac{d}{dt}(EA) \qquad [\because\ \Phi_E = EA]$$
$$I_d = \varepsilon_o \frac{d}{dt}\left(\frac{V}{d}\right) A = \frac{\varepsilon_o A}{d}\left[\frac{dV}{dt}\right]$$
$$I_d = \frac{\varepsilon_o A}{d}\left[\frac{d}{dt}(325 \sin 100\ \pi\ t)\right]$$
$$I_d = \frac{\varepsilon_o A}{d}\ [325\ X100\ \pi\ X \cos 100\ \pi\ t\ ]$$
$$I_d = \frac{8.85\ X\ 10^{-12} X\ 20\ X\ 10^{-4}}{1\ X\ 10^{-3}}\ X\ 325\ X\ 100\ X\ 3.14\ X \cos 100\ \pi(1)$$
$$I_d = 825\ X\ 20\ X\ 325\ X\ 314\ X\ 10^{-13}\ X\ (1) \qquad [\because \cos 100\ \pi = 1]$$
$$\boldsymbol{I_d = 1.806\ X\ 10^7\ X\ 10^{-13} = 1.806\ X\ 10^{-6}\ A = 1.806\ \mu\ A}$$

2. The relative magnetic permeability of the medium is 2.5 and the relative electrical permittivity of the medium is 2.25. Compute the refractive index of the medium.

Solution :- $\mu_r = 2.5$; $\varepsilon_r = 2.25$; $n = ?$

No	Log
$\sqrt{5.625}$	0. 7501 X $\frac{1}{2}$
ALog	0.3751 2. 372 X 10 ^{0}

❖ The refractive index of the medium,

$$n = \sqrt{\mu_r\ \varepsilon_r}$$
$$n = \sqrt{2.5\ X\ 2.25} = \sqrt{5.625}$$
$$\boldsymbol{n = 2.372\ \ (no\ unit)}$$

3. Compute the speed of the electromagnetic wave in a medium if the amplitude of electric and magnetic fields are 3 × 10⁴ N C⁻¹ and 2 × 10⁻⁴ T, respectively.

Solution :- $E_o = 3\ X\ 10^4\ N\ C^{-1}$; $B_o = 2\ X\ 10^{-4}\ T$; $v = ?$

❖ The speed of the electromagnetic wave

$$v = \frac{E_o}{B_o} = \frac{3\ X\ 10^4}{2\ X\ 10^{-4}} = \frac{3}{2}\ X\ 10^8$$
$$\boldsymbol{v = 1.5\ X\ 10^8\ m\ s^{-1}}$$

4. A magnetron in a microwave oven emits electromagnetic waves (em waves) with frequency f = 2450 MHz. What magnetic field strength is required for electrons to move in circular paths with this frequency?

Solution :- $f = 2450\ MHz = 2450\ X\ 10^6\ Hz$; $q = |e| = 1`.6\ X\ 10^{-9}\ C$;

$m = 9.11\ X\ 10^{-31}\ kg$; $B = ?$

No	Log
2	0. 3010
3.14	0. 4969
2450	3. 3892
9.11	0. 9595
(+) 1.6	5. 1466 0. 2041
(-) ALog	4. 9425 8.760 X 10 ^{4}

❖ Angular frequency of the circular motion,,

$$\omega = \frac{B\ q}{m}$$
$$(or) \qquad 2\pi\ f = \frac{B\ q}{m}$$

❖ Therefore, the magnetic field required is,

$$B = \frac{2\ \pi\ f\ m}{q}$$
$$B = \frac{2\ X\ 3.14\ X\ 2450\ X\ 10^6\ X\ 9.11\ X\ 10^{-31}}{1.6\ X\ 10^{-19}}$$
$$B = \frac{2\ X\ 3.14\ X\ 2450\ \ X\ 9.11\ X\ 10^{-6}}{1.6}$$
$$B = 8.76\ X\ 10^4\ X\ 10^{-6}$$
$$\boldsymbol{B = 8.76\ X\ 10^{-2}\ T = 0.0876\ T}$$

EXERCISE PROBLEMS

1. Consider a parallel plate capacitor whose plates are closely spaced. Let R be the radius of the plates and the current in the wire connected to the plates is 5 A, calculate the displacement current through the surface passing between the plates by directly calculating the rate of change of flux of electric field through the surface.

Solution :- $I_C = 5\ A$; $I_d = ?$

❖ Electric flux,

$$\Phi_E = \oint E\ dA \cos 0°$$

$$\Phi_E = E\ A = \frac{\sigma}{\varepsilon_o} A = \frac{q}{\varepsilon_o}$$

❖ Hence displacement current,

$$I_d = \varepsilon_o \frac{d\Phi_E}{dt} = \varepsilon_o \frac{d}{dt}\left(\frac{q}{\varepsilon_o}\right)$$

$$I_d = \varepsilon_o \frac{1}{\varepsilon_o} \frac{dq}{dt}$$

$$I_d = \frac{dq}{dt}$$

$$\boldsymbol{I_d = I_C = 5\ A}$$

2. A transmitter consists of LC circuit with an inductance of 1 μH and a capacitance of 1 μF. What is the wavelength of the electromagnetic waves it emits?

Solution :- $L = 1\ \mu H = 1\ X\ 10^{-6}\ H$; $C = 1\ \mu F = 1\ X\ 10^{-6}\ F$; $\lambda = ?$

❖ Wavelength of electromagnetic waves,

$$\lambda = \frac{C}{f} = \frac{C}{\left(\frac{1}{2\ \pi\ \sqrt{L\ C}}\right)}$$

$$\lambda = C\ \left(2\ \pi\ \sqrt{L\ C}\right)$$

$$\lambda = 3\ X\ 10^8\ \left(2\ X\ 3.14\ X\ \sqrt{1\ X\ 10^{-6}\ X\ 1\ X\ 10^{-6}}\right)$$

$$\lambda = 3\ X\ 10^8 X\ 2\ X\ 3.14\ X\ 1\ X\ 10^{-6}$$

$$\boldsymbol{\lambda = 18.84\ X\ 10^2\ m = 1884\ m}$$

3. A pulse of light of duration 10^{-6} s is absorbed completely by a small object initially at rest. If the power of the pulse is 60×10^{-3} W, calculate the final momentum of the object.

Solution :- $t = 10^{-6}\ s$; $P = 60\ X\ 10^{-3}\ W$; $p = ?$

❖ Final momentum,

$$p = \frac{E}{C} \qquad [E = m\ C^2 = p\ C]$$

$$p = \frac{P\ X\ t}{C} \qquad \left[P = \frac{W}{t} = \frac{E}{t}\right]$$

$$p = \frac{60\ X\ 10^{-3}\ X\ 10^{-6}}{3\ X\ 10^8}$$

$$\boldsymbol{p = 20\ X\ 10^{-17}\ kg\ m\ s^{-1}}$$

4. Let an electromagnetic wave propagate along the x - direction, the magnetic field oscillates at a frequency of 10^{10} Hz and has an amplitude of 10^{-5} T, acting along the y - direction. Then, compute the wavelength of the wave. Also write down the expression for electric field in this case.

Solution :- $f = 10^{10}\ Hz$; $B_o = 10^{-5}\ T$; $\lambda = ?$; $\vec{E}\ (x,t) = ?$

❖ Wavelength of electromagnetic waves,

$$\boldsymbol{\lambda = \frac{C}{f} = \frac{3\ X\ 10^8}{10^{10}} = 3\ X\ 10^{-2}\ m}$$

❖ Expression for electric field,

$$E\ (x,t) = E_o \sin(kx - \omega t) \qquad ---------\ (1)$$

❖ We know that, the velocity of electromagnetic waves,

$$C = \frac{E_o}{B_o}$$

$$(or) \qquad \boldsymbol{E_o = B_o\ C = 10^{-5}\ X\ 3\ X\ 10^8 = 3\ X\ 10^3\ N\ C^{-1}}$$

❖ Angular frequency,

$$\boldsymbol{\omega = 2\ \pi\ f = 2\ X\ 3.14\ X\ 10^{10} = 6.28\ X\ 10^{10}\ rad\ s^{-1}}$$

❖ And wave number,

$$\boldsymbol{k = \frac{\omega}{C} = \frac{6.28\ X\ 10^{10}}{3\ X\ 10^8} = 2.093\ X\ 10^2\ rad\ m^{-1}}$$

❖ Put this in equation (1),

$$\boldsymbol{E\ (x,t) = 3\ X\ 10^3 \sin(2.093\ X\ 10^2\ x - 6.28\ X\ 10^{10}\ t)\ N\ C^{-1}}$$

❖ Since the electric field oscillates along z -axis,

$$\boldsymbol{\vec{E}\ (x,t) = 3\ X\ 10^3 \sin(2.093\ X\ 10^2\ x - 6.28\ X\ 10^{10}\ t)\ \hat{k}\ N\ C^{-1}}$$

5. If the relative permeability and relative permittivity of a medium are 1.0 and 2.25 respectively, find the speed of the electromagnetic wave in this medium.

Solution :- : $\mu_r = 1.0$; $\varepsilon_r = 2.25$; $v = ?$

❖ Refractive index of the medium,

$$\mu = \sqrt{\mu_r\ \varepsilon_r}$$

$$(or) \qquad \frac{C}{v} = \sqrt{\mu_r\ \varepsilon_r}$$

$$\therefore \qquad v = \frac{C}{\sqrt{\mu_r\ \varepsilon_r}} = \frac{3\ X\ 10^8}{\sqrt{1.0\ X\ 2.25}}$$

$$v = \frac{3\ X\ 10^8}{1.5}$$

$$\boldsymbol{v = 2\ X\ 10^8\ m\ s^{-1}}$$