Ch 8- Electromagnetic Waves

LAKSHYA BATCH

Lect-03

Winners of Formula Sheet Competition-05

Anjali Singh

Umme Rumaan

Formula Sheet Competition-06

- Submit your Formula Sheet of Chapter-06 Electromagnetic Induction on the link given (https://forms.gle/AZBvzzGWLwnasUBF8)

Prize Money
Rs 2100

- We are accepting only Form entries.

Winners – 2

- Submit your sheet in Maximum 3 pages.

A-4

- Link is open till Saturday,10.10.20 , 11:00 am

Today's Goal

Equation of Electric Field & Magnetic Field in an Electromagnetic Wave

Electromagnetic Wave

1. Electromagnetic Wave is radiated(produced) by an accelerated (or oscillating) charge particle.

2. Electromagnetic Wave propagates in space through Oscillations of Electric and Magnetic Field , perpendicular to each other and also perpendicular to the direction of wave propagation.

3. Since the oscillation of Electric Field and Magnetic Field occur perpendicular to direction of wave propagation, EMW is a Transverse Wave

EMW → Transverse

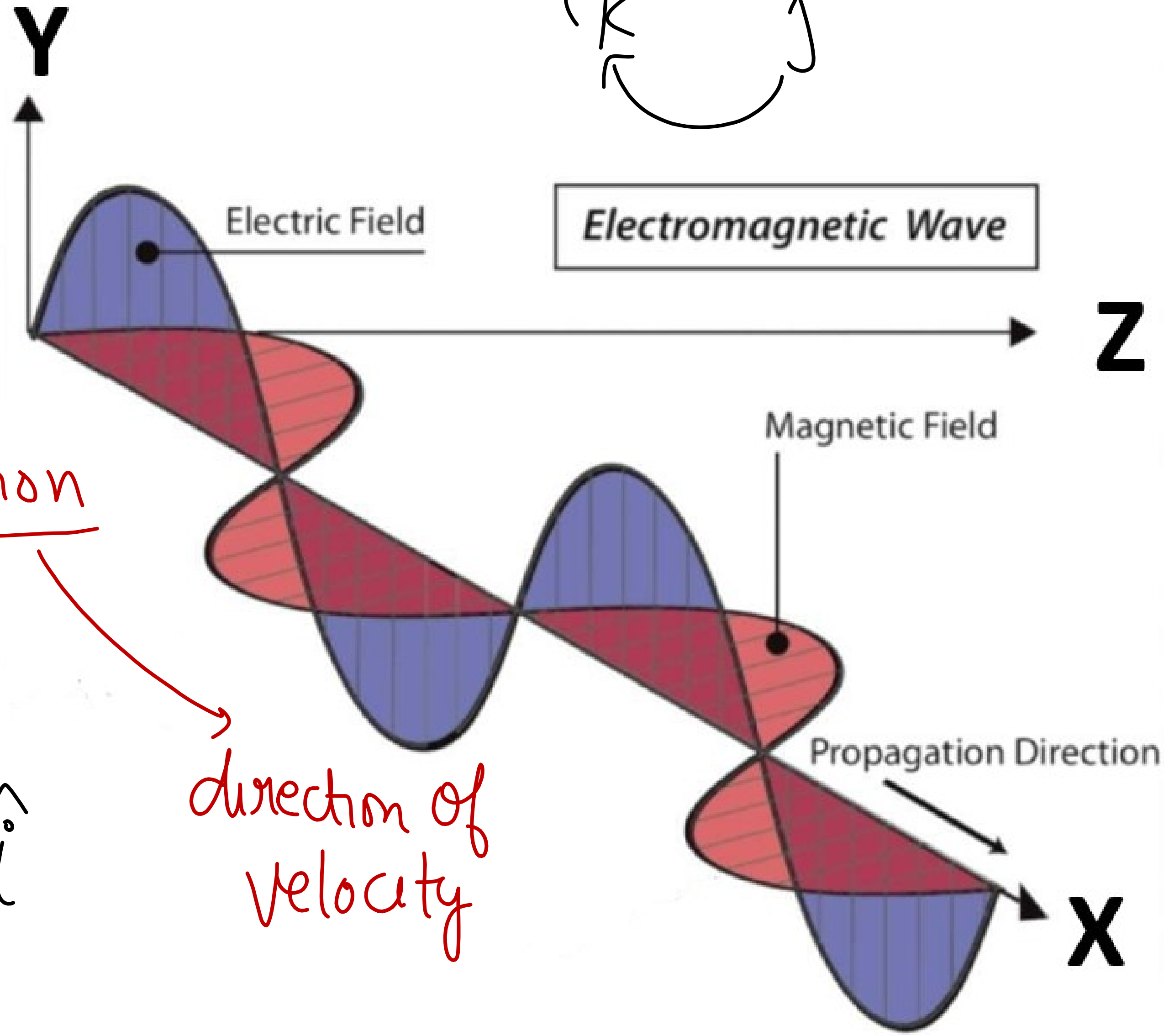
$\vec{E} \perp$ propogation

$\vec{B} \perp$ Propogation

direction of Propogation

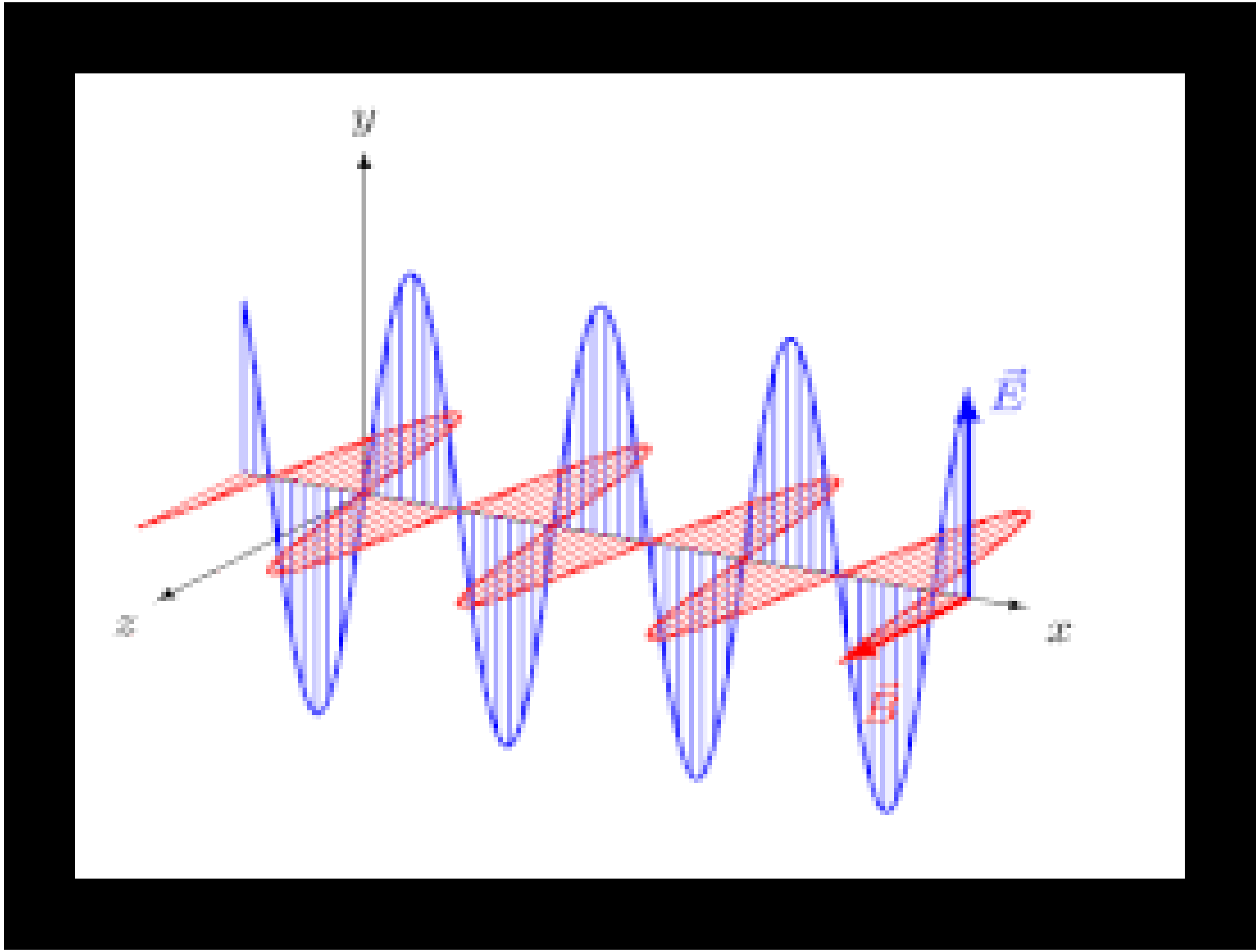
$= \vec{E} \times \vec{B}$

$\hat{j} \times \hat{k} = \hat{i}$



direction of velocity

Equation of Electric Field
&
Equation of Magnetic Field



Travelling wave

Brief Introduction to Travelling Wave → Recap Class 11th

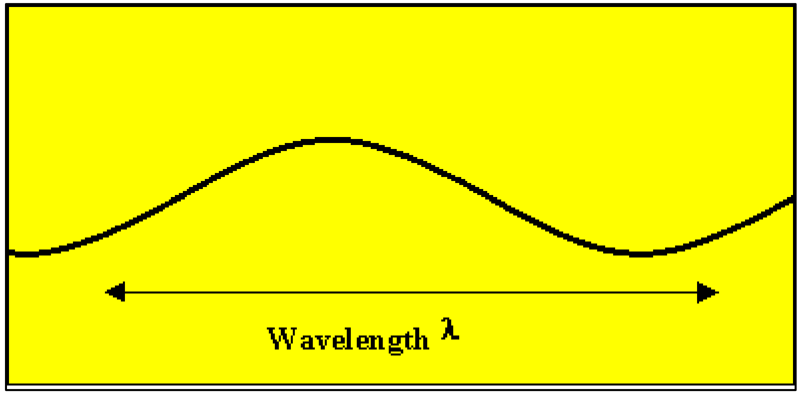
wavelength = λ

✓ wave number $K = \frac{2\pi}{\lambda}$

Time Period = T

frequency ⇒ $f = \frac{1}{T}$

✓ Angular frequency $\omega = \frac{2\pi}{T} = 2\pi f$



Speech: $V = \frac{\omega}{K} = \frac{2\pi f}{2\pi / \lambda}$

$v = f\lambda$

(+) → wave travelling in −ve x

(−) → " " " +ve x

Displacement of particle(y)

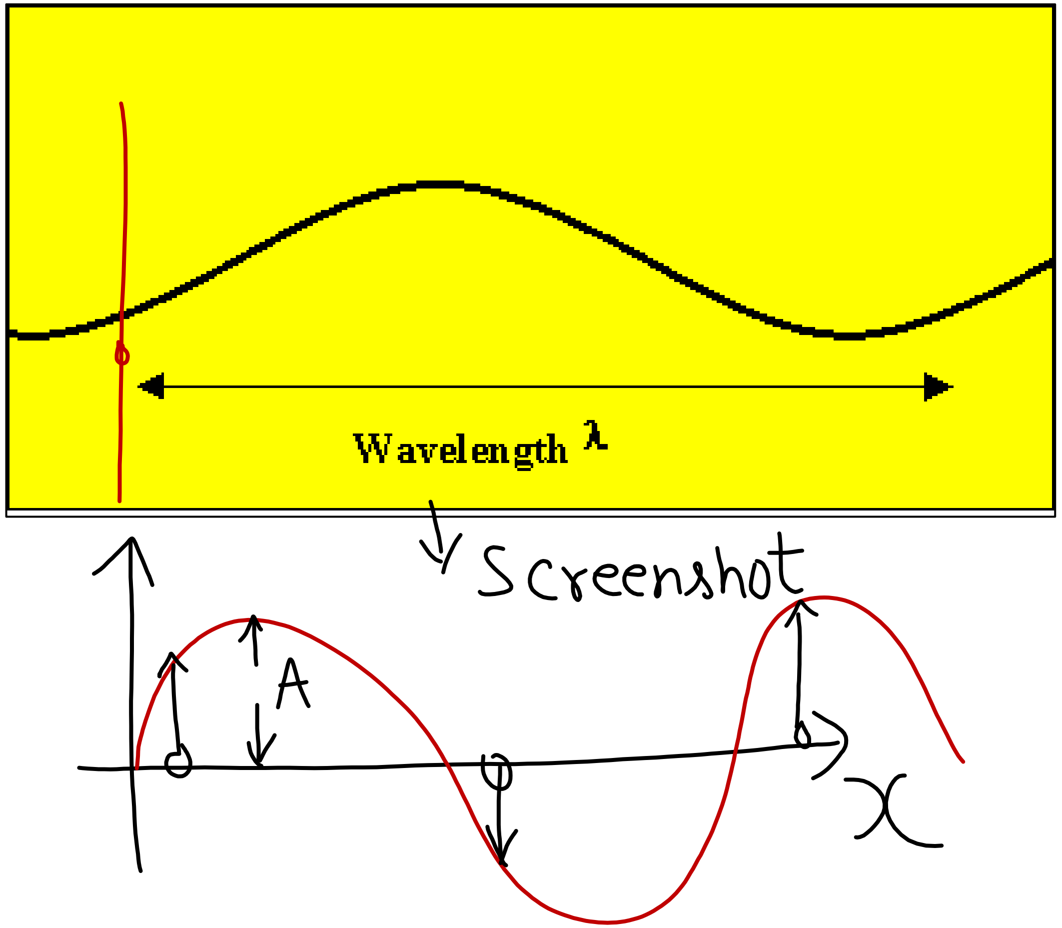
Amplitude = A

$y = f(x)$, $y = f(t)$ $\Rightarrow y = f(x, t)$

Wave → Sinosudiol

$y = A\sin(Kx \pm \omega t)$

$y = A\sin(\omega t \pm Kx)$



Equation of Electromagnetic Waves

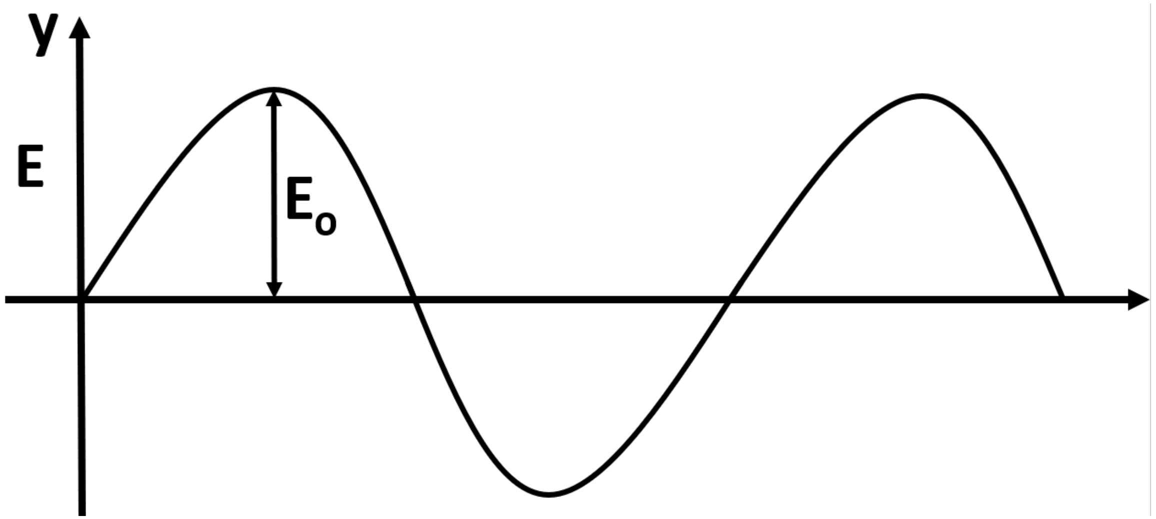
1. Electric Field $\vec{E}$

$\ominus \rightarrow$ wave travelling in +ve x

$$E_y = E_0 \sin(kx - \omega t)\,\hat{j}$$

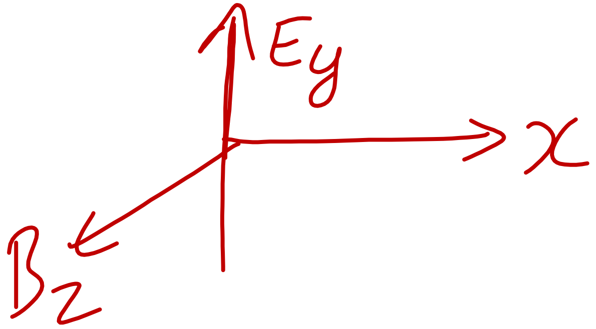
$$E = E_0 \sin\left(\frac{2\pi}{\lambda}x - \frac{2\pi}{T}t\right)$$

$$E = E_0 \sin\left[2\pi\left(\frac{x}{\lambda} - \frac{t}{T}\right)\right]$$

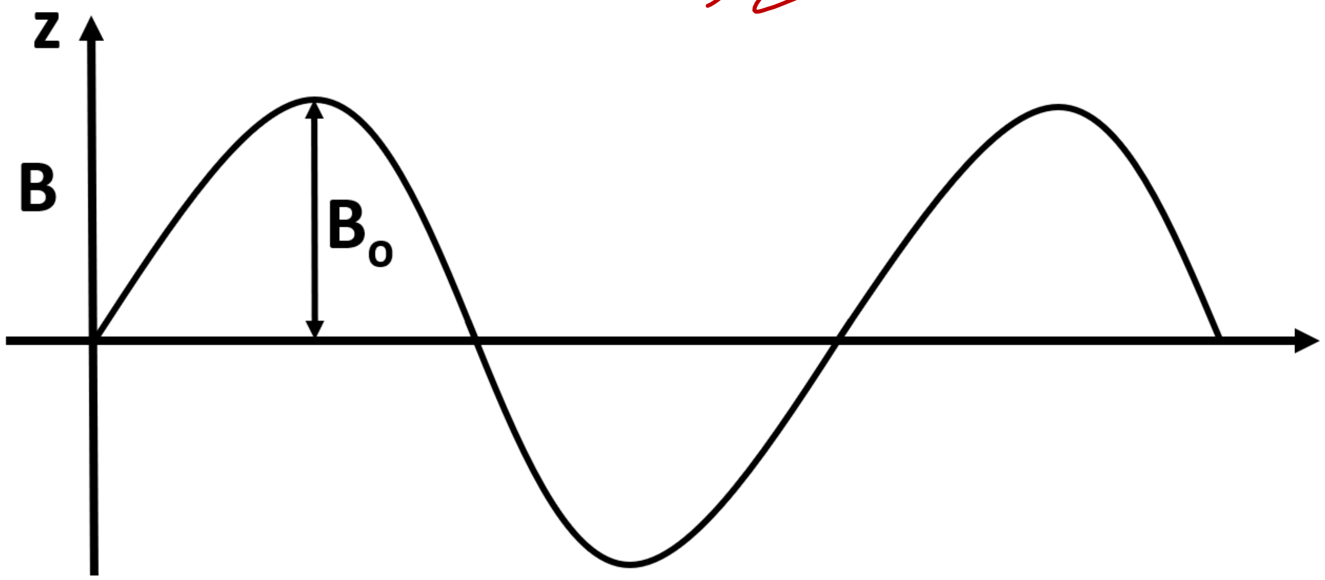


$$E = E_0 \sin\left[2\pi\left(\frac{x}{\lambda} - ft\right)\right]$$

2. Magnetic Field $\vec{B}$



$$B_z = B_0 \sin(kx - \omega t)\hat{k}$$



$$B = B_0 \sin\left(\frac{2\pi}{\lambda}x - \frac{2\pi}{T}t\right)$$

$$B = B_0 \sin\left[2\pi\left(\frac{x}{\lambda} - \frac{t}{T}\right)\right]$$

example

$$B = B_0 \sin\left(0.5x + 1.5\times10^8 t + \frac{\pi}{2}\right)$$

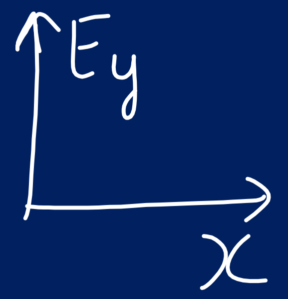
$$E = E_0 \sin\left(\quad " \quad \right)$$

Both are in same Phase

Q1) The electric field in a plane electromagnetic wave is given by $E_y = 2\sin(0.5\times 10^3 x + 1.5\times10^{11} t)\frac{N}{C}$

a) What is the direction of propagation (of wave)

b) Speed of wave



a) $E_y = 2\sin(0.5\times10^3 x + 1.5\times10^{11} t)$ → travelling in $-x$ direction

b) $v = \frac{\omega}{K} = \frac{1.5\times10^{11}}{0.5\times10^{3}} = 3\times10^{8}\ m/s = c$

Peak Value of $\vec{E}$ (E_o) and $\vec{B}$ (Bo)

Maxwell

$$\frac{E_0}{B_0} = c$$

Q2) The magnetic field in the plane electromagnetic wave is given by $B_z = 2\times10^{-7}\sin(0.5\times10^3 x + 1.5\times10^{11} t)$ tesla. The expression for electric field will be

a) $E_z = 30\sqrt{2}\sin(0.5\times10^3 x + 1.5\times10^{11} t)$ V/m

b) $E_z = 60\sin(0.5\times10^3 x + 0.5\times10^{11} t)$ V/m

c) $E_y = 30\sqrt{2}\sin(0.5\times10^{11} x + 0.5\times10^3 t)$ V/m

d) $E_y = 60\sin(0.5\times10^3 x + 1.5\times10^{11} t)$ V/m

B & E same phase

Need X X $\frac{E_0}{B_0} = c$ $\quad \frac{E_0}{2\times10^{-7}} = 3\times10^8 \Rightarrow E_0 = 60$

Q3) The magnetic field in a travelling electromagnetic wave has a peak value of 20 nT. The peak value of electric field strength is

(1) 6 V/m (2) 9 V/m

(3) 12 V/m (4) 3 V/m **(JEE Main 2013)**

$$\frac{E_0}{B_0} = c \Rightarrow E_0 = B_0 c$$

$$E_0 = 20 \times 10^{-9} \times 3 \times 10^8$$

$$= 60 \times 10^{-1} = 6 \frac{V}{m}$$

Permeability & Permittivity of Medium {Maxwell}

1. **In air/vacuum/free space**

$$C = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}$$

2. **In any other medium**

$$v = \frac{1}{\sqrt{\mu_m \varepsilon_m}}$$

$$\mu_r = \frac{\mu_m}{\mu_0}$$

$$\varepsilon_r = \frac{\varepsilon_m}{\varepsilon_0}$$

ε_r ↓ dielectric constant

Q4) If c is the speed of electromagnetic waves in vacuum ,its speed in a medium of dielectric constant K and relative permeability μ_r is

a) $v = \frac{1}{\sqrt{\mu_r K}}$

b) $v = c\sqrt{\mu_r K}$

c) $v = \frac{c}{\sqrt{\mu_r K}}$

d) $v = \frac{K}{\sqrt{\mu_r C}}$

medium

$$V = \frac{1}{\sqrt{\mu_m \varepsilon_m}}$$

$$K = \varepsilon_r = \frac{\varepsilon_m}{\varepsilon_0}$$

$$= \frac{1}{\sqrt{\mu_r \mu_0 \varepsilon_0 K}}$$

$$\mu_r = \frac{\mu_m}{\mu_0}$$

$$= \frac{1}{\sqrt{\mu_r K}} \times \frac{1}{\sqrt{\mu_0 \varepsilon_0}} = \frac{c}{\sqrt{\mu_r K}}$$

Q5) A plane electromagnetic wave $E_z=100\cos(6\times10^8 t+4x)$ V/m propagates in a non magnetic medium of dielectric constant

non magnetic medium → μ_0

a) 1.5

b) 2.0

c) 2.4

d) 4.0

$$V=\frac{\omega}{K}=\frac{6\times10^8}{4}=\frac{3}{2}\times10^8=\frac{c}{2}$$

$$V=\frac{1}{\sqrt{\varepsilon_m\mu_m}}=\frac{1}{\sqrt{\varepsilon_0 K\mu_0}}=\frac{c}{\sqrt{K}}$$

$$\frac{c}{2}=\frac{c}{\sqrt{K}}\Rightarrow K=4$$

$$K=\varepsilon_r=\frac{\varepsilon_m}{\varepsilon_0}$$

$$\varepsilon_m=\varepsilon_0 K$$

Q6) If ε_o and μ_o represent the permittivity and permeability of vacuum ε and μ represent the permittivity and permeability of medium, the refractive index of the medium is given by

a) $\sqrt{\dfrac{\varepsilon_o\mu_o}{\varepsilon\mu}}$

b) $\sqrt{\dfrac{\varepsilon\mu}{\varepsilon_o\mu_o}}$

c) $\sqrt{\dfrac{\varepsilon}{\varepsilon_o\mu_o}}$

d) $\sqrt{\dfrac{\varepsilon_o\mu_o}{\varepsilon}}$

Refractive index (η)

$$\eta = \frac{c}{v}$$

$$\eta = \frac{\frac{1}{\sqrt{\mu_0\varepsilon_0}}}{\frac{1}{\sqrt{\mu\varepsilon}}} = \sqrt{\frac{\mu\varepsilon}{\mu_0\varepsilon_0}}$$

Q6) An EM wave from air enters a medium. The electric fields are $\vec{E}_1 = E_{01}\hat{x}\cos\left[2\pi v\left(\frac{z}{c} - t\right)\right]$ in air $\vec{E}_2 = E_{02}\hat{x}\cos[k(2z - ct)]$ in medium, where the wave number k and frequency v refer to their values in air. The medium is non-magnetic . If ε_{r1} and ε_{r2} refer to relative permittivites of air and medium respectively, which of the following options is correct? [JEE MAIN 2018]

a) $\frac{\varepsilon_{r1}}{\varepsilon_{r2}} = \frac{1}{2}$

b) $\frac{\varepsilon_{r1}}{\varepsilon_{r2}} = 4$

c) $\frac{\varepsilon_{r1}}{\varepsilon_{r2}} = 2$

d) $\frac{\varepsilon_{r1}}{\varepsilon_{r2}} = \frac{1}{4}$ ✓

air speed $= \frac{\omega}{K} = \frac{2\pi v}{\frac{2\pi v}{c}} = c$

aasae

medium speed $= \frac{\omega}{K} = \frac{Kc}{2K} = \frac{c}{2}$

air speed = C

medium speed = $\frac{C}{2}$

→ $V = \frac{1}{\sqrt{\varepsilon_m \mu_m}}$

medium

$\varepsilon_{r_2} = \frac{\varepsilon_m}{\varepsilon_0}$

$V = \frac{1}{\sqrt{\varepsilon_m \mu_0}}$

$V_{medium} = \frac{1}{\sqrt{\varepsilon_{r_2} \varepsilon_0 \mu_0}}$

$\frac{C}{2} = \frac{C}{\sqrt{\varepsilon_{r_2}}}$

$\varepsilon_{r_2} = 4$

air

$\varepsilon_{r_1} = \frac{\varepsilon_0}{\varepsilon_0} = 1$

↓

air relative permittivity

$\varepsilon_{r_1} = 1$

Thank You

Download lecture notes of this lecture right after this session.