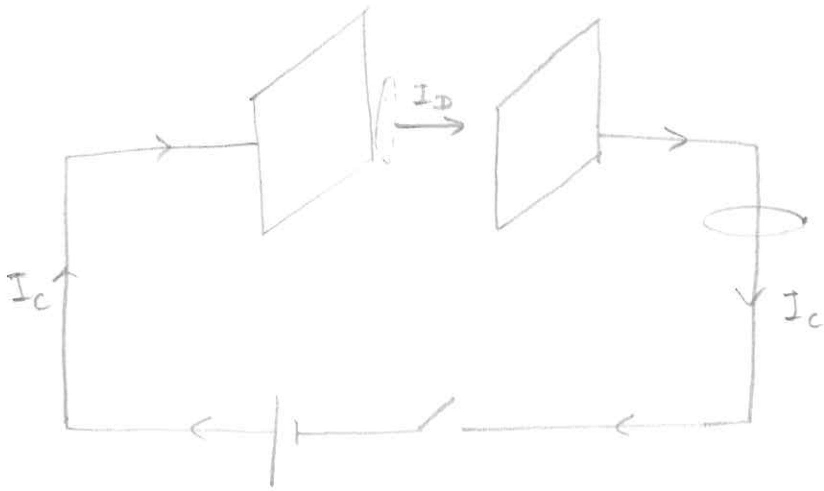
Electromagnetic wave :-

Faraday's laws :-

$$\oint \vec{E}\cdot\vec{dl} = -A\cdot\frac{dB}{dt}$$

Maxwell concept of displacement current :-



$$E = \frac{V}{d}$$

During charging.

$V\uparrow \Rightarrow E\uparrow$.

that means E is variable $\Rightarrow$ B produce

→ Imaginary current due to variable Electric field is called Displacement current

→ $I_c = I_D$ (principle of continuity)

→ I_c and I_D are supplementary of each other.

→ $$I_D = I_c = \frac{dq}{dt}$$

$$I_D = \frac{d}{dt}(CV)$$

$$\boxed{I_D = C\frac{dV}{dt}}$$

→ $I_D = \frac{d}{dt}(CV) = \frac{d}{dt}\left(\frac{\epsilon_0 A}{d} \cdot V\right)$

$= \epsilon_0 \cdot \frac{d}{dt}\left(\frac{V}{d} \cdot A\right)$

$= \epsilon_0 \cdot \frac{d}{dt}(E \cdot A)$

$$\boxed{I_D = \epsilon_0 \cdot \frac{d\phi_E}{dt} = \epsilon_0 \cdot A \frac{dE}{dt}}$$

→ $\oint \vec{B} \cdot \vec{dl} = \mu_0 \Sigma I$ Ampere's law

→ $\oint \vec{B} \cdot \vec{dl} = \mu_0 \Sigma (I_c + I_D)$ modified Ampere's law

Maxwell's Equation :-

1. $\oint \vec{E} \cdot \vec{dS} = \frac{\Sigma q}{\epsilon_0}$ (Gauss in electrostatics)

2. $\oint \vec{B} \cdot \vec{dS} = \mu_0 \Sigma m = 0$ (Gauss in magnetism)

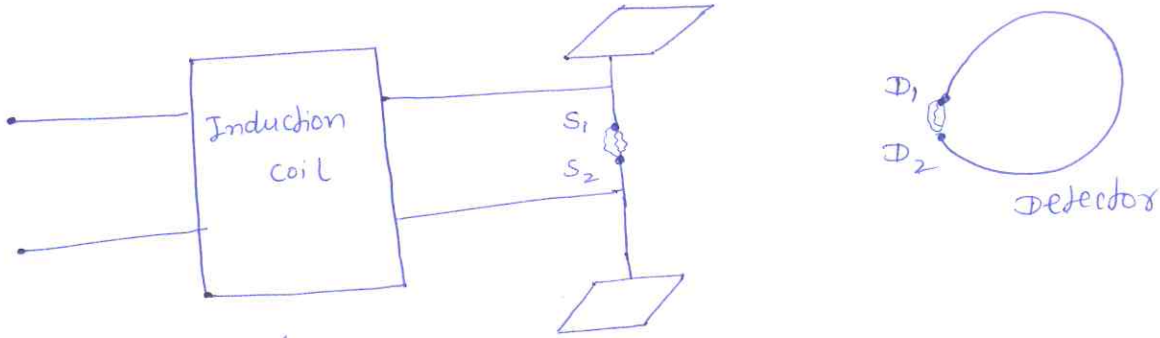
3. $\oint \vec{E} \cdot \vec{dl} = -A \cdot \frac{dB}{dt}$ (faraday's law)

4. $\oint \vec{B} \cdot \vec{dl} = \mu_0 \Sigma (I_c + I_D)$ (Maxwell Ampere's law).

using mathematical analysis maxwell correllated E and B and confirmed time varying E produces, time varying B and vice-versa..
this variable E and B propagates in spaces so it is called Electro-magnetic wave.

Hertz Experiment :-

→ it practically demonstrated production, Broadcasting and detection of EMW

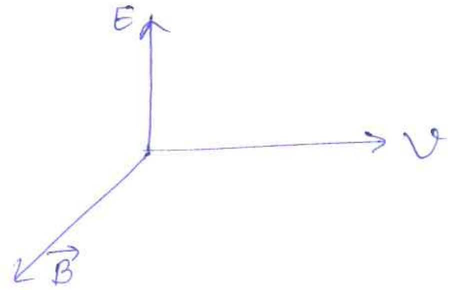


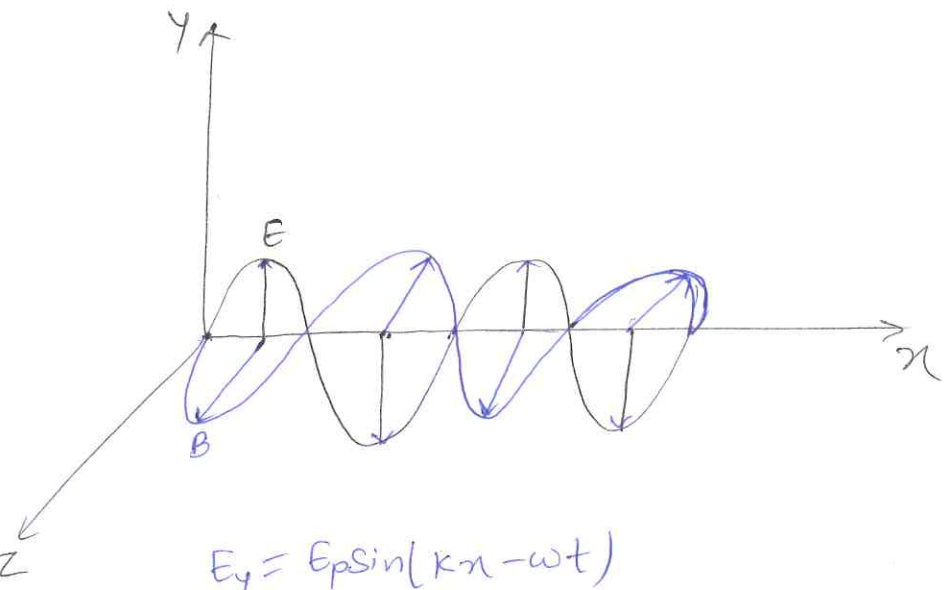
3×10^6 V/m

EMW :-

→ It has sinesoidally variable in E and B where E, B and direction of propagation are mutually perpendicular.

→





$$E_y = E_p \sin(kx - \omega t)$$

$$B_z = B_p \sin(kx - \omega t)$$

→ $\omega = 2\pi f = \frac{2\pi}{T}$

→ propagation constant

$$k = \frac{2\pi}{\lambda}$$

$$v = \frac{\omega}{k}$$

→ E and B same phase.

→ E is responsible for all visual effect so it is called light vector.

→ it travels in vaccum and medium both.

Q In EMW $E = 10 \sin(2\pi \times 10^6 t - \pi \times 10^{-2} z)$

(i) Direction of propagation :- +z-direction.

(ii) frequency in Hz :-

$\omega = 2\pi \times 10^6$ rad/sec

$f = \frac{\omega}{2\pi} = 10^6$ Hz

(iii) propagation constant

$K = \pi \times 10^{-2}$ per m

(iv) speed of wave

$v = \frac{\omega}{K} = \frac{2\pi \times 10^6}{\pi \times 10^{-2}}$

$= 2 \times 10^8$ m/sec

$v < c$

that wave medium में चल रहा है।

(1) speed :-

$\left.\begin{aligned} * \quad v &= \frac{E}{B} \\ c &= \frac{E_0}{B_0} \end{aligned}\right\} v < c$

Q Neet

$B_p = 20\,nT$

$\Rightarrow E_p = ?$

Soln:- $c = \frac{E_p}{B_p}$

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

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

$E_p = 6$ V/m

* $v = \frac{1}{\sqrt{\mu \epsilon}}$

$c = \frac{1}{\sqrt{\mu_0 \epsilon_0}}$

$n = \frac{c}{v} = \sqrt{\mu_r \epsilon_r}$

$\simeq \sqrt{\epsilon_r}$ (for most of medium $\mu_r \simeq 1$)

$n \to$ refractive index

ferro $\mu_r >>> 1$

$0 \leq (\mu_r)$ para $\to$ 1 से 2

dia $\to$ 0 से 1

Q jee An EMW enters in a medium $\epsilon_r = 4$

then (i) refractive index

Soln:- $n \simeq \sqrt{\epsilon_r} = 2$

(ii) Speed in medium

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

$2 = \frac{c}{v}$

$v = \frac{c}{2}$

(iii) $v = f\lambda$ ($f \to$ const)

$f \to$ characteristic of source.

$v \propto \lambda$

$\lambda' = \frac{\lambda}{2}$

(2) Characteristics Impedence of medium (z) (or) Z :- It is opposition offered by medium to wave propagation.

→ unit :- ohm

⇒ $Z = \frac{E}{H} = \frac{E}{(B/\mu)} = \mu_0 (E/B)$.

$= \mu . v = \mu . \frac{1}{\sqrt{\mu \epsilon}} = \sqrt{\frac{\mu}{\epsilon}}\ \Omega$

→ $Z_{vacum/air} = \sqrt{\frac{\mu_0}{\epsilon_0}} = 120\pi = 377\Omega$

Neet 2019 $\mu_r = 1$, $\epsilon_r = 1.44$ find wave speed ?

Soln :-

$$n = \sqrt{\mu_r \cdot \epsilon_r} = 1.2$$

$$\frac{c}{v} = 1.2$$

$$v = \frac{c}{1.2}$$

(3) Energy density (u) :⇒ Energy of EMW is equally divided b/w E and B.

→ Energy per unit volume is called Energy density.

→ Unit → J/m^3

$$\rightarrow \quad u = u_E + u_B$$

$$= \frac{1}{2}\epsilon E^2 + \frac{B^2}{2\mu}$$

$$= \epsilon E^2 = \frac{B^2}{\mu}$$

(4) Mean Energy density ($\bar{u}$) :- It is average of energy density for one cycle.

→ unit is J/m^3

$$\bar{u} = \langle u \rangle_T$$

$$= \langle \epsilon E^2 \rangle_T$$

$$= \langle \epsilon E_p^2 \sin^2(kx - \omega t) \rangle_T$$

$$\boxed{\bar{u} = \frac{1}{2}\epsilon E_p^2 = \frac{B_p^2}{2\mu}}$$

$$\boxed{\bar{u}_E = \bar{u}_B = \frac{\bar{u}}{2} = \frac{1}{4}\epsilon E_p^2}$$

Q An EMW $E = 100\sin(kx - \omega t)$ find avg. energy density of (1)
(i) wave
(ii) electric field.
(iii) magnetic field

Soln:- (i) $\bar{u} = \frac{1}{2}\epsilon_0 E_p^2$

$= \frac{1}{2} \times 8.85 \times 10^{-12} \times (100)^2$

$= 4.4 \times 10^{-8}\ J/m^3$

(ii) $\bar{u}_E = \frac{1}{4}\epsilon_0 E_p^2 = 2.2 \times 10^{-8}\ J/m^3$

(iii) $= \bar{u}_B = 2.2 \times 10^{-8}\ J/m^3$

gee'

Q In EMW value of Electricfield is $\underset{\downarrow\ E_{rms}}{720\,N/C}$ find mean energy density of wave.

Soln:-

$\bar{u} = \frac{1}{2}\epsilon_0 E_p^2$

$= \frac{1}{2} \times 8.85 \times 10^{-12} \times (72\sqrt{2})^2$

(5) pointing vector ($\vec{S}$) :- It is rate of energy flow per unit cross-sectiona area.

→ unit :→ $\frac{J}{sec \times m^2}$, $\frac{Watt}{m^2}$

$\vec{S} = \vec{E} \times \vec{H} = \frac{1}{\mu}(\vec{E} \times \vec{B})$

$= \frac{1}{\mu}(EB\sin 90^\circ \hat{n})$

$= \frac{EB}{\mu}\hat{n}$

$|S| = \frac{EB}{\mu} = \left(\frac{E}{\mu}\right)\left(\frac{E}{v}\right)$ WKT $\left(v = \frac{E}{B}\right)$

$= \left(\frac{E}{\mu}\right) \times \left(\frac{E}{v}\right) \times \frac{v}{v}$

$= \frac{vE^2}{\cancel{\mu} \cdot \frac{1}{\cancel{\mu}\epsilon}}$

$= \boxed{v\epsilon E^2}$

$\rightarrow \quad \hat{S} = \hat{E} \times \hat{B}$

pointing vector is along the direction of propagation.

Neet 2018 vel. of wave $\vec{V} = v\hat{i}$

Electricfield is along + y direction

Mag.field direction = ?

Soln.:-

$\hat{S} = \hat{E} \times \hat{B}$

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

$\Rightarrow \hat{B} = \hat{k}$

$= (+z \text{ direction})$

Q jee EMW is propagating in +z-direction than which of the following combination is possible direction electricfield and magneticfield vector.

(1) $(\hat{i} + 2\hat{j})$ and $(2\hat{i} - \hat{j})$

(2) $(-2\hat{i} - 3\hat{j})$ and $(3\hat{i} - 2\hat{j})$

(3) $(2\hat{i} + 3\hat{j})$ and $(\hat{i} + 2\hat{j})$

(4) $(3\hat{i} + 4\hat{j})$ and $(4\hat{i} - 3\hat{j})$

Soln.:-

	$\vec{E} \cdot \vec{B}$	$\vec{S} = \frac{1}{\mu}(\vec{E} \times \vec{B})$ (or) $\vec{S} = \frac{1}{\mu}(\vec{E} \times \vec{B})$
(1)	$+2-2=0$	$-\frac{1}{\mu}(5\hat{k})$
(2)	$-6+6=0$	$+\frac{1}{\mu}(13\hat{k})$
(3)	$+2+6 \neq 0$	- No Need to check
(4)	$12-12=0$	$-\frac{1}{\mu}(25\hat{k})$

(16) Intensity (I) :- It is average of pointing vector for one cycle.

→ unit :- $\frac{Watt}{m^2}$

→ $I = \langle S \rangle_T$

$= \langle \epsilon v E^2 \rangle_T$

$= \langle \epsilon v E_p^2 \sin^2(\omega t - kx) \rangle_T$

$\boxed{I = \frac{1}{2} \epsilon v E_p^2} \boxed{= v \cdot \bar{u}}$ (or) $\boxed{I = \frac{1}{2} \frac{v}{\mu_0} \times B_p^2}$

Q jee $E = 100 \sin(\omega t - kx)$ find Intensity

Soln:-

$I = \frac{1}{2} \epsilon_0 c E_p^2$

$= \frac{1}{2} \times 8.8 \times 10^{-12} \times 3 \times 10^8 \times (100)^2$

$= 132 \frac{Watt}{m^2}$

Q $E = 10 \sin(2\pi \times 10^6 t - \pi \times 10^{-2} z)$ find

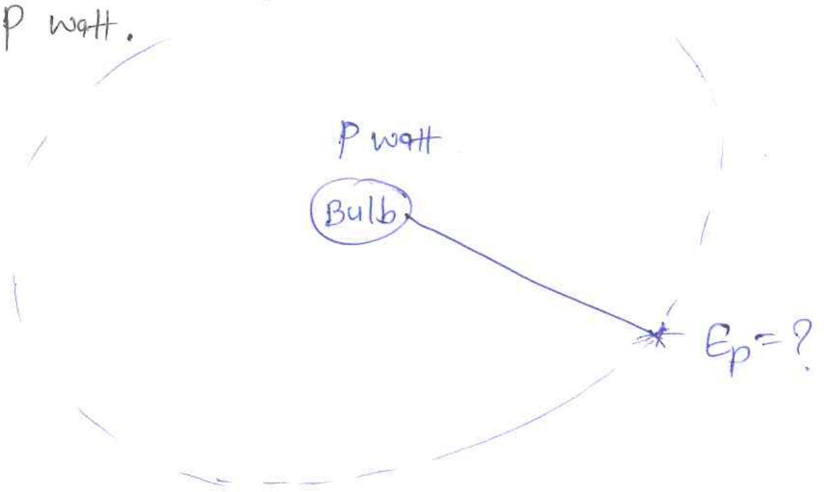
Soln:-

$v = \frac{\omega}{k} = 2 \times 10^8 m/s$

$n = \frac{c}{v} = 1.5 = \sqrt{\epsilon_r}$ $\epsilon_r = 2.25$

Q find Amplitude of Electricfield at r distance from bulb of P watt.

soln:-



$$I = \frac{P}{4\pi r^2} = \frac{1}{2}\epsilon_0 C E_p^2 \text{ (or) } \boxed{\frac{1}{2}\frac{1}{\mu_0} C B_p^2}$$

$$E_p = \sqrt{\frac{P}{2\pi C \epsilon_0 r^2}}$$

Q jee

Electromagnetic spectrum :-

EMW spectrum

γ-rays	x-Rays	U.V	Visible	IR	MW	Radio wave

VIBGYOR

$\longrightarrow \lambda \uparrow$

$\longrightarrow (\text{Energy})_{\text{photon}} \downarrow$