Nishant Jindal

Q.

Momentum of E.M Wave

$$E = h\nu = \frac{hc}{\lambda} \Rightarrow \frac{h}{\lambda} = \frac{E}{c}$$

$$\lambda = \frac{h}{mv} = \frac{h}{p}$$

$$p = \frac{h}{\lambda} = \frac{E}{c}$$

$$\boxed{p = \frac{E}{c}}$$

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Radiant pressure

Change in Momentum

$$\Delta p = p\cos\theta - (-p\cos\theta)$$

$$\Delta p = 2p\cos\theta$$

$$\vec{F} = \frac{\vec{\Delta p}}{\Delta t}$$

Force acting per second

$$\vec{F} = \vec{\Delta p} = (2p\cos\theta)\hat{j}$$

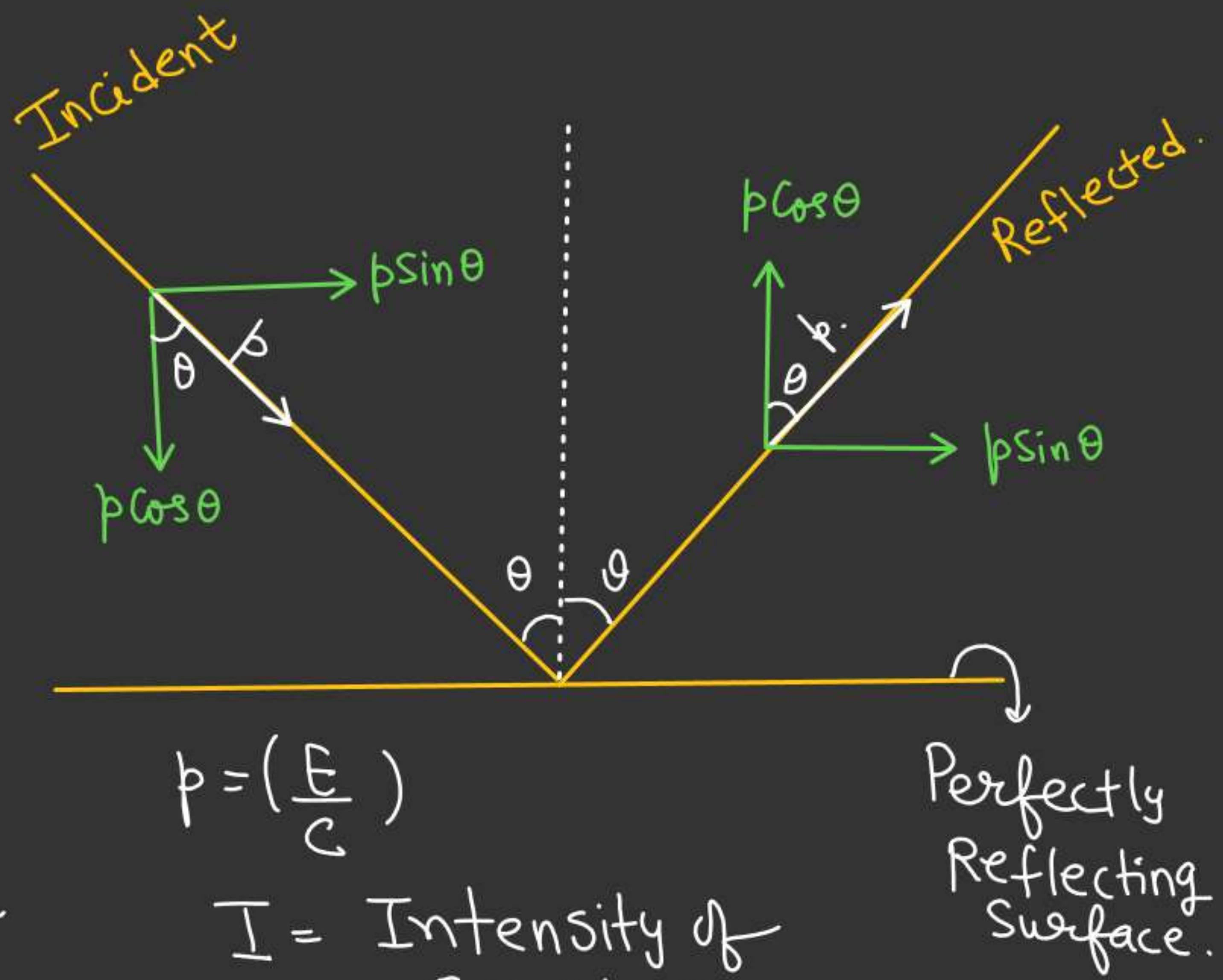
$$F = (2p\cos\theta) = \frac{2E}{c}\cos\theta$$

$$F = \frac{2}{c}(IA)\cos\theta$$

$$F/A = \frac{2I}{c}\cos\theta$$

$$\boxed{P = \frac{2I}{c}\cos\theta}$$

Radiant pressure.



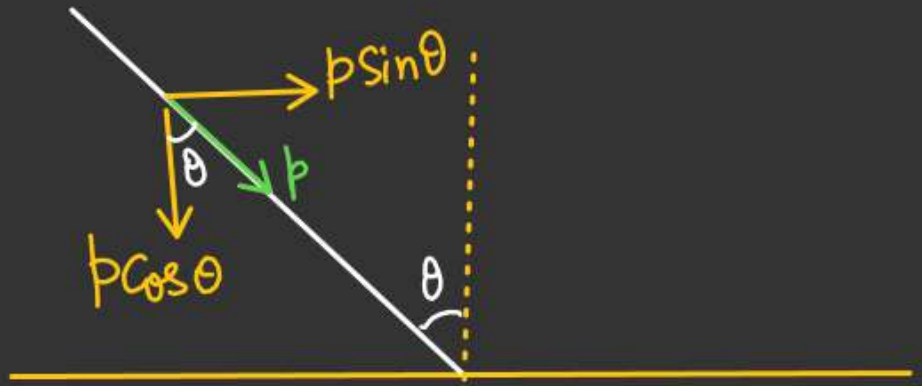
$$p = \left(\frac{E}{c}\right)$$

I = Intensity of E.M Wave.

$$I = \frac{E}{t \cdot A} \quad (t = 1\,sec)$$

$$I = (E/A)\ (\text{Per Second})$$

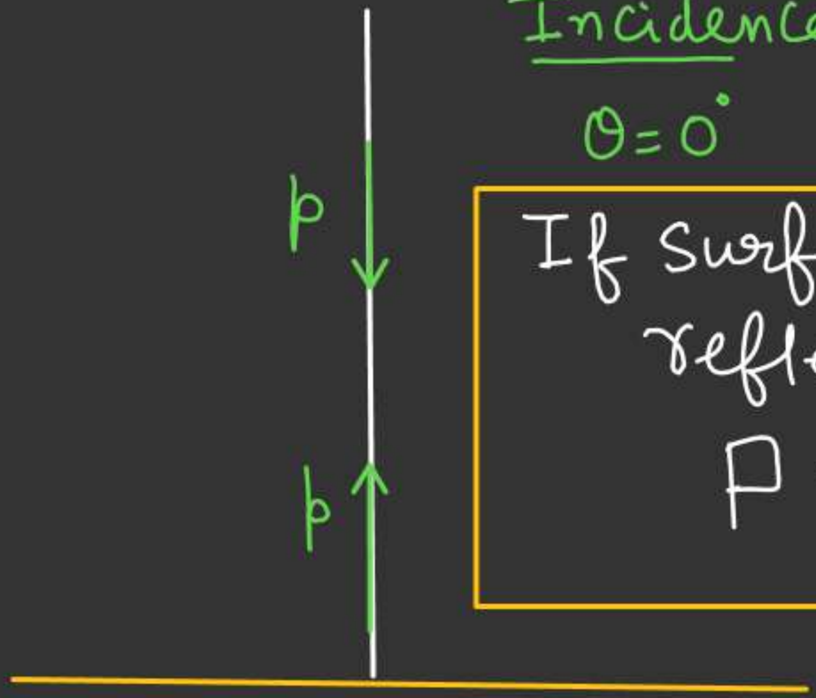
(a) For perfectly absorbing Surfaces



$$\boxed{P = \frac{I}{c}\cos\theta}$$

For Normal Incidence

$\theta = 0^\circ$



$$I = \frac{E}{A\,t}$$

$$E = IA$$

If surface is perfectly reflecting

$$P = \frac{2I}{c}$$

If surface is perfectly absorbing

$$P = \frac{I}{c}$$

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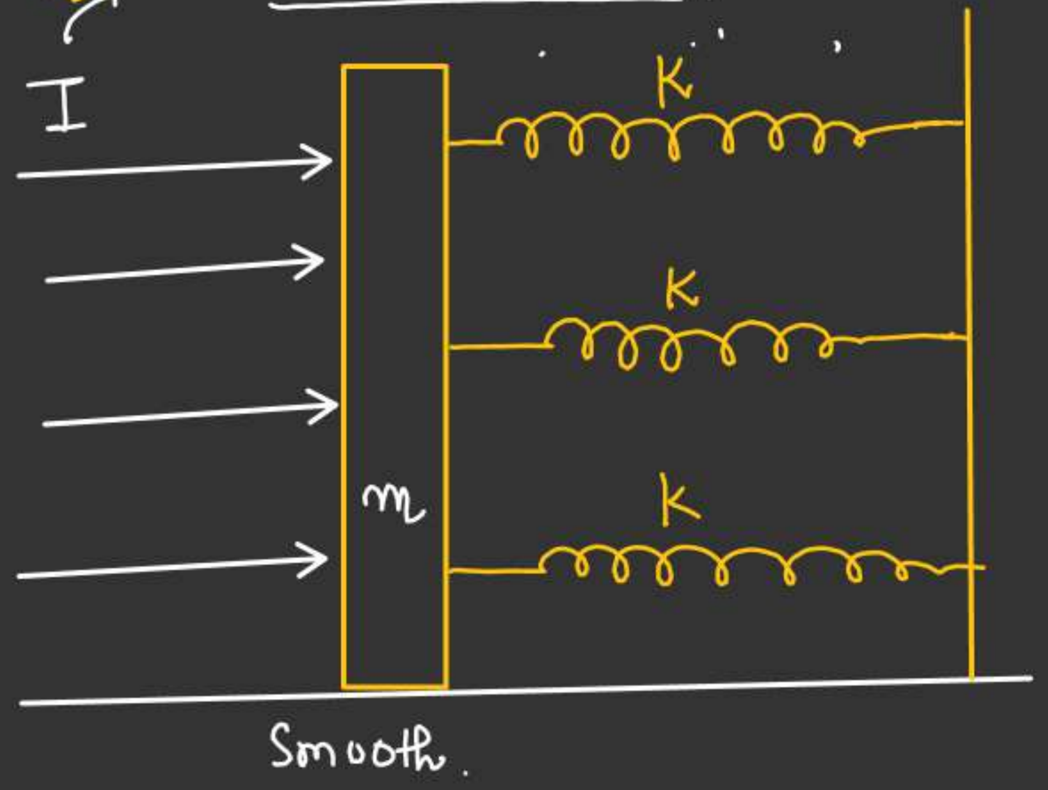
A = Area of plate. (Plate is perfectly absorbing.)

Intensity of Radiation

Find Maximum Compression in the Spring.

Initially Spring at its natural length.



Force on the plate due to radiation $= P \cdot A$

$$= \frac{IA}{C}$$

At Equlibrium, let Compression in Spring be x_0

$K_{eq} = (3K)$

$$\frac{IA}{C} = 3Kx_0$$

$$x_0 = \left(\frac{IA}{3KC}\right)$$

$$x_{max} = 2x_0 = \left(\frac{2IA}{3KC}\right)$$ Ans.

ELECTROMAGNETIC WAVES

Q.1 The magnetic field of a plane electromagnetic wave is given by:

$(kx + \omega t)$

$$\vec{B} = 2 \times 10^{-8} \sin(0.5 \times 10^{3} x + 1.5 \times 10^{11} t)\hat{j}\ \text{T}.$$

July 26,2022 (I)

The amplitude of the electric field would be:

X (A) $6\,\text{Vm}^{-1}$ along x-axis

(B) $3\,\text{Vm}^{-1}$ along z-axis

(C) $6\,\text{Vm}^{-1}$ along z-axis ✓

(D) $2 \times 10^{-8}\,\text{Vm}^{-1}$ along z-axis

$B_0 = 2 \times 10^{-8}$

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

$E_0 = B_0 c$

$= 2 \times 10^{-8} \times 3 \times 10^{8}$

$= 6$

$\vec{E} \to +z.$

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

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

ELECTROMAGNETIC WAVES

Q.2 The displacement current of $4.425 \mu A$ is developed in the space between the plates of parallel plate capacitor when voltage is changing at a rate of $10^6 Vs^{-1}$. The area of each plate of the capacitor is $40\ cm^2$. The distance between each plate of the capacitor is $x \times 10^{-3}$ m. The value of x is, (Permittivity of free space, E_0 ε_0 $= 8.85 \times 10^{-12} C^2 N^{-1} m^{-2}$) **June 29, 2022(II)**

Ans. 8 ✓

$$i_d = \varepsilon_0 \left(\frac{d\phi_E}{dt}\right)$$

$$\phi_E = E \cdot A$$

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

$$\phi_E = \left(\frac{V}{d} A\right)$$

$$i_d = \frac{\varepsilon_0 A}{d}\left(\frac{dV}{dt}\right)$$

$$d = \left(\frac{\varepsilon_0 A}{i_d}\right)\left(\frac{dV}{dt}\right)$$

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.3 An EM wave propagating in x-direction has a wavelength of $8\,\mathrm{mm}$. The electric field vibrating y-direction has maximum magnitude of $60\,\mathrm{Vm}^{-1}$. Choose the correct equations for electric and magnetic fields if the EM wave is propagating in vacuum :

June 28,2022(II)

$y = A\sin(kx -$

Wave prop in $+x$ d

(A) $E_y = 60\sin\left[\frac{\pi}{4}\times 10^3(x-3\times 10^8 t)\right]\hat{j}\,\mathrm{Vm}^{-1} \Rightarrow B_z = 2\sin\left[\frac{\pi}{4}\times 10^3(x-3\times 10^8 t)\right]\hat{k}\,\mathrm{T}$

B_0

(B) $E_y = 60\sin\left[\frac{\pi}{4}\times 10^3(x-3\times 10^8 t)\right]\hat{j}\,\mathrm{Vm}^{-1} \Rightarrow B_z = 2\times 10^{-7}\sin\left[\frac{\pi}{4}\times 10^3(x-3\times 10^8 t)\right]\hat{k}\,\mathrm{T}$

(C) $E_y = 2\times 10^{-7}\sin\left[\frac{\pi}{4}\times 10^3(x-3\times 10^8 t)\right]\hat{j}\,\mathrm{Vm}^{-1} \Rightarrow B_z = 60\sin\left[\frac{\pi}{4}\times 10^3(x-3\times 10^8 t)\right]\hat{k}\mathrm{T}$

(D) $E_y = 2\times 10^{-7}\sin\left[\frac{\pi}{4}\times 10^4(x-4\times 10^8 t)\right]\hat{j}\,\mathrm{Vm}^{-1} \Rightarrow B_z = 60\sin\left[\frac{\pi}{4}\times 10^4(x-4\times 10^8 t)\right]\hat{k}\mathrm{T}$

$\frac{E_0}{B_0} = C \Rightarrow B_0 = \frac{E_0}{C} = \frac{60}{3\times 10^8} = 20\times 10^{-8} = (2\times 10^{-7})$

$E \to \hat{j}$

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

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

ELECTROMAGNETIC WAVES

Q.4 If electric field intensity of a uniform plane electromagnetic wave is given as

$$\vec{E} = -\underbrace{301.6}_{E_{01}}\sin(kz-\omega t)\hat{a}_x + \underbrace{452.4}_{E_{02}}\sin(kz-\omega t)\hat{a}_y \frac{V}{m}$$

Then, magnetic intensity H of this wave in Am^{-1} will be:'

[Given: Speed of light in vacuum $c = 3 \times 10^8\ ms^{-1}$, permeability of vacuum

$\mu_0 = 4\pi \times 10^{-7} NA^{-2}$]

June 26, 2022(I)

(A) $+0.8\sin(kz-\omega t)\hat{a}_y + 0.8\sin(kz-\omega t)\hat{a}_x$

(B) $+1.0 \times 10^{-6}\sin(kz-\omega t)\hat{a}_y + 1.5 \times 10^{-6}(kz-\omega t)\hat{a}_x$

(C) $-0.8\sin(kz-\omega t)\hat{a}_y - 1.2\sin(kz-\omega t)\hat{a}_x$

(D) $-1.0 \times 10^{-6}\sin(kz-\omega t)\hat{a}_y - 1.5 \times 10^{-6}\sin(kz-\omega t)\hat{a}_x$

$H = \left(\frac{B}{\mu_0}\right)$

wave propagation in $(+\hat{k})$

$\hat{E}_{01} \times \hat{B}_{01} = \hat{k}$

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

$\frac{E_{01}}{B_{01}} = c$

$B_{01} = \frac{E_{01}}{c}$

$H_{01} = \frac{B_{01}}{\mu} = \left(\frac{E_{01}}{\mu c}\right)$

$H_{02} = \left(\frac{E_{02}}{\mu c}\right)$

$H_{01} = \left(\frac{301.6}{4\pi \times 10^{-7} \times 3 \times 10^{8}}\right)$

ELECTROMAGNETIC WAVES

Q.5 The electric field in an electromagnetic wave is given by $E = 56.5 \sin \omega(t - x/c) NC^{-1}$. Find the intensity of the wave if it is propagating along x-axis in the free space.

June25,2022(I)

(Given $\varepsilon_0 = 8.85 \times 10^{-12} C^2 N^{-1} m^{-2}$)

(A) $5.65 Wm^{-2}$

★ (B) $4.24 Wm^{-2}$

(C) $1.9 \times 10^{-7} Wm^{-2}$

(D) $56.5 Wm^{-2}$

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

$K = \frac{2\pi}{v \times T}$

$\left(K = \frac{\omega}{v}\right)$ ✓

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

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

$y = A\sin\omega\left(t - \frac{K}{\omega} \cdot x\right)$

$y = A\sin\omega\left(t - \frac{x}{v}\right)$

$I = \frac{1}{2}(\varepsilon_0 E_0^2)c$

$I = \left[\frac{1}{2} \times (8.85 \times 10^{-12}) (56.5)^2 \times (3 \times 10^8)\right]$

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ELECTROMAGNETIC WAVES

B_0

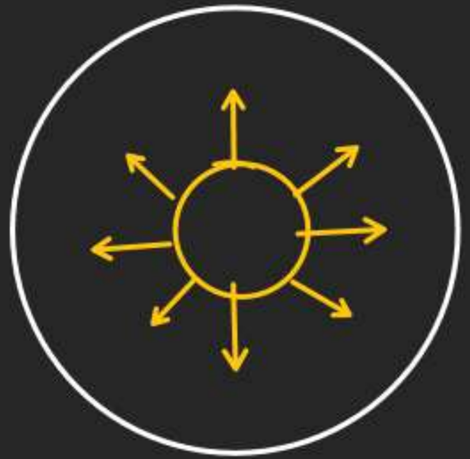
Q.6 An electric bulb is rated as $200\ \text{W}$. What will be the peak magnetic field at $4\ \text{m}$ distance produced by the radiations coming from this bulb? Consider this bulb as a point source with 3.5% efficiency. **June 24,2022(II)**

(A) $1.19 \times 10^{-8}\ \text{T}$

★ (B) $1.71 \times 10^{-8}\ \text{T}$ ✓

(C) $0.84 \times 10^{-8}\ \text{T}$

(D) $3.36 \times 10^{-8}\ \text{T}$



$$I = \left(\frac{B_0^2}{2\mu_0} \times c\right)$$

$\downarrow$

$$\mu_0 = 4\pi \times 10^{-7}$$

$$\left(\frac{P}{4\pi r^2}\right)\left(\frac{3.5}{100}\right) = \frac{B_0^2}{2\mu_0} \times c$$

$$\sqrt{\frac{3.5}{100} \times \frac{200}{\cancel{4\pi}\,(4)^2} \times \frac{2 \times (\cancel{4\pi} \times 10^{-7})}{(3 \times 10^8)}} = B_0$$

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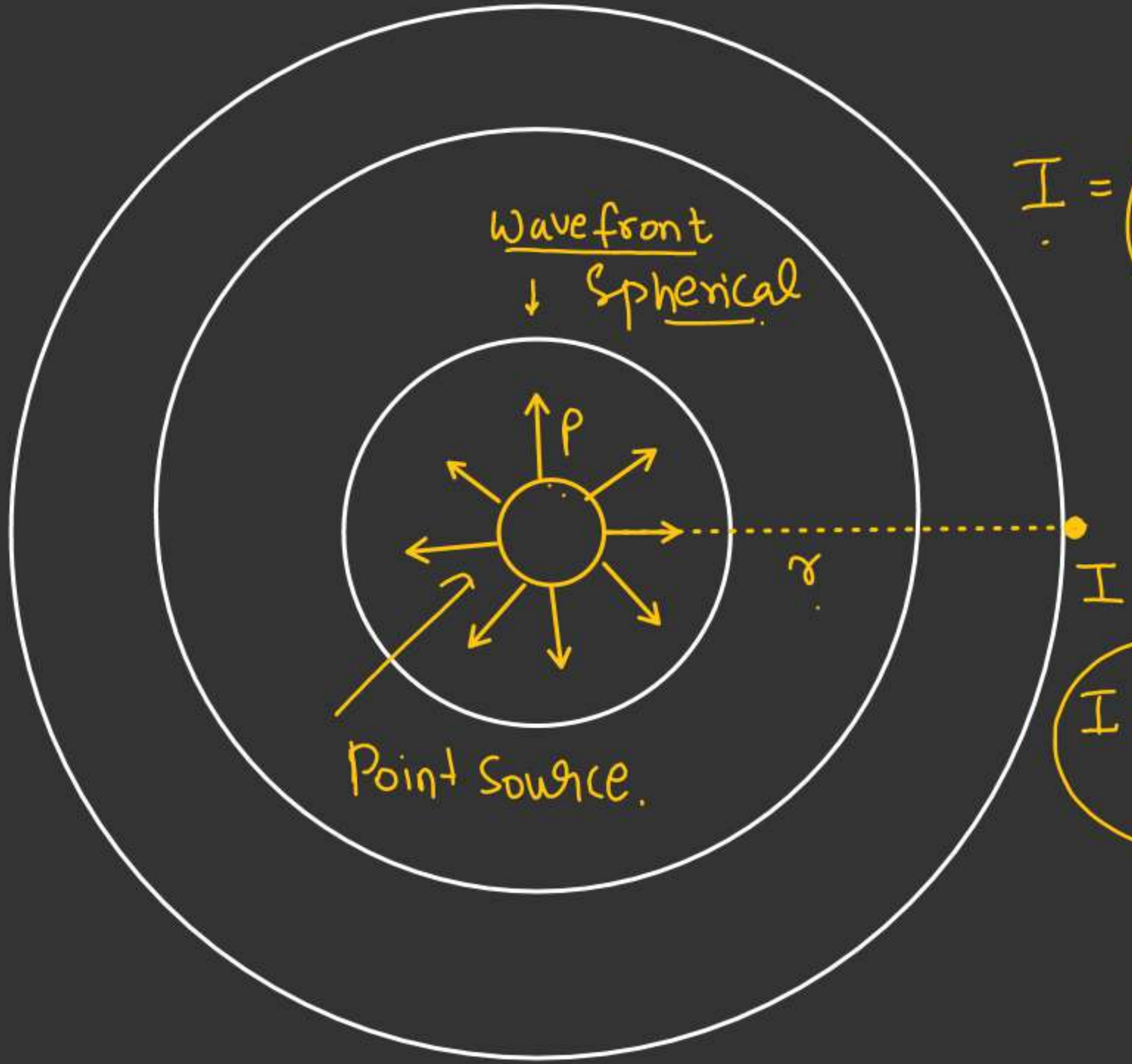
Intensity of a Point Source at a radial distance r



$$I = \left(\frac{P}{4\pi r^2}\right)$$

$$P = \frac{E}{t}$$
⇓
Power

$$I \propto \frac{1}{r^2}$$

ELECTROMAGNETIC WAVES

Q.7 Electric field of plane electromagnetic wave propagating through a non-magnetic medium is given by $E = 20\cos\left(2 \times 10^{10}t - 200x\right)V/m$. The dielectric constant of the medium is equal to : (Take $\mu_r = 1$) **Sep.1, 2021(II)**

(A) 9 ✓

(B) 2

(C) $\frac{1}{3}$

(D) 3

$K = \varepsilon_r$

$y = A\cos(\omega t - Kx)$

$\omega = 2\times10^{10}$

$K = 200$

$K = \frac{\omega}{v} \Rightarrow v = \frac{\omega}{K} = \frac{2\times10^{10}}{2\times10^{2}}$

$v = 10^8$ m/s

v_m

$v_m = \frac{c}{\sqrt{\mu_r \cdot \varepsilon_r}}$

$\cancel{10^8} = \frac{3\times\cancel{10^8}}{\sqrt{\mu_r \cdot \varepsilon_r}}$

$\varepsilon_r = 9$

Q.8 The electric field in an electromagnetic wave is given by $E = (50NC^{-1})\sin\omega(t - x/c)$

The energy contained in a cylinder of volume V is 5.5×10^{-12} J. The value of V is _____ cm^3. (given $\epsilon_0 = 8.8 \times 10^{-12} C^2 N^{-1} m^{-2}$) **NA, Aug.31,2021(I)**

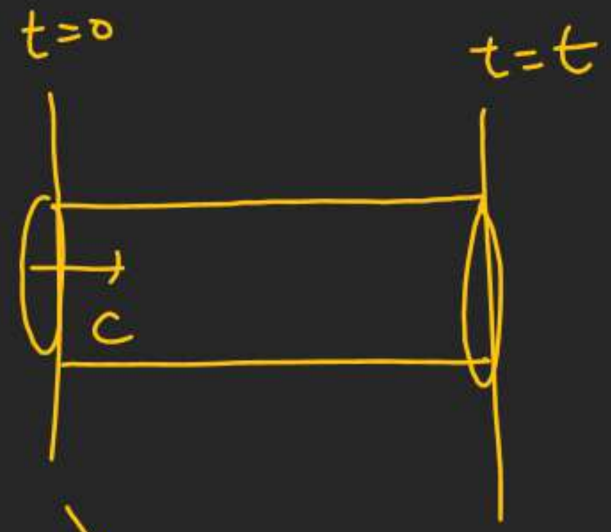
Ans. 500

Total Energy density

$$u = \frac{1}{2}\varepsilon_0 E_0^2$$

$$\frac{E^{\,\to \text{Energy}}}{V} = \frac{1}{2}\varepsilon_0 E_0^2$$

$$V = \left(\frac{2E}{\varepsilon_0 E_0^2}\right) = \left(\frac{2 \times 5.5 \times 10^{-12}}{8.85 \times 10^{-12} \times (50)^2}\right)$$



ELECTROMAGNETIC WAVES

$\vec{E} = E_0\left(\frac{-\hat{i}+\hat{j}}{\sqrt{2}}\right)\sin(kz-\omega t)$ $\quad \frac{\pi}{k}, \frac{3\pi}{k}$, $t=0$

Q.9 The magnetic field vector of an electromagnetic wave is given by $B = B_0\frac{\hat{i}+\hat{j}}{\sqrt{2}}\cos(kz-\omega t)$; where $\hat{i}, \hat{j}$ represents unit vector along x and y-axis respectively. At $t = 0$ s, two electric charges q_1 of 4π coulomb and q_2 of 2π coulomb located at $\left(0, 0, \frac{\pi}{k}\right)$ and $\left(0, 0, \frac{3\pi}{k}\right)$ respectively, have the same velocity of $0.5c\hat{i}$, (where c is the velocity of light). The ratio of the force acting on charge q_1 to q_2 is

Aug,31,2021(II)

(A) $2\sqrt{2}: 1$

(B) $1: \sqrt{2}$

★ (C) $2: 1$ ✓

(D) $\sqrt{2}: 1$

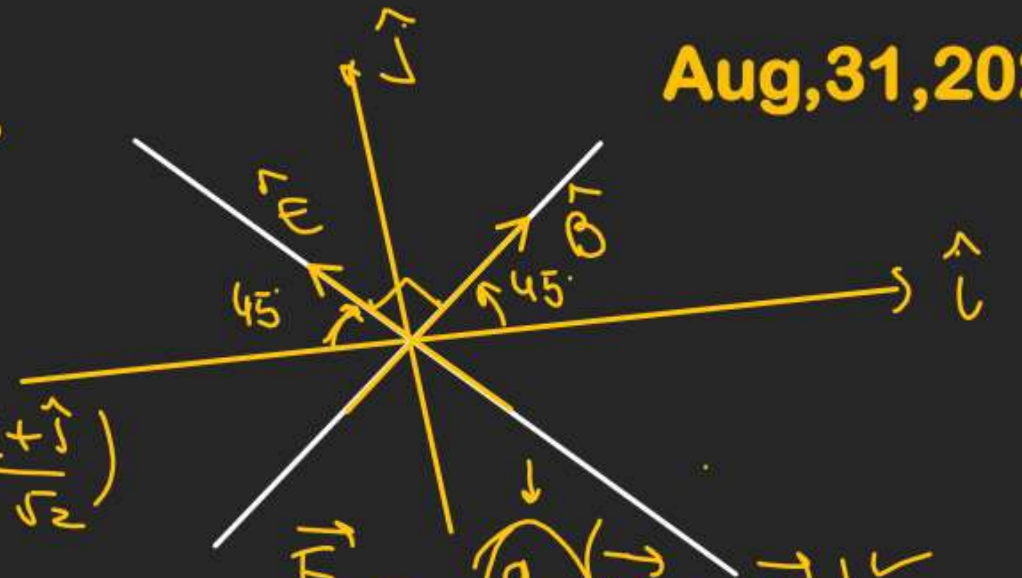
$\frac{E_0}{B_0} = c \Rightarrow E_0 = cB_0$

$\hat{v} \to \hat{k}$ at $z = \pi/k$

$\vec{B}_1 = B_0\cos\left(k\times\frac{\pi}{k}\right)\left(\frac{\hat{i}+\hat{j}}{\sqrt{2}}\right)$

$= -B_0\left(\frac{\hat{i}+\hat{j}}{\sqrt{2}}\right)$

$\vec{B}_2$ at $z = \frac{3\pi}{k}, t=0$ $= -B_0\left(\frac{\hat{i}+\hat{j}}{\sqrt{2}}\right)$



$\vec{F}_{B_1} = q_1(\vec{v}\times\vec{B}_1)$

$\vec{F}_{B_2} = q_2(\vec{v}\times\vec{B}_2)$

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ELECTROMAGNETIC WAVES

Q.10 The electric field in a plane electromagnetic wave is given by $\vec{E} = 200\cos\left[\left(\frac{0.5\times10^3}{m}\right)x - \left(1.5\times10^{11}\frac{rad}{s}\times t\right)\right]\frac{V}{m}\hat{j}$ If this wave falls normally on a perfectly reflecting surface having an area of $100\ cm^2$. If the radiation pressure exerted by the E.M. wave on the surface during a 10 minute exposure is $\frac{x}{10^9}\frac{N}{m^2}$. Find the value of x.

Avg.

Ans. 354

$P = \frac{2I}{c}$

$I = \left(\frac{1}{2}\varepsilon_0 E_0^2 \times c\right)$

$P = \cancel{\frac{2}{c}} \times \frac{1}{\cancel{2}}\varepsilon_0 E_0^2 \times \cancel{c}$

$P = \frac{354}{10^9}$ ⇒ x

$P = (\varepsilon_0 E_0^2) = 8.85\times10^{-12}\times4\times10^4$

$= 35\cancel{4}0\times10^{-10}$

$= 35\cancel{4}\times10^{-9}$

ELECTROMAGNETIC WAVES

H-W

Q.11 A plane electromagnetic wave of frequency $100\mathrm{MHz}$ is travelling in vacuum along the x-direction. At a particular point in space and time, $\vec{B} = 2.0 \times 10^{-8}\hat{k}\mathrm{T}$. (where, $\hat{k}$ is unit vector along z-direction) What is $\vec{E}$ at this point? (speed of light $c = 3\vec{E}10^{8}\ \mathrm{m/s}$) **March18,2021(I)**

★(A) $6.0\hat{j}\ \mathrm{V/m}$

(B) $0.6\hat{j}\mathrm{V/m}$

(C) $0.6\hat{k}\mathrm{V/m}$

(D) $6.0\hat{k}\mathrm{V/m}$

ELECTROMAGNETIC WAVES

H-W

Q.12 If 2.5×10^{-6} N average force is exerted by a light wave on a non-reflecting surface of $30\ \text{cm}^2$ area during 40 minutes of time span, the energy flux of light just before it falls on the surface is ____W/cm^2. (Round off to the Nearest Integer) (Assume complete adsorption and normal incidence conditions are there) March 17,2021 (I)

Ans. 25

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ELECTROMAGNETIC WAVES

H.W

Q.13 For a plane electromagnetic wave, the magnetic field at a point x and time t is $\vec{B}(x,t) = [1.2 \times 10^{-7}\sin(0.5 \times 10^{3}x + 1.5 \times 10^{11}t)\hat{k}]\,T$

The instantaneous electric field $\vec{E}$ corresponding to $\vec{B}$ is:

(speed of light $c = 3 \times 10^{8}\ ms^{-1}$) Sep.06,2020 (II)

(A) $\vec{E}(x,t) = [-36\sin(0.5 \times 10^{3}x + 1.5 \times 10^{11}t)\hat{j}]\,\frac{V}{m}$

(B) $\vec{E}(x,t) = [36\sin(1 \times 10^{3}x + 0.5 \times 10^{11}t)\hat{j}]\,\frac{V}{m}$

(C) $\vec{E}(x,t) = [36\sin(0.5 \times 10^{3}x + 1.5 \times 10^{11}t)\hat{k}]\,\frac{V}{m}$

(D) $\vec{E}(x,t) = [36\sin(1 \times 10^{3}x + 1.5 \times 10^{11}t)\hat{i}]\,\frac{V}{m}$

ELECTROMAGNETIC WAVES

H.W

Q.14 The electric field of a plane electromagnetic wave is given by $\vec{E} = E_0(\hat{x} + \hat{y})\sin(kz - \omega t$ Its magnetic field will be given by: Sep.04,2020 (II)

★(A) $\frac{E_0}{c}(-\hat{x} + \hat{y})\sin(kz - \omega t)$

(B) $\frac{E_0}{c}(\hat{x} + \hat{y})\sin(kz - \omega t)$

(C) $\frac{E_0}{c}(\hat{x} - \hat{y})\sin(kz - \omega t)$

(D) $\frac{E_0}{c}(\hat{x} - \hat{y})\cos(kz - \omega t)$

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H-W

Q.15 The electric fields of two plane electromagnetic plane waves in vacuum are given by $\vec{E}_1 = E_0\hat{j}\cos(\omega t - kx)$ and $\vec{E}_2 = E_0\hat{k}\cos(\omega t - ky)$.

At $t = 0$, a particle of charge q is at origin with a velocity $\vec{v} = 0.8c\hat{j}$ (c is the speed of light in vacuum). The instantaneous force experienced by the particle is: **9Jan,2020 (I)**

(A) $E_0q(0.8\hat{i} - \hat{j} + 0.4\hat{k})$

(B) $E_0q(0.4\hat{i} - 3\hat{j} + 0.8\hat{k})$

(C) $E_0q(-0.8\hat{i} + \hat{j} + \hat{k})$

★(D) $E_0q(0.8\hat{i} + \hat{j} + 0.2\hat{k})$

ELECTROMAGNETIC WAVES

H.W

Q.16 If the magnetic field in a plane electromagnetic wave is given by $\vec{B} = 3 \times 10^{-8} \sin(1.6 \times 10^3 x + 48 \times 10^{10} t)\hat{j}$ T, then what will be expression for electric field? 7Jan,2020 (I)

(A) $\vec{E} = (60 \sin(1.6 \times 10^3 x + 48 \times 10^{10} t)\hat{k} v/m)$

★(B) $\vec{E} = (9 \sin(1.6 \times 10^3 x + 48 \times 10^{10} t)\hat{k} v/m)$

(C) $\vec{E} = (3 \times 10^{-8} \sin(1.6 \times 10^3 x + 48 \times 10^{10} t)\hat{k} v/m)$

(D) $\vec{E} = (3 \times 10^{-8} \sin(1.6 \times 10^3 x + 48 \times 10^{10} t)\hat{k} v/m)$

ELECTROMAGNETIC WAVES

H-W

Q.17 Light is incident normally on a completely absorbing surface with an energy flux of $25 \mathrm{Wcm}^{-2}$. If the surface has an area of $25\ \mathrm{cm}^2$, the momentum transferred to the surface in 40 min time duration will be: 10April 2019 (II)

(A) $6.3 \times 10^{-4}\mathrm{Ns}$

(B) $1.4 \times 10^{-6}\mathrm{Ns}$

★(C) $5.0 \times 10^{-3}\mathrm{Ns}$

(D) $3.5 \times 10^{-6}\mathrm{Ns}$

ELECTROMAGNETIC WAVES

H.W

Q.18 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 and $\vec{E}_2 = E_{02}\hat{x}\cos[k(2z - ct)]$ in medium, where the wave number k and frequency v refer to their values in air. The medium is nonmagnetic. If ϵ_{r_1} and ϵ_{r_2} refer to relative permittivity's of air and medium respectively, which of the following options is correct? **9 Jan 2019 (I)**

(A) $\frac{\epsilon_{r_1}}{\epsilon_{r_2}} = 4$

(B) $\frac{\epsilon_{r_1}}{\epsilon_{r_2}} = 2$

★(C) $\frac{\epsilon_{r_1}}{\epsilon_{r_2}} = \frac{1}{4}$

(D) $\frac{\epsilon_{r_1}}{\epsilon_{r_2}} = \frac{1}{2}$

ELECTROMAGNETIC WAVES

H.W

Q.19 For plane electromagnetic waves propagating in the $z-$direction, which one of the following combination gives the correct possible direction for $\vec{E}$ and $\vec{B}$ field respectively? **Online April 11, 2015**

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

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

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

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