Electromagnetic Waves JEE Main PYQ - 1

Total Time: 25 Minute **Total Marks:** 40

Instructions

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1. Test will auto submit when the Time is up.
2. The Test comprises of multiple choice questions (MCQ) with one or more correct answers.
3. The clock in the top right corner will display the remaining time available for you to complete the examination.

Navigating & Answering a Question

1. The answer will be saved automatically upon clicking on an option amongst the given choices of answer.
2. To deselect your chosen answer, click on the clear response button.
3. The marking scheme will be displayed for each question on the top right corner of the test window.

Electromagnetic Waves

1. The magnetic field of an electromagnetic wave is given by : $\vec{B} = 1.6 \times 10^{-6} \cos\left(2 \times 10^7 z + 6 \times 10^{15} t\right)\left(2\hat{i} + \hat{j}\right) \frac{Wb}{m^2}$ The associated electric field will be :- **(+4, -1)**

[8 April 2019 II]

a. $\vec{E} = 4.8 \times 10^2 \cos\left(2 \times 10^7 z + 6 \times 10^{15} t\right)\left(\hat{i} - 2\hat{j}\right) \frac{V}{m}$

b. $\vec{E} = 4.8 \times 10^2 \cos\left(2 \times 10^7 z - 6 \times 10^{15} t\right)\left(2\hat{i} + \hat{j}\right) \frac{V}{m}$

c. $\vec{E} = 4.8 \times 10^2 \cos\left(2 \times 10^7 z - 6 \times 10^{15} t\right)\left(-2\hat{i} + \hat{j}\right) \frac{V}{m}$

d. $\vec{E} = 4.8 \times 10^2 \cos\left(2 \times 10^7 z + 6 \times 10^{15} t\right)\left(-1\hat{i} + 2\hat{j}\right) \frac{V}{m}$

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2. A $27\, mW$ laser beam has a cross-sectional area of $10\ mm^2$. The magnitude of the maximum electric field in this electromagnetic wave is given by [Given permittivity of space $\in_0 = 9 \times 10^{-12}$ SI units, Speed of light $c = 3 \times 10^8\ m/s$] : **(+4, -1)**

[11 Jan 2019, II]

a. $1\, kV/m$

b. $2\, kV/m$

c. $1.4\, kV/m$

d. $0.7\, kV/m$

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3. A plane electromagnetic wave is propagating along the direction $\frac{\hat{i}+\hat{i}}{\sqrt{2}}$, with its polarization along the direction $\hat{k}$. The correct form of the magnetic field of the wave would be (here B_0 is an appropriate constant): **(+4, -1)**

[9 Jan 2020, II]

a. $B_0 \frac{\hat{i}-\hat{j}}{\sqrt{2}} cos\left(\omega t - k\frac{\hat{i}+\hat{j}}{\sqrt{2}}\right)$

b. $B_0 \frac{\hat{j}-\hat{i}}{\sqrt{2}} cos\left(\omega t - k\frac{\hat{i}+\hat{j}}{\sqrt{2}}\right)$

c. $B_0 \frac{\hat{i}+\hat{j}}{\sqrt{2}} cos\left(\omega t - k\frac{\hat{i}+\hat{j}}{\sqrt{2}}\right)$

d. $B_0 \hat{k}\, cos\left(\omega t - k\frac{\hat{i}+\hat{j}}{\sqrt{2}}\right)$

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4. A lamp emits monochromatic green light uniformly in all directions. The lamp is 3% efficient in converting electrical power to electromagnetic waves and consumes $100\,W$ of power. The amplitude of the electric field associated with the electromagnetic radiation at a distance of $5\,m$ from the lamp will be nearly : **(+4, -1)**

[Online April 12, 2014]

a. $1.34\,V/m$

b. $2.68\,V/m$

c. $4.02\,V/m$

d. $5.36\,V/m$

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5. A plane electromagnetic wave in a non-magnetic dielectric medium is given by $\vec{E} = \vec{E}_0\left(4 \times 10^{-7}\,x - 50t\right)$ with distance being in meter and time in seconds. The dielectric constant of the medium is: **(+4, -1)**

[Online April 22, 2013]

a. 2.4

b. 5.8

c. 8.2

d. 4.8

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6. A plane electromagnetic wave of wavelength λ has an intensity I. It is propagating along the positive Y-direction. The allowed expressions for the electric and magnetic fields are given by : **(+4, -1)**

[Online April 16, 2018]

a. $\vec{E} = \sqrt{\frac{2I}{\epsilon_o c}} \cos\left[\frac{2\pi}{\lambda}(y - ct)\right]\hat{k}; \vec{B} = +\frac{1}{c}E\hat{i}$

b. $\vec{E} = \sqrt{\frac{2I}{\epsilon_o c}} \cos\left[\frac{2\pi}{\lambda}(y + ct)\right]\hat{k}; \vec{B} = \frac{1}{c}E\hat{i}$

c. $\vec{E} = \sqrt{\frac{I}{\epsilon_o c}} \cos\left[\frac{2\pi}{\lambda}(y - ct)\right]\hat{k}; \vec{B} = \frac{1}{c}E\hat{i}$

d. $\vec{E} = \sqrt{\frac{I}{\epsilon_o c}} \cos\left[\frac{2\pi}{\lambda}(y - ct)\right]\hat{i}; \vec{B} = \frac{1}{c}E\hat{k}$

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7. A plane electromagnetic wave travels in free space along the x-direction. The electric field component of the wave at a particular point of space and time is $E = 6\ V\ m^{-1}$ along y-direction. Its corresponding magnetic field component, B would be : **(+4, -1)**

[8 April 2019 I]

a. 6×10^{-8} T along z-direction

b. 6×10^{-8} T along x-direction

c. 2×10^{-8} T along z-direction

d. 2×10^{-8} T along y-direction

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8. A plane polarized monochromatic EM wave is traveling in vacuum along z direction such that at $t = t_1$ it is found that the electric field is zero at a spatial point z_1. The next zero that occurs in its neighbourhood is at z_2. The frequency of the electromagnetic wave is : **(+4, -1)**

a. $\frac{3\times10^8}{|z_2-z_1|}$

b. $\frac{1.5\times10^8}{|z_2-z_1|}$

c. $\frac{6\times10^8}{|z_2-z_1|}$

d. $\frac{1}{t_1+\frac{|z_2-z_1|}{3\times10^8}}$

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9. 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 ? refer to their values in air. The medium is non-magnetic . If $\in_{r_1}$ and $\in_{r_2}$ refer to relative permittivities of air and medium respectively, which of the following options is correct ? **(+4, -1)**

[9 Jan 2019, I]

a. $\frac{\in_{r_1}}{\in_{r_2}} = 4$

b. $\frac{\in_{r_1}}{\in_{r_2}} = 2$

c. $\frac{\in_{r_1}}{\in_{r_2}} = \frac{1}{4}$

d. $\frac{\in_{r_1}}{\in_{r_2}} = \frac{1}{2}$

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10. Consider an electromagnetic wave propagating in vacuum. Choose the correct statement : (+4, -1)

[Online April 10, 2016]

a. For an electromagnetic wave propagating in $+y$ direction the electric field is $\vec{E} = \frac{1}{\sqrt{2}} E_{yz}(x,t)\hat{z}$ and the magnetic field is $\vec{B} = \frac{1}{\sqrt{2}} B_z(x,t)\hat{y}$

b. For an electromagnetic wave propagating in $+y$ direction the electric field is $\vec{E} = \frac{1}{\sqrt{2}} E_{yz}(x,t)\hat{y}$ and he magnetic field is $\vec{B} = \frac{1}{\sqrt{2}} B_{yz}(x,t)\hat{z}$

c. For an electromagnetic wave propagating in $+x$ direction the electric field is $\vec{E} = \frac{1}{\sqrt{2}} E_{yz}(y,z,t)(\hat{y}+\hat{z})$ and the magnetic field is $\vec{B} = \frac{1}{\sqrt{2}} B_{yz}(y,z,t)(\hat{y}+\hat{z})$

d. For an electromagnetic wave propagating in $+x$ direction the electric field is $\vec{E} = \frac{1}{\sqrt{2}} E_{yz}(x,t)(\hat{y}-\hat{z})$ and eh magnetic field is $B = \frac{1}{\sqrt{2}} B_{yz}(x,t)(\hat{y}+\hat{z})$

Answers

1. **Answer: a**

Explanation:

If we use that direction of light propagation will be along $\vec{E} \times \vec{B}$? Then (4) option is correct.
Detailed solution is as following.
magnitude of E = CB
$E = 3 \times 10^8 \times 1.6 \times 10^{-6} \times \sqrt{5}$
$E = 4.8 \times 10^2 \sqrt{5}$
$\vec{E}$ and $\vec{B}$ are perpendicular to each other
$\Rightarrow \vec{E}.\vec{B} = 0$
$\Rightarrow$ either direction of $\vec{E}$ is $\hat{i} - 2\hat{j}$ or $-\hat{i} + 2\hat{j}$ from given option
Also wave propagation direction is parallel to
$\vec{E} \times \vec{B}$ which is $-\hat{k}$
$\Rightarrow \vec{E}$ is along $(-\hat{i} + 2\hat{j})$

Concepts:

1. Electromagnetic waves:

The waves that are produced when an electric field comes into contact with a magnetic field are known as Electromagnetic Waves or EM waves. The constitution of an oscillating magnetic field and electric fields gives rise to electromagnetic waves.

Types of Electromagnetic Waves:

Electromagnetic waves can be grouped according to the direction of disturbance in them and according to the range of their frequency. Recall that a wave transfers energy from one point to another point in space. That means there are two things going on: the disturbance that defines a wave, and the propagation of wave. In this context the waves are grouped into the following two categories:

- **Longitudinal waves:** A wave is called a longitudinal wave when the disturbances in the wave are parallel to the direction of propagation of the wave. For example, sound waves are longitudinal waves because the change of pressure occurs parallel to the direction of wave propagation.

- **Transverse waves:** A wave is called a transverse wave when the disturbances in the wave are perpendicular (at right angles) to the direction of propagation of the wave.

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2. **Answer: c**

Explanation:

The correct answer is C:$1.4kv/m$
EM wave's intensity;
$I = \frac{\text{Power}}{\text{Area}} = \frac{1}{2}\varepsilon_0 E_0^2 C$
Now using this formula and putting in the values we get;
$\frac{10^{-3}\times 27}{10^{-6}\times 10} = \frac{1}{2}\times 10^8 \times E^2 \times 10^{-12} \times 3 \times 9$
Simplifying above equation we get;
$E = 1.4kv/m$

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3. **Answer: a**

Explanation:

Direction of polarisation $= \hat{E} = \hat{k}$
Direction of propagation $= \hat{E} \times \hat{B} = \frac{\hat{i}+\hat{j}}{\sqrt{2}}$
$\therefore \hat{E} \times \hat{B} = \frac{\hat{i}+\hat{j}}{\sqrt{2}}$
$\hat{B} = \frac{\hat{i}+\hat{j}}{\sqrt{2}}$

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4. **Answer: b**

Explanation:

$$I = < u > c = \frac{P}{4\pi r^2}$$
$$\frac{\epsilon_0 \in_0^2}{2} C = \frac{P}{4\pi r^2}$$
$$\epsilon_0^2 = \frac{P}{2\pi r^2 \epsilon_0 C}$$
$$\epsilon_0 = \sqrt{\frac{P}{2\pi r^2 \in_0 C}}$$
$$= \sqrt{\frac{3}{2\pi (5)^2 \times 8.85 \times 10^{-12} \times 3 \times 10^8}}$$
$$\epsilon_0 = 2.68\, volt/metre$$

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5. **Answer: b**

Explanation:

Given equation of wave

$\vec{E} = \vec{E}_0 \left(4 \times 10^{-7} x - 50t\right)$

comparing with general equation of wave

$\vec{E} = \vec{E}_0 (kx - \omega t)$

we get

$\omega = 50 rad/s; k = 4 \times 10^{-7} m^{-1}$

Thus velocity of wave

$V = \frac{\omega}{k} = \frac{50}{4 \times 10^{-7}} = 1.25 \times 10^{8} m/s$

So, refractive index of medium

$\mu = \frac{e}{V} = \frac{3 \times 10^{8}}{1.25 \times 10^{8}} = 2.4$

using

$\mu^2 = km.ke$

(km and ke are di-magnetic and dielectric constants)

as medium is non diamagnetic, $km = 1$

$\Rightarrow ke = \mu^2 = (2.4)^2$

$\Rightarrow ke = 5.76 = 5.8$

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the wave.

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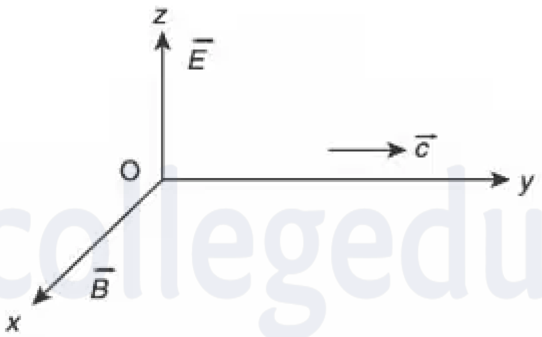
6. **Answer: a**

Explanation:

$\vec{E}$ is electric field vector, $\vec{B}$ is magnetic field vector perpendicular to $\vec{E}$. The direction of propagation is $(\vec{E} \times \vec{B})$.
The direction of propagation of wave is along $+y$ axis, then $\vec{E}$ is along $+z$ axis and $\vec{B}$ is along $+x$ axis.



$(E\hat{k} \times B\hat{t}) = EB(\hat{k} \times \hat{i}) = EB\hat{j}$
As wave is travelling along $+y$ -axis with time, we will use $(y - ct)$ in wave equation.
Also intensity is given by
$I = \frac{1}{2} c\varepsilon_0 E_0^2$
And $E = cB$
So, $|E_0| = \sqrt{\frac{2I}{c\varepsilon_0}}$
Therefore, $\vec{E} = \sqrt{\frac{2I}{c\varepsilon_0}} \cos\left[\frac{2\pi}{\lambda}(y - ct)\right] \hat{k}$
And $\vec{B} = \frac{E}{c}\hat{i} \Rightarrow \frac{1}{c}E\hat{i}$

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7. **Answer: c**

Explanation:

The direction of propogation of an EM wave is direction of $\vec{E} \times \vec{B}$.

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

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

$C = \frac{E}{B} \Rightarrow B = \frac{E}{C} = \frac{6}{3 \times 10^8}$

$B = 2 \times 10^{-8} T$ along z direction.

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8. **Answer: b**

Explanation:

The correct option is(B): $\frac{1.5\times10^8}{|z_2-z_1|}$

Since $c = f\lambda \Rightarrow f = \frac{c}{\lambda}$.
Here, $\lambda = 2\,|z_2 - z_1|$ and $c = 3\times10^8$. Therefore,
$f = \frac{3\times10^8}{2|z_2-z_1|} = \frac{1.5\times10^8}{|z_2-z_1|}$

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9. **Answer: c**

Explanation:

$\vec{E}_1 = E_{01}\hat{x}\cos\left[2\pi v\left(\frac{z}{c} - t\right)\right]$ air

$\vec{E}_2 = E_{02}\hat{x}\cos[k(2z - ct)]$ medium

During refraction, frequency remains unchanged, whereas wavelength gets changed.

$\therefore k' = 2k$ (From equations)

$\Rightarrow \frac{2\pi}{\lambda'} = 2\left(\frac{2\pi}{\lambda_0}\right)$

$\Rightarrow \lambda' = \frac{\lambda_0}{2}$

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

$\Rightarrow \frac{1}{\sqrt{\mu_0\varepsilon_2}} = \frac{1}{2} \times \frac{1}{\sqrt{\mu_0\varepsilon_1}}$

$\Rightarrow \frac{\varepsilon_1}{\varepsilon_2} = \frac{1}{4}$

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10. **Answer: d**

Explanation:

If wave is propagating in x direction, $\vec{E}\,\&\,\vec{B}$ must be functions of $(x, t)\&$ must be in $y-z$ plane.

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