CHAPTER

15 Electromagnetic Waves

1. An EM wave from air enters a medium. The electric fields are $\vec{E}_1 = E_{01}\hat{x}\cos\left[2\pi\upsilon\left(\frac{z}{c}-t\right)\right]$ in air and $\vec{E}_2 = E_{02}\hat{x}\cos[k(2z-ct)]$ in medium, where the wave number k and frequency υ refer to their values in air. The medium is non-magnetic. If ε_{r_1} and ε_{r_2} refer to relative permittivities of air and medium respectively, which of the following options is correct?

(a) $\frac{\varepsilon_{r_1}}{\varepsilon_{r_2}} = 4$ (b) $\frac{\varepsilon_{r_1}}{\varepsilon_{r_2}} = 2$ (c) $\frac{\varepsilon_{r_1}}{\varepsilon_{r_2}} = \frac{1}{4}$ (d) $\frac{\varepsilon_{r_1}}{\varepsilon_{r_2}} = \frac{1}{2}$ *(2018)*

2. A monochromatic beam of light has a frequency $\upsilon = \frac{3}{2\pi}\times 10^{12}$ Hz and is propagating along the direction $\frac{\hat{i}+\hat{j}}{\sqrt{2}}$. It is polarized along the $\hat{k}$ direction. The acceptable form for the magnetic field is

(a) $\frac{E_0}{C}\frac{(\hat{i}+\hat{j}+\hat{k})}{\sqrt{3}}\cos\left[10^4\frac{(\hat{i}+\hat{j})}{\sqrt{2}}\cdot\vec{r}+(3\times10^{12})t\right]$

(b) $\frac{E_0}{C}\frac{(\hat{i}-\hat{j})}{\sqrt{2}}\cos\left[10^4\frac{(\hat{i}+\hat{j})}{\sqrt{2}}\cdot\vec{r}-(3\times10^{12})t\right]$

(c) $\frac{E_0}{C}\frac{(\hat{i}-\hat{j})}{\sqrt{2}}\cos\left[10^4\frac{(\hat{i}-\hat{j})}{\sqrt{2}}\cdot\vec{r}-(3\times10^{12})t\right]$

(d) $\frac{E_0}{C}\hat{k}\cos\left[10^4\frac{(\hat{i}+\hat{j})}{\sqrt{2}}\cdot\vec{r}+(3\times10^{12})t\right]$ *(Online 2018)*

3. A plane polarized monochromatic EM wave is travelling 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

(a) $\frac{1}{t_1+\frac{|z_2-z_1|}{3\times10^8}}$ (b) $\frac{3\times10^8}{|z_2-z_1|}$

(c) $\frac{6\times10^8}{|z_2-z_1|}$ (d) $\frac{1.5\times10^8}{|z_2-z_1|}$ *(Online 2018)*

4. 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

(a) $\vec{E} = \sqrt{\frac{I}{\varepsilon_0 c}}\cos\left[\frac{2\pi}{\lambda}(y-ct)\right]\hat{i}\,;\vec{B} = \frac{1}{c}E\hat{k}$

(b) $\vec{E} = \sqrt{\frac{2I}{\varepsilon_0 c}}\cos\left[\frac{2\pi}{\lambda}(y+ct)\right]\hat{k};\vec{B} = \frac{1}{c}E\hat{i}$

(c) $\vec{E} = \sqrt{\frac{2I}{\varepsilon_0 c}}\cos\left[\frac{2\pi}{\lambda}(y-ct)\right]\hat{k};\vec{B} = \frac{1}{c}E\hat{i}$

(d) $\vec{E} = \sqrt{\frac{I}{\varepsilon_0 c}}\cos\left[\frac{2\pi}{\lambda}(y-ct)\right]\hat{k};\vec{B} = \frac{1}{c}E\hat{i}$ *(Online 2018)*

5. Magnetic field in a plane electromagnetic wave is given by $\vec{B} = B_0\sin(kx+\omega t)\hat{j}\,$T

Expression for corresponding electric field will be (Where c is speed of light.)

(a) $\vec{E} = -B_0c\sin(kx+\omega t)\hat{k}$ V/m

(b) $\vec{E} = B_0c\sin(kx-\omega t)\hat{k}$ V/m

(c) $\vec{E} = \frac{B_0}{c}\sin(kx+\omega t)\hat{k}$ V/m

(d) $\vec{E} = B_0c\sin(kx+\omega t)\hat{k}$ V/m *(Online 2017)*

6. The electric field component of a monochromatic radiation is given by $\vec{E} = 2E_0\hat{i}\cos kz\cos\omega t$

Its magnetic field is then given by

(a) $\frac{2E_0}{c}\hat{j}\cos kz\cos\omega t$ (b) $\frac{2E_0}{c}\hat{j}\sin kz\cos\omega t$

(c) $\frac{2E_0}{c}\hat{j}\sin kz\sin\omega t$ (d) $-\frac{2E_0}{c}\hat{j}\sin kz\sin\omega t$

(Online 2017)

7. Arrange the following electromagnetic radiations per quantum in the order of increasing energy

A : Blue light B : Yellow light

C : X-ray D : Radiowave

(a) D, B, A, C (b) A, B, D, C

(c) C, A, B, D (d) B, A, D, C *(2016)*

8. Microwave oven acts on the principle of

(a) giving rotational energy to water molecules

(b) giving translational energy to water molecules

(c) giving vibrational energy to water molecules

(d) transferring electrons from lower to higher energy levels in water molecule. *(Online 2016)*

9. Consider an electromagnetic wave propagating in vacuum. Choose the correct statement.

(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 fields is $\vec{E} = \frac{1}{\sqrt{2}} E_{yz}(x, t)\hat{y}$ and the 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 the magnetic field is $\vec{B} = \frac{1}{\sqrt{2}} B_{yz}(x,t)(\hat{y}+\hat{z})$

(Online 2016)

10. A red LED emits light at 0.1 watt uniformly around it. The amplitude of the electric field of the light at a distance of 1 m from the diode is

(a) 5.48 V/m (b) 7.75 V/m
(c) 1.73 V/m (d) 2.45 V/m *(2015)*

11. An electromagnetic wave travelling in the x-direction has frequency of 2×10^{14} Hz and electric field amplitude of 27 V m^{-1}. From the options given below, which one describes the magnetic field for this wave?

(a) $\vec{X}$- 1 . = -8×65$^{-=}$ ^. ^{j} -uz g7π-63 ×65$^{-=}$ −7×65^{69} .i

(b) $\vec{X}$- 1 . = ->×65$^{-=}$ ^. ^{j} -uz g7π-63 ×65$^{-;}$ −7×65^{69} .i

(c) $\vec{X}$- 1 . = ->×65$^{-=}$ ^. ^{j} -uz g7π-63 ×65$^{-=}$ −7×65^{69} .i

(d) $\vec{X}$- 1 . = ->×65$^{-=}$ ^. ^{j} -uz g63 ×65$^{-;}$ −7×65^{69} i

(Online 2015)

12. For plane electromagnetic waves propagating in the z direction, which one of the following combination gives the correct possible direction for field respectively?

(a) -^{j} + 7^{j}. mz p -7^{j} − ^{j}. (b) -−7^{j} − 8^{j}. mz p -8^{j} − 7^{j}.
(c) -7^{j} + 8^{j}. mz p -^{j} + 7^{j}. (d) -8^{j} + 9^{j}. mz p -9^{j} − 8^{j}.

(Online 2015)

13. Match List-I (Electromagnetic wave type) with List-II (Its association/application) and select the correct option from the choices given below the lists:

List-I	**List-II**
(P) Infrared waves	(i) To treat muscular strain
(Q) Radio waves	(ii) For broadcasting
(R) X-rays	(iii) To detect fracture of bones
(S) Ultraviolet rays	(iv) Absorbed by the ozone layer of the atmosphere

	P	Q	R	S
(a)	(i)	(ii)	(iii)	(iv)
(b)	(iv)	(iii)	(ii)	(i)
(c)	(i)	(ii)	(iv)	(iii)
(d)	(iii)	(ii)	(i)	(iv)

(2014)

14. During the propagation of electromagnetic waves in a medium

(a) both electric and magnetic energy densities are zero
(b) electric energy density is double of the magnetic energy density
(c) electric energy density is half of the magnetic energy density
(d) electric energy density is equal to the magnetic energy density *(2014)*

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

(a) 12 V/m (b) 3 V/m
(c) 6 V/m (d) 9 V/m *(2013)*

16. An electromagnetic wave in vacuum has the electric and magnetic fields $\vec{E}$ and $\vec{B}$, which are always perpendicular to each other. The direction of polarization is given by $\vec{X}$ and that of wave propagation by $\vec{k}$. Then

(a) $\vec{X} \parallel \vec{E}$ and $\vec{k} \parallel \vec{E} \times \vec{B}$ (b) $\vec{X} \parallel \vec{B}$ and $\vec{k} \parallel \vec{E} \times \vec{B}$
(c) $\vec{X} \parallel \vec{E}$ and $\vec{k} \parallel \vec{B} \times \vec{E}$ (d) $\vec{X} \parallel \vec{B}$ and $\vec{k} \parallel \vec{B} \times \vec{E}$

(2012)

17. The rms value of the electric field of the light coming from the sun is 720 N/C. The average total energy density of the electromagnetic wave is

(a) 3.3×10^{-3} J/m^3 (b) 4.58×10^{-6} J/m^3
(c) 6.37×10^{-9} J/m^3 (d) 81.35×10^{-12} J/m^3.

(2006)

18. An electromagnetic wave of frequency $\upsilon = 3.0$ MHz passes from vacuum into a dielectric medium with permitivity $\varepsilon = 4.0$. Then

(a) wavelength is doubled and the frequency remains unchanged
(b) wavelength is doubled and frequency becomes half
(c) wavelength is halved and frequency remains unchanged
(d) wavelength and frequency both remain unchanged.

(2004)

19. Which of the following are not electromagnetic waves?

(a) cosmic rays (b) gamma rays
(c) β-rays (d) X-rays. *(2002)*

20. Electromagnetic waves are transverse in nature is evident by

(a) polarization (b) interference
(c) reflection (d) diffraction *(2002)*

21. Infrared radiation is detected by

(a) spectrometer (b) pyrometer
(c) nanometer (d) photometer *(2002)*

ANSWER KEY

1. (c)	**2.** (b)	**3.** (d)	**4.** (c)	**5.** (d)	**6.** (c)	**7.** (a)	**8.** (a)	**9.** (d)	**10.** (d)	**11.** (*)	**12.** (b)
13. (a)	**14.** (d)	**15.** (c)	**16.** (a)	**17.** (b)	**18.** (c)	**19.** (c)	**20.** (a)	**21.** (b)			

Explanations

1. **(c) :** In air, EM wave is $\vec{E}_1 = E_{01}\hat{x}\cos\left[2\pi\upsilon\left(\frac{z}{c}-t\right)\right]$

$= E_{01}\hat{x}\cos[k(z-ct)]$ $\left(\because\ k = \frac{2\pi}{\lambda_0} = \frac{2\pi\upsilon}{c}\right)$

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

$= E_{02}\,\hat{x}\cos\left[2k\left(z-\frac{c}{2}t\right)\right]$

During refraction, frequency remains unchanged, whereas wavelength gets changed

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

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

Since, $v = \frac{c}{2}$; $\frac{1}{\sqrt{\mu_0\varepsilon_{r_2}}} = \frac{1}{2}\times\frac{1}{\sqrt{\mu_0\varepsilon_{r_1}}}$; $\therefore\ \frac{\varepsilon_{r_1}}{\varepsilon_{r_2}} = \frac{1}{4}$

2. **(b) :** $\vec{E}\times\vec{B}$ gives direction of wave propagation.

$\Rightarrow\ \hat{k}\times\vec{B}\,\|\,\frac{\hat{i}+\hat{j}}{\sqrt{2}}$

Now, $\hat{k}\times\left(\frac{\hat{i}-\hat{j}}{\sqrt{2}}\right) = \frac{\hat{j}-(-\hat{i})}{\sqrt{2}} = \frac{\hat{i}+\hat{j}}{\sqrt{2}}$

Wave propagation vector should be along $\frac{\hat{i}+\hat{j}}{\sqrt{2}}$ and direction of magnetic field is along $\frac{\hat{i}-\hat{j}}{\sqrt{2}}$.

3. **(d) :** Electric field in electromagnetic wave is given by $E = E_0\sin(\omega t_1 - kz_1)$

Also, $E' = E_0\sin(\pi + \omega t_1 - kz_2)$

As per question, $E = E' = 0$ $\therefore\ \omega t_1 - kz_1 = (\pi + \omega t_1 - kz_2)$

$\pi = k(z_2 - z_1) = \frac{2\pi}{\lambda}|z_2 - z_1|$

$\lambda = 2|z_2 - z_1|$

$\upsilon = \frac{c}{\lambda} = \frac{3\times10^8}{2|z_2-z_1|} = \frac{1.5\times10^8}{|z_2-z_1|}$

4. **(c) :** If E is magnitude of electric field then $\frac{1}{2}\varepsilon_0E^2\times c = I$

$E = \sqrt{\frac{2I}{c\varepsilon_0}}$ and $B = \frac{E}{c}$

Direction of $\vec{E}\times\vec{B}$ will be along $+\hat{j}$.

5. **(d) :** Given : $\vec{B} = B_0\sin(kx+\omega t)\hat{j}$ T

The relation between electric and magnetic field is,

$$c = \frac{E}{B} \text{ or } E = cB$$

The electric field component is perpendicular to the direction of propagation and the direction of magnetic field. Therefore, the electric field component along z-axis is obtained as

$$E = cB_0\sin(kx+\omega t)\hat{k}$$

6. **(c) :** $\frac{dE}{dz} = -\frac{dB}{dt}$

$\frac{dE}{dz} = -2E_0k\sin kz\cos\omega t = -\frac{dB}{dt}$

$dB = +2E_0k\sin kz\cos\omega t\,dt$

$B = +2E_0k\sin kz\int\cos\omega t\,dt = +2E_0\frac{k}{\omega}\sin kz\sin\omega t$

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

$B = \frac{2E_0}{c}\sin kz\sin\omega t$ $\therefore$ $\vec{B} = \frac{2E_0}{c}\sin kz\sin\omega t\,\hat{j}$

7. **(a) :** $E_{\text{radiowave}} < E_{\text{yellow}} < E_{\text{blue}} < E_{x\text{-ray}}$

(D) (B) (A) (C)

8. **(a)**

9. **(d) :** An electromagnetic wave propagating in $+x$ direction means electric field and magnetic field should be function of x and t.

Also, $\vec{E}\perp\vec{B}$ or $\hat{E}\perp\hat{B}$ *i.e.*

$(\hat{y}-\hat{z})\cdot(\hat{y}+\hat{z}) = \hat{y}\cdot\hat{y} - \hat{z}\cdot\hat{z} = 0$

10. **(d) :** Intensity of light, $I = u_{av}c$

Hx{ 1 $f = \frac{m}{9\pi\ 7}$ mzp m $= \frac{6}{7}\varepsilon_5 b_5^7$

$\therefore$ $\frac{m}{9\pi\ 7} = \frac{6}{7}\varepsilon_5 b_5^7$ { ~ $b_5 = \sqrt{\frac{7m}{9\pi\varepsilon_5\ 7}}$

Here, $P = 0.1$ W, $r = 1$ m, $c = 3\times10^8$ m s^{-1}

$\frac{6}{9\pi\varepsilon_5} = >\times65^{>}$ N C^{-2} m^2

$\therefore$ $b_5 = \sqrt{\frac{7\times536\times>\times65^{>}}{6^7\times8\times65^{=}}} = \sqrt{;} = 739$: b y $^{-6}$

11. **(*) :** $\upsilon = 2\times10^{14}$ Hz

$E_0 = 27$ V m^{-1}

We know, $\frac{b_5}{X_5} =$ so $B_0 = \frac{7<}{8\times65^{=}} = >\times65^{-=}$ ^

$\lambda = \frac{\ }{\upsilon} = \frac{8\times65^{=}}{7\times65^{69}} = 1.5\times10^{-6}$ m

$X = X_5$ –uz $7\pi\left(\frac{\ }{\lambda} - \upsilon\ \right)$

$B = (9\times10^{-8}\text{ T})\sin\ 7\pi\left(\frac{\ }{63\times65^{-;}} - 7\times65^{69}\ \right)$

Oscillation of B can be along either j {~ j direction.

*None of the given options is correct.

12. (b) : For electromagnetic wave, direction of propagation, $\vec{b}$ and $\vec{X}$ are transverse in nature.
According to question,
$\vec{b} \times \vec{X} =$ direction of propagation = $+z$ direction. Only option (b) satisfies both conditions (i) $\vec{b} \cdot \vec{X} = 5$ (ii) $-\vec{b} \times \vec{X}$. directed along the z-axis.

13. (a) : Infrared waves are used to treat muscular strain. Radio waves are used for broadcasting.
X-rays are used to detect fracture of bones. Ultraviolet rays are absorbed by the ozone layer of the atmosphere.

14. (d) : In an em wave, energy is equally divided between the electric and the magnetic fields.

15. (c) : In electromagnetic wave, the peak value of electric field (E_0) and peak value of magnetic field (B_0) are related by $E_0 = B_0 c$
$E_0 = (20 \times 10^{-9}\ \text{T})(3 \times 10^{8}\ \text{m s}^{-1}) = 6\ \text{V/m}$

16. (a) : The direction of polarization is parallel to electric field. $\therefore\ \vec{X} \parallel \vec{E}$
The direction of wave propagation is parallel to $\vec{E} \times \vec{B}$.
$\therefore\ \vec{k} \parallel \vec{E} \times \vec{B}$

17. (b) : $u = \frac{1}{2}\varepsilon_0 E_{\text{rms}}^2 + \frac{1}{2\mu_0} B_{\text{rms}}^2$

$$= \frac{1}{2}\varepsilon_0 E_{\text{rms}}^2 + \frac{1}{2\mu_0}\left(\frac{E_{\text{rms}}^2}{c^2}\right) = \frac{1}{2}\varepsilon_0 E_{\text{rms}}^2 + \frac{1}{2\mu_0} E_{\text{rms}}^2 \varepsilon_0 \mu_0$$

$$= \frac{1}{2}\varepsilon_0 E_{\text{rms}}^2 + \frac{1}{2}\varepsilon_0 E_{\text{rms}}^2 = \varepsilon_0 E_{\text{rms}}^2$$

$= (8.85 \times 10^{-12}) \times (720)^2 = 4.58 \times 10^{-6}\ \text{J m}^{-3}$

18. (c) : During propogation of a wave from one medium to another, frequency remains constant and wavelength changes

$$\mu = \sqrt{\frac{\varepsilon}{\varepsilon_0}} = \sqrt{4} = 2$$

Since $\mu \propto \frac{1}{\lambda}$ $\therefore$ Wavelength is halved.
Hence option (c) holds good.

19. (c) : β-rays are not electromagnetic waves.

20. (a) : Polarization proves the transverse nature of electromagnetic waves.

21. (b) : Infrared radiation produces thermal effect and is detected by pyrometer.