ELECTROMAGNETIC WAVES 22

1. When an electromagnetic wave with poynting vector $\vec{S}$ is incident an a perfectly absorbing surface, then radiation pressure on surface is

(a) $P = \frac{S}{c}$ (b) $P = \frac{S}{2c}$

(c) $\frac{2S}{3c}$ (d) Sc

2. An electromagnetic wave passes through space and its equation is given by $E = E_0 \sin(\omega t - kx)$ where E is electric field. Energy density of electromagnetic wave in space is

(a) $\frac{1}{2}\varepsilon_0 E_0^2$ (b) $\frac{1}{4}\varepsilon_0 E_0^2$

(c) $\varepsilon_0 E_0^2$ (d) $2\varepsilon_0 E_0^2$

3. A plane electromagnetic wave is incident on a plane surface of area A, normally and is perfectly reflected. If energy E strikes the surface in time t then force exerted on the surface is (c = speed of light)

(a) $\frac{2E}{Atc}$ (b) $\frac{E}{2c}$

(c) $\frac{2E}{ct}$ (d) zero

4. A plane electromagnetic wave is incident on a material surface. If the wave delivers momentum p and energy E, then

(a) $p = 0, E = 0$ (b) $p \neq 0, E \neq 0$

(c) $p \neq 0, E = 0$ (d) $p = 0, E \neq 0$

5. The pressure exerted by an electromagnetic wave of intensity I (watts/m^2) on a nonreflecting surface is [c is the velocity of light]

(a) Ic (b) Ic^2

(c) I/c (d) None

6. The electric field of an electromagnetic wave travelling through vaccum is given by the equation $E = E_0 \sin(kx - \omega t)$. The quantity that is independent of wavelength is

(a) $k\omega$ (b) $\frac{k}{\omega}$

(c) $k^2\omega$ (d) ω

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

(a) 3 V/m (b) 4 V/m

(c) 6 V/m (d) 9 V/m

8. In an electromagnetic wave, the amplitudes of magnetic field B_0 and electric field E_0 in free space are related as:

(a) $B_0 = E_0$ (b) $B = \frac{E_0}{c}$

(c) $B_0 = E_0\sqrt{\mu_0 \varepsilon_0}$ (d) $B_0 = E_0\sqrt{\frac{\varepsilon_0}{\mu_0}}$

9. The magnetic field in a plane electromagnetic wave is given by

$B_y = 2 \times 10^{-7} \sin(0.5 \times 10^3 x + 1.5 \times 10^{11} t)$

The electromagnetic wave is

(a) A visible light

(b) An infrared wave

(c) A micro wave

(d) A radio wave

10. If microwaves, X rays, infrared, gamma rays, ultra-violet, radio waves and visible parts of the electromagnetic spectrum are denoted by M, X, I, G, U, R and V then which of the following is the arrangement in ascending order of wavelength ?

(a) R, M, I, V, U, X and G

(b) M, R, V, X, U, G and I

(c) G, X, U, V, I, M and R

(d) I, M, R, U, V, X and G

11. An electromagnetic wave going through vacuum is described by $E = E_0 \sin(kx - \omega t)$; $B = B_0 \sin(kx - \omega t)$. Which of the following equations is true

(a) $E_0 k = B_0 \omega$ (b) $E_0 \omega = B_0 k$

(c) $E_0 B_0 = \omega k$ (d) None of these

12. A plane electromagnetic wave travels in free space along X-direction. If the value of $\vec{B}$ (in tesla) at a particular point in space and time is $1.2 \times 10^{-8}\ \hat{k}$T. The value of $\vec{E}$ (in Vm^{-1}) at that point is

(a) $2.2\ \hat{j}$ (b) $2.6\ \hat{k}$

(c) $3.2\ \hat{k}$ (d) $3.6\ \hat{j}$

13. The magnetic field in the plane electromagnetic field is given by: $B_y = 2 \times 10^{-7} \sin(0.5 \times 10^3 z + 1.5 \times 10^{11} t)$ T

The expression for the electric field may be given by

(a) $E_y = 2 \times 10^{-7} \sin(2.5 \times 10^3 z + 1.5 \times 10^{11} t)$ V/m

(b) $E_x = 2 \times 10^{-7} \sin(2.5 \times 10^3 z + 1.5 \times 10^{11} t)$ V/m

(c) $E_y = 60 \sin(0.5 \times 10^3 z + 1.5 \times 10^{11} t)$ V/m

(d) $E_x = 60 \sin(0.5 \times 10^3 z + 1.5 \times 10^{11} t)$ V/m

14. A plane electromagnetic wave propagating in the X-direction has wavelength of 6.0 mm. The electric field is in the Y-direction and its maximum magnitude is 33 Vm^{-1}. The equation for the electric field as a function of x and t is

(a) $11 \sin \pi \left(t - \frac{x}{c} \right)$

(b) $33 \sin \left[\pi \times 10^{11} \left(t - \frac{x}{c} \right) \right]$

(c) $33 \sin \pi \left(t - \frac{x}{c} \right)$

(d) $11 \sin \left[\pi \times 10^{11} \left(t - \frac{x}{c} \right) \right]$

15. Given below is a list of electromagnetic spectrum and its mode of production. Which one does not match?

(a) Gamma rays – Radioactive decay of the nucleus

(b) Ultraviolet rays – Magnetron valve

(c) Radio wave – Rapid acceleration and deceleration of electrons in conducting wires

(d) X-rays – X-ray tubes or inner shell electrons

16. 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:

(a) 1.34 V/m (b) 2.68 V/m

(c) 4.02 V/m (d) 5.36 V/m

17. An electromagnetic wave of frequency 1×10^{14} hertz is propagating along z-axis. The amplitude of electric field is 4 V/m. If $\varepsilon_0 = 8.8 \times 10^{-12}\ C^2/N\text{-}m^2$, then average energy density of electric field will be:

(a) $35.2 \times 10^{-8}\ J/m^3$ (b) $35.2 \times 10^{-7}\ J/m^3$

(c) $35.2 \times 10^{-12}\ J/m^3$ (d) $35.2 \times 10^{-9}\ J/m^3$

18. A plane electromagnetic wave travels in free space along x-axis. At a particular point in space, the electric field along y-axis is 9.3 V m^{-1}. The magnetic induction (B) along z-axis is

(a) 3.1×10^{-8} T (b) 3×10^{-5} T

(c) 3×10^{-6} T (d) 9.3×10^{-6} T

19. The electric field associated with an e.m. wave in vacuum is given by $\vec{E} = \hat{i}\ 40\cos(kz - 6 \times 10^8 t)$, where E, z and t are in volt/m, meter and seconds respectively. The value of wave vector k is

(a) $2\ m^{-1}$ (b) $0.5\ m^{-1}$

(c) $6\ m^{-1}$ (d) $3\ m^{-1}$

20. 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 $\epsilon_0 = 9 \times 10^{-12}$ SI units, Speed of light $c = 3 \times 10^8$ m/s]

(a) 2kV/m (c) 0.7 kV/m

(b) 1kV/m (d) 1.4 kV/m

21. If the magnetic field of a plane electromagnetic wave is given by (The speed of light = 3×10^8 m/s)

$$B = 100 \times 10^{-6} \sin\left[2\pi \times 2 \times 10^{15}\left(t - \frac{x}{c}\right)\right]$$

then the maximum electric field associated with it is:

(a) 6×10^4 N/C (b) 3×10^4 N/C

(c) 4×10^4 N/C (d) $4.5\ 10^4$ N/C

22. A plane electromagnetic wave of frequency 50 MHz travels in free space along the positive x-direction. At a particular point in space and time, $\vec{E} = 6.3\ \hat{j}$ V / m. The corresponding magnetic field $\vec{B}$, at that point will be:

(a) $18.9 \times 10^{-8}\ \hat{k}$T (b) $2.1 \times 10^{-8}\ \hat{k}$T

(c) $6.3 \times 10^{-8}\ \hat{k}$T (d) $18.9 \times 10^{8}\ \hat{k}$T

23. The mean intensity of radiation on the surface of the Sun is about 10^8 W/m^2. The rms value of the corresponding magnetic field is closest to :

(a) 1 T (b) 10^2 T

(c) 10^{-2} T (d) 10^{-4} T

24. An electron is constrained to move along the y-axis with a speed of 0.1 c (c is the speed of light) in the presence of electromagnetic wave, whose electric field is $\vec{E} = 30\hat{j}\ \sin(1.5 \times 10^7 t - 5 \times 10^{-2} x)$ V/m. The maximum magnetic force experienced by the electron will be :

(given $c = 3 \times 10^8\ ms^{-1}$ & electron charge = 1.6×10^{-19}C)

(a) 3.2×10^{-18} N (b) 2.4×10^{-18} N

(c) 4.8×10^{-19} N (d) 1.6×10^{-19} N

25. A plane electromagnetic wave, has frequency of 2.0×10^{10} Hz and its energy density is 1.02×10^{-8} J/m^3 in vacuum. The amplitude of the magnetic field of the wave is close to

$\left(\frac{1}{4\pi\varepsilon_0} = 9 \times 10^9 \frac{Nm^2}{C^2}\right.$ and speed of light = $3 \times 10^8\ ms^{-1}$) :

(a) 150 nT (b) 160 nT

(c) 180 nT (d) 190 nT

ANSWER KEY

1	(a)	4	(b)	7	(c)	10	(c)	13	(d)	16	(b)	19	(a)	22	(b)	25	(b)
2	(a)	5	(c)	8	(c)	11	(a)	14	(b)	17	(c)	20	(d)	23	(d)		
3	(c)	6	(b)	9	(c)	12	(d)	15	(b)	18	(a)	21	(b)	24	(c)		

22 Electromagnetic Waves

1. **(a)** Electromagnetic waves carry momentum and hence can exert pressure (P) on surfaces, which is called **radiation pressure**. For an electromagnetic wave with poynting vector $\vec{S}$, incident on a perfectly absorbing surface then, $P = \frac{S}{c}$ and if incident on a perfectly reflecting surface then, $P = \frac{2S}{c}$

2. **(a)** Energy density (EM waves)

$$= \varepsilon_0 E_{rms}^2 = \varepsilon_0 \left(\frac{E_0}{\sqrt{2}}\right)^2 = \frac{1}{2}\varepsilon_0 E_0^2$$

3. **(c)** Incident momentum, $p = \frac{E}{c}$

For perfectly reflecting surface with normal incidence

$$\Delta p = 2p = \frac{2E}{c}; \quad F = \frac{\Delta p}{\Delta t} = \frac{2E}{ct}$$

4. **(b)** EM waves carry momentum and hence can exert pressure on surfaces. They also transfer energy to the surface so $p \neq 0$ and $E \neq 0$.

5. **(c)**

6. **(b)** Here, $k = \frac{2\pi}{\lambda}$, $\omega = 2\pi\upsilon$

$$\therefore \quad \frac{k}{\omega} = \frac{2\pi/\lambda}{2\pi\upsilon} = \frac{1}{\lambda\upsilon} = \frac{1}{c} \qquad (\because c = \upsilon\lambda)$$

where c is the speed of electromagnetic wave in vacuum. It is a constant whose value is 3×10^8 $m\ s^{-1}$

7. **(c)** $E_0 = B_0 C = 20 \times 10^{-9} \times 3 \times 10^8 = 6$ v/m

8. **(c)** Relation between E_0 and B_0

$$\frac{B_0}{E_0} = \frac{1}{c} = \sqrt{\mu_0\varepsilon_0} \quad \text{i.e. } B_0 = E_0\sqrt{\varepsilon_0\mu_0}$$

9. **(c)**

10. **(c)** Gamma rays < X-rays < Ultra violet < Visible rays < Infrared rays < Microwaves < Radio waves.

11. **(a)** $\frac{E_0}{B_0} = c$, also $k = \frac{2\pi}{\lambda}$ and $\omega = 2\pi v$

These relation gives $E_0 k = B_0 \omega$

12. **(d)** Given : $\vec{B} = 1.2 \times 10^{-8}\hat{k}$T

$\vec{E} = ?$

From formula,

$E = Bc = (1.2 \times 10^{-8}\,T)(3 \times 10^8\,ms^{-1}) = 3.6\,Vm^{-1}$

$\vec{B}$ is along Z-direction and the wave propagates along X-direction. Therefore $\vec{E}$ should be along Y-direction.

Thus, $\vec{E} = 3.6\hat{j}\ Vm^{-1}$

13. **(d)** $B_y = 2 \times 10^{-7}\sin(0.5 \times 10^3 z + 1.5 \times 10^{11} t)$ T

The electric vector is perpendicular to B as well as direction of propagation of electromagnetic wave.

Therefore E_x has to be taken.

Further, $E_0 = B_0 \times c = 2 \times 10^{-7} \times 3 \times 10^8$ V/m

$E_0 = 2 \times 10^{-7} \times 3 \times 10^8 = 60$ V/m

$\therefore$ The corresponding value of the electric field is

$E_x = 60\sin(0.5 \times 10^3 z + 1.5 \times 10^{11} t)$ V/m

14. **(b)** $\omega = 2\pi v = \frac{2\pi c}{\lambda} = \frac{2\pi \times 3 \times 10^8}{6 \times 10^{-3}} = \pi \times 10^{11}$ rad/sec

The equation for the electric field, along y-axis in the electromagnetic wave is

$$E_y = E_0 \sin\omega\left(t - \frac{x}{c}\right)$$

$$= 33\sin\left[\pi \times 10^{11}\left(t - \frac{x}{c}\right)\right]$$

15. **(b)**

16. **(b)** Wavelength of monochromatic green light $= 5.5 \times 10^{-5}$ cm

$$\text{Intensity } I = \frac{\text{Power}}{\text{Area}} = \frac{100 \times (3/100)}{4\pi(5)^2}$$

$$= \frac{3}{100\pi}\,\text{Wm}^{-2}$$

Now, half of this intensity (I) belongs to electric field and half of that to magnetic field, therefore,

$$\frac{I}{2} = \frac{1}{4}\varepsilon_0 E_0^2 C \text{ or } E_0 = \sqrt{\frac{2I}{\varepsilon_0 C}}$$

$$= \sqrt{\frac{2 \times \left(\frac{3}{100\pi}\right)}{\left(\frac{1}{4\pi \times 9 \times 10^9}\right) \times (3 \times 10^8)}} = \sqrt{\frac{6}{25} \times 30}$$

$$= \sqrt{7.2}$$

$$\therefore \quad E_0 = 2.68\,\text{V/m}$$

17. **(c)** **Given:** Amplitude of electric field,

$$E_0 = 4\,\text{V/m}$$

Absolute permitivity,

$$\varepsilon_0 = 8.8 \times 10^{-12}\,\text{c}^2/\text{N-m}^2$$

Average energy density $u_E = ?$

Applying formula,

$$\text{Average energy density } u_E = \frac{1}{4}\varepsilon_0 E_0^2$$

$$\Rightarrow \quad u_E = \frac{1}{4} \times 8.8 \times 10^{-12} \times (4)^2$$

$$= 35.2 \times 10^{-12}\,\text{J/m}^3$$

18. **(a)** Velocity of light

$$c = \frac{E}{B} \Rightarrow B = \frac{E}{c} = \frac{9.3}{3 \times 10^8} = 3.1 \times 10^{-8}\,\text{T}$$

19. **(a)** On comparing the given equation to

$$\vec{E} = a_0\hat{i}\cos(\omega t - kz),\ \omega = 6 \times 10^8,\ k = \frac{2p}{l} = \frac{w}{c}$$

$$k = \frac{\omega}{c} = \frac{6 \times 10^8}{3 \times 10^8} = 2\,\text{m}^{-1}$$

20. **(d)** EM wave intensity

$$\Rightarrow I = \frac{\text{Power}}{\text{Area}} = \frac{1}{2}\varepsilon_0 E_0^2 c$$

[where E_0 = maximum electric field]

$$\Rightarrow \frac{27 \times 10^{-3}}{10 \times 10^{-6}} = \frac{1}{2} \times 9 \times 10^{-12} \times E_0^2 \times 3 \times 10^8$$

$$\Rightarrow E_0 = \sqrt{2} \times 10^3\,\text{kV/m} = 1.4\,\text{kV/m}$$

21. **(b)** Using, formula $E_0 = B_0 \times C$

$= 100 \times 10^{-6} \times 3 \times 10^8$

$= 3 \times 10^4\,\text{N/C}$

Here we assumed that

$B_0 = 100 \times 10^{-6}$ is in tesla (T) units

22. **(b)** As we know,

$$|\vec{B}| = \frac{|\vec{E}|}{C} = \frac{6.3}{3 \times 10^8} = 2.1 \times 10^{-8}\,\text{T}$$

and $\hat{E} \times \hat{B} = \hat{C}$

$\hat{J} \times \hat{B} = \hat{i}$ [$\because$ EM wave travels along +(ve) x-direction.]

$\therefore\ \hat{B} = \hat{k}$ or $\vec{B} = 2.1 \times 10^{-8}\hat{k}\,\text{T}$

23. **(d)** $I = \dfrac{B_0^2}{2\mu_0} \cdot C$

$$\Rightarrow \frac{B_0^2}{2} = \frac{I\mu_0}{C}$$

$$\Rightarrow B_{rms} = \sqrt{\frac{I\mu_0}{C}}$$

$$= \sqrt{\frac{10^8 \times 4\pi \times 10^{-7}}{3 \times 10^8}}$$

$\simeq 6 \times 10^{-4}$ T

Which is closest to 10^{-4}.

24. **(c)** In electromagnetic wave, $\frac{E_0}{B_0} = C$

$\therefore$ Maximum value of magnetic field, $B_0 = \frac{E_0}{C}$

$$F_{max} = qVB_{max} \sin 90^\circ = \frac{qV_0E_0}{C}$$

(Given $V_0 = 0.1$ C and $E_0 = 30$)

$$= \frac{1.6 \times 10^{-19} \times 0.1 \times 3 \times 10^8 \times 30}{3 \times 10^8} = 4.8 \times 10^{-19} \text{N}$$

25. **(b)** Energy density $= \frac{1}{2}\frac{B^2}{\mu_0}$

$$\Rightarrow B = \sqrt{2 \times \mu_0 \times \text{Energy density}}$$

$$\mu_0 = \frac{1}{C^2\varepsilon_0} = 4\pi \times 10^{-7}$$

$$\therefore B = \sqrt{2 \times 4\pi \times 10^{-7} \times 1.02 \times 10^{-8}} = 160 \times 10^{-9}$$

$= 160$ nT