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Electromagnetic Waves

TOPIC 1 Electromagnetic Waves, Conduction and Displacement Current

1. For a plane electromagnetic wave, the magnetic field at a point x and time t is
$\vec{B}(x,t) = [1.2 \times 10^{-7} \sin(0.5 \times 10^3 x + 1.5 \times 10^{11} t)\hat{k}]\,\text{T}$
The instantaneous electric field $\vec{E}$ corresponding to $\vec{B}$ is: (speed of light $c = 3 \times 10^8\ \text{ms}^{-1}$) **[Sep. 06, 2020 (II)]**
(a) $\vec{E}(x,t) = [-36 \sin(0.5 \times 10^3 x + 1.5 \times 10^{11} t)\hat{j}]\dfrac{\text{V}}{\text{m}}$
(b) $\vec{E}(x,t) = [36 \sin(1 \times 10^3 x + 0.5 \times 10^{11} t)\hat{j}]\dfrac{\text{V}}{\text{m}}$
(c) $\vec{E}(x,t) = [36 \sin(0.5 \times 10^3 x + 1.5 \times 10^{11} t)\hat{k}]\dfrac{\text{V}}{\text{m}}$
(d) $\vec{E}(x,t) = [36 \sin(1 \times 10^3 x + 1.5 \times 10^{11} t)\hat{i}]\dfrac{\text{V}}{\text{m}}$

2. 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 $c = 3 \times 10^8\ \text{ms}^{-1}$ & electron charge $= 1.6 \times 10^{-19}$C) **[Sep. 05, 2020 (I)]**
(a) 3.2×10^{-18} N (b) 2.4×10^{-18} N
(c) 4.8×10^{-19} N (d) 1.6×10^{-19} N

3. 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) $\dfrac{E_0}{c}(-\hat{x} + \hat{y})\sin(kz - \omega t)$
(b) $\dfrac{E_0}{c}(\hat{x} + \hat{y})\sin(kz - \omega t)$
(c) $\dfrac{E_0}{c}(\hat{x} - \hat{y})\sin(kz - \omega t)$
(d) $\dfrac{E_0}{c}(\hat{x} - \hat{y})\cos(kz - \omega t)$

4. The magnetic field of a plane electromagnetic wave is
$\vec{B} = 3 \times 10^{-8} \sin[200\pi(y + ct)]\hat{i}T$
where $c = 3 \times 10^8\ \text{ms}^{-1}$ is the speed of light.
The corresponding electric field is : **[Sep. 03, 2020 (I)]**
(a) $\vec{E} = 9 \sin[200\pi(y + ct)]\hat{k}$ V/m
(b) $\vec{E} = -10^{-6} \sin[200\pi(y + ct)]\hat{k}$ V/m
(c) $\vec{E} = 3 \times 10^{-8} \sin[200\pi(y + ct)]\hat{k}$ V/m
(d) $\vec{E} = -9 \sin[200\pi(y + ct)]\hat{k}$ V/m

5. The electric field of a plane electromagnetic wave propagating along the x direction in vacuum is $\vec{E} = E_0\hat{j}\cos(\omega t - kx)$. The magnetic field $\vec{B}$, at the moment $t = 0$ is : **[Sep. 03, 2020 (II)]**
(a) $\vec{B} = \dfrac{E_0}{\sqrt{\mu_0\varepsilon_0}}\cos(kx)\hat{k}$
(b) $\vec{B} = E_0\sqrt{\mu_0\varepsilon_0}\cos(kx)\hat{j}$
(c) $\vec{B} = E_0\sqrt{\mu_0\varepsilon_0}\cos(kx)\hat{k}$
(d) $\vec{B} = \dfrac{E_0}{\sqrt{\mu_0\varepsilon_0}}\cos(kx)\hat{j}$

6. 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
($\dfrac{1}{4\pi\varepsilon_0} = 9 \times 10^9 \dfrac{Nm^2}{C^2}$ and speed of light $= 3 \times 10^8\ \text{ms}^{-1}$) : **[Sep. 02, 2020 (I)]**
(a) 150 nT (b) 160 nT
(c) 180 nT (d) 190 nT

7. In a plane electromagnetic wave, the directions of electric field and magnetic field are represented by $\hat{k}$ and $2\hat{i}-2\hat{j}$, respectively. What is the unit vector along direction of propagation of the wave. **[Sep. 02, 2020 (II)]**

(a) $\frac{1}{\sqrt{2}}(\hat{i}+\hat{j})$ (b) $\frac{1}{\sqrt{2}}(\hat{j}+\hat{k})$

(c) $\frac{1}{\sqrt{5}}(\hat{i}+2\hat{j})$ (d) $\frac{1}{\sqrt{5}}(2\hat{i}+\hat{j})$

8. 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: **[9 Jan 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) $E_0q(0.8\hat{i}+\hat{j}+0.2\hat{k})$

9. A plane electromagnetic wave is propagating along the direction $\frac{\hat{i}+\hat{j}}{\sqrt{2}}$, 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): **[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) $B_0\hat{k}\cos\left(\omega t - k\frac{\hat{i}+\hat{j}}{\sqrt{2}}\right)$

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

10. A plane electromagnetic wave of frequency 25 GHz is propagating in vacuum along the z-direction. At a particular point in space and time, the magnetic field is given by $\vec{B} = 5\times10^{-8}\,\hat{j}\,T$. The corresponding electric field $\vec{E}$ is (speed of light $c = 3\times10^{8}$ ms^{-1}) **[8 Jan 2020, II]**

(a) $1.66\times10^{-16}\,\hat{i}$ V/m (b) $-1.66\times10^{-16}\,\hat{i}$ V/m

(c) $-15\,\hat{i}$ V/m (d) $15\,\hat{i}$ V/m

11. If the magnetic field in a plane electromagnetic wave is given by $\vec{B} = 3\times10^{-8}\sin(1.6\times10^{3}x + 48\times10^{10}t)\,\hat{j}$ T, then what will be expression for electric field? **[7 Jan 2020, I]**

(a) $\vec{E} = (60\sin(1.6\times10^{3}x + 48\times10^{10}t)\,\hat{k}$ v/m)

(b) $\vec{E} = (9\sin(1.6\times10^{3}x + 48\times10^{10}t)\,\hat{k}$ v/m)

(c) $\vec{E} = (3\times10^{-8}\sin(1.6\times10^{3}x + 48\times10^{10}t)\,\hat{k}$ v/m)

(d) $\vec{E} = (3\times10^{-8}\sin(1.6\times10^{3}x + 48\times10^{10}t)\,\hat{k}$ v/m)

12. The electric field of a plane electromagnetic wave is given by

$$\vec{E} = E_0\frac{\hat{i}+\hat{j}}{\sqrt{2}}\cos(kz+\omega t)$$

At $t = 0$, a positively charged particle is at the point $(x, y, z) = \left(0, 0, \frac{\pi}{k}\right)$. If its instantaneous velocity at $(t = 0)$ is $v_0\hat{k}$, the force acting on it due to the wave is: **[7 Jan 2020, II]**

(a) parallel to $\frac{\hat{i}+\hat{j}}{\sqrt{2}}$ (b) zero

(c) antiparallel to $\frac{\hat{i}+\hat{j}}{\sqrt{2}}$ (d) parallel to $\hat{k}$

13. An electromagnetic wave is represented by the electric field $\vec{E} = E_0\hat{n}\sin[\omega t + (6y - 8z)]$. Taking unit vectors in x, y and z directions to be $\hat{i}, \hat{j}, \hat{k}$, the direction of propogation $\hat{s}$ is : **[12 April 2019, I]**

(a) $\hat{s} = \frac{3\hat{i}-4\hat{j}}{5}$ (b) $\hat{s} = \frac{-4\hat{k}+3\hat{j}}{5}$

(c) $\hat{s} = \left(\frac{-3\hat{j}+4\hat{k}}{5}\right)$ (d) $\hat{s} = \frac{3\hat{j}-3\hat{k}}{5}$

14. A plane electromagnetic wave having a frequency $v = 23.9$ GHz propagates along the positive z-direction in free space. The peak value of the Electric Field is 60 V/m. Which among the following is the acceptable magnetic field component in the electromagnetic wave ? **[12 April 2019, II]**

(a) $\vec{B} = 2\times10^{7}\sin(0.5\times10^{3}z + 1.5\times10^{11}t)\hat{i}$

(b) $\vec{B} = 2\times10^{-7}\sin(0.5\times10^{3}z - 1.5\times10^{11}t)\hat{i}$

(c) $\vec{B} = 60\sin(0.5\times10^{3}x + 1.5\times10^{11}t)\hat{k}$

(d) $\vec{B} = 2\times10^{-7}\sin(1.5\times10^{2}x + 0.5\times10^{11}t)\hat{j}$

15. The electric field of a plane electromagnetic wave is given by $\vec{E} = E_0\hat{i}\cos(kz)\cos(\omega t)$

The corresponding magnetic field is then given by : **[10 April 2019, I]**

(a) $\vec{B} = \frac{E_0}{C}\hat{j}\sin(kz)\sin(\omega t)$

(b) $\vec{B} = \frac{E_0}{C}\hat{j}\sin(kz)\cos(\omega t)$

(c) $\vec{B} = \frac{E_0}{C}\hat{j}\cos(kz)\sin(\omega t)$

(d) $\vec{B} = \frac{E_0}{C}\hat{k}\sin(kz)\cos(\omega t)$

16. Light is incident normally on a completely absorbing surface with an energy flux of 25 Wcm^{-2}. If the surface has an area of 25 cm^2, the momentum transferred to the surface in 40 min time duration will be: **[10 April 2019, II]**
(a) 6.3×10^{-4} Ns (b) 1.4×10^{-6} Ns
(c) 5.0×10^{-3} Ns (d) 3.5×10^{-6} Ns

17. The magnetic field of a plane electromagnetic wave is given by:
$$\vec{B} = B_0\hat{i}[\cos(kz-\omega t)] + B_1\hat{j}\cos(kz+\omega t)$$
Where $B_0 = 3\times10^{-5}$ T and $B_1 = 2\times10^{-6}$ T.
The rms value of the force experienced by a stationary charge $Q = 10^{-4}$ C at z = 0 is closest to: **[9 April 2019 I]**
(a) 0.6 N (b) 0.1 N
(c) 0.9 N (d) 3×10^{-2} N

18. 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: **[9 April 2019 I]**
(a) $18.9\times10^{-8}\,\hat{k}$T (b) $2.1\times10^{-8}\,\hat{k}$T
(c) $6.3\times10^{-8}\,\hat{k}$T (d) $18.9\times10^{8}\,\hat{k}$T

19. 50 W/m^2 energy density of sunlight is normally incident on the surface of a solar panel. Some part of incident energy (25%) is reflected from the surface and the rest is absorbed. The force exerted on 1m^2 surface area will be close to ($c = 3\times10^8$ m/s): **[9 April 2019, II]**
(a) 15×10^{-8} N (b) 20×10^{-8} N
(c) 10×10^{-8} N (d) 35×10^{-8} N

20. 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 Vm^{-1} along y-direction. Its corresponding magnetic field component, B would be: **[8 April 2019 I]**
(a) 2×10^{-8} T along z-direction
(b) 6×10^{-8} T along x-direction
(c) 6×10^{-8} T along z-direction
(d) 2×10^{-8} T along y-direction

21. The magnetic field of an electromagnetic wave is given by:
$$\vec{B} = 1.6\times10^{-6}\cos\left(2\times10^7 z + 6\times10^{15}t\right)\left(2\hat{i}+\hat{j}\right)\frac{Wb}{m^2}$$
The associated electric field will be : **[8 April 2019, II]**
(a) $\vec{E} = 4.8\times10^2\cos(2\times10^7 z - 6\times10^{15}t)\left(2\hat{i}+\hat{j}\right)\frac{V}{m}$
(b) $\vec{E} = 4.8\times10^2\cos(2\times10^7 z - 6\times10^{15}t)(-2\hat{j}+\hat{i})\frac{V}{m}$
(c) $\vec{E} = 4.8\times10^2\cos(2\times10^7 z + 6\times10^{15}t)\left(-\hat{i}+2\hat{j}\right)\frac{V}{m}$
(d) $\vec{E} = 4.8\times10^2\cos(2\times10^7 z + 6\times10^{15}t)\left(\hat{i}-2\hat{j}\right)\frac{V}{m}$

22. 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 : **[12 Jan 2019, II]**
(a) 1 T (b) 10^2 T (c) 10^{-2} T (d) 10^{-4} T

23. An electromagnetic wave of intensity 50 Wm^{-2} enters in a medium of refractive index 'n' without any loss. The ratio of the magnitudes of electric fields, and the ratio of the magnitudes of magnetic fields of the wave before and after entering into the medium are respectively, given by : **[11 Jan 2019, I]**
(a) $\left(\frac{1}{\sqrt{n}},\frac{1}{\sqrt{n}}\right)$ (b) $\left(\sqrt{n},\sqrt{n}\right)$
(c) $\left(\sqrt{n},\frac{1}{\sqrt{n}}\right)$ (d) $\left(\frac{1}{\sqrt{n}},\sqrt{n}\right)$

24. 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 $\epsilon_0 = 9\times10^{-12}$ SI units, Speed of light $c = 3\times10^8$ m/s] **[11 Jan 2019, II]**
(a) 2 kV/m (c) 0.7 kV/m
(b) 1 kV/m (d) 1.4 kV/m

25. If the magnetic field of a plane electromagnetic wave is given by (The speed of light = 3×10^8 m/s)
$$B = 100\times10^{-6}\sin\left[2\pi\times2\times10^{15}\left(t-\frac{x}{c}\right)\right]$$
then the maximum electric field associated with it is: **[10 Jan. 2019 I]**
(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

26. The electric field of a plane polarized electromagnetic wave in free space at time t = 0 is given by an expression
$$\vec{E}(x,y) = 10\hat{j}\cos[(6x+8z)]$$
The magnetic field $\vec{B}(x,z,t)$ is given by: (c is the velocity of light) **[10 Jan 2019, II]**
(a) $\frac{1}{c}(6\hat{k}+8\hat{i})\cos[(6x-8z+10ct)]$
(b) $\frac{1}{c}(6\hat{k}-8\hat{i})\cos[(6x+8z-10ct)]$
(c) $\frac{1}{c}(6\hat{k}+8\hat{i})\cos[(6x+8z-10ct)]$
(d) $\frac{1}{c}(6\hat{k}-8\hat{i})\cos[(6x+8z+10ct)]$

27. 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 permittivities 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) $\frac{\epsilon_{r_1}}{\epsilon_{r_2}} = \frac{1}{2}$

28. The energy associated with electric field is (U_E) and with magnetic fields is (U_B) for an electromagnetic wave in free space. Then : **[9 Jan 2019, II]**

(a) $U_E = \frac{U_B}{2}$ (b) $U_E > U_B$

(c) $U_E < U_B$ (d) $U_E = U_B$

29. 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 **[Online April 16, 2018]**

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

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

30. A monochromatic beam of light has a frequency $v = \frac{3}{2\pi}\times 10^{12}$ 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: **[Online April 15, 2018]**

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

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

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

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

31. 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 $\vec{B}$ is then given by : **[Online April 9, 2017]**

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

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

32. 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. **[Online April 8, 2017]**

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

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

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

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

33. Consider an electromagnetic wave propagating in vacuum. Choose the correct statement : **[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 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 $\vec{B} = \frac{1}{\sqrt{2}}B_{yz}(x,t)(\hat{y}+\hat{z})$

34. 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 $(2\hat{i}-\hat{j})$

35. An electromagnetic wave travelling in the x-direction has frequency of 2×10^{14} Hz and electric field amplitude of 27 Vm^{-1}. From the options given below, which one describes the magnetic field for this wave ? **[Online April 10, 2015]**

(a) $\vec{B}(x,t) = (3\times10^{-8}T)\hat{j}$ $\sin\left[2\pi(1.5\times10^{-8}x - 2\times10^{14}t)\right]$

(b) $\vec{B}(x,t) = (9\times10^{-8}T)\hat{i}$ $\sin\left[2\pi(1.5\times10^{-8}x - 2\times1014\,t)\right]$

(c) $\vec{B}(x,t) = (9\times10^{-8}T)\hat{j}$ $\sin\left[1.5\times10^{-6}x - 2\times10^{14}t\right]$

(d) $\vec{B}(x,t) = (9\times10^{-8}T)\hat{k}$ $\sin\left[2\pi(1.5\times10^{-6}x - 2\times10^{14}t)\right]$

36. During the propagation of electromagnetic waves in a medium: **[2014]**
(a) Electric energy density is double of the magnetic energy density.
(b) Electric energy density is half of the magnetic energy density.
(c) Electric energy density is equal to the magnetic energy density.
(d) Both electric and magnetic energy densities are zero.

37. 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: **[Online April 12, 2014]**
(a) 1.34 V/m (b) 2.68 V/m
(c) 4.02 V/m (d) 5.36 V/m

38. 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: **[Online April 11, 2014]**
(a) $35.2 \times 10^{-10}\ J/m^3$ (b) $35.2 \times 10^{-11}\ J/m^3$
(c) $35.2 \times 10^{-12}\ J/m^3$ (d) $35.2 \times 10^{-13}\ J/m^3$

39. The magnetic field in a travelling electromagnetic wave has a peak value of 20 nT. The peak value of electric field strength is : **[2013]**
(a) 3 V/m (b) 6 V/m (c) 9 V/m (d) 12 V/m

40. A plane electromagnetic wave in a non-magnetic dielectric medium is given by $\vec{E} = \vec{E}_0 (4\times10^{-7} x - 50t)$ with distance being in meter and time in seconds. The dielectric constant of the medium is : **[Online April 22, 2013]**
(a) 2.4 (b) 5.8 (c) 8.2 (d) 4.8

41. Select the correct statement from the following : **[Online April 9, 2013]**
(a) Electromagnetic waves cannot travel in vacuum.
(b) Electromagnetic waves are longitudinal waves.
(c) Electromagnetic waves are produced by charges moving with uniform velocity.
(d) Electromagnetic waves carry both energy and momentum as they propagate through space.

42. An electromagnetic wave in vacuum has the electric and magnetic field $\vec{E}$ 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 **[2012]**
(a) $\vec{X} \parallel \vec{B}$ and $\vec{k} \parallel \vec{B}\times\vec{E}$
(b) $\vec{X} \parallel \vec{E}$ and $\vec{k} \parallel \vec{E}\times\vec{B}$
(c) $\vec{X} \parallel \vec{B}$ and $\vec{k} \parallel \vec{E}\times\vec{B}$
(d) $\vec{X} \parallel \vec{E}$ and $\vec{k} \parallel \vec{B}\times\vec{E}$

43. An electromagnetic wave with frequency ω and wavelength λ travels in the $+y$ direction. Its magnetic field is along $+x$-axis. The vector equation for the associated electric field (of amplitude E_0) is **[Online May 19, 2012]**
(a) $\vec{E} = -E_0 \cos\left(\omega t + \frac{2\pi}{\lambda} y\right)\hat{x}$
(b) $\vec{E} = E_0 \cos\left(\omega t - \frac{2\pi}{\lambda} y\right)\hat{x}$
(c) $\vec{E} = E_0 \cos\left(\omega t - \frac{2\pi}{\lambda} y\right)\hat{z}$
(d) $\vec{E} = -E_0 \cos\left(\omega t + \frac{2\pi}{\lambda} y\right)\hat{z}$

44. An electromagnetic wave of frequency $\nu = 3.0$ MHz passes from vacuum into a dielectric medium with permittivity $\in = 4.0$. Then **[2004]**
(a) wave length is halved and frequency remains unchanged
(b) wave length is doubled and frequency becomes half
(c) wave length is doubled and the frequency remains unchanged
(d) wave length and frequency both remain unchanged.

45. *Electromagnetic waves are transverse in nature* is evident by **[2002]**
(a) polarization (b) interference
(c) reflection (d) diffraction

TOPIC 2 Electromagnetic Spectrum

46. The correct match between the entries in column I and column II are : **[Sep. 05, 2020 (II)]**

I Radiation	II Wavelength
(A) Microwave	(i) 100 m
(B) Gamma rays	(ii) 10^{-15} m
(C) A.M. radio waves	(iii) 10^{-10} m
(D) X-rays	(iv) 10^{-3} m

(a) (A)-(ii), (B)-(i), (C)-(iv), (D)-(iii)
(b) (A)-(i), (B)-(iii), (C)-(iv), (D)-(ii)
(c) (A)-(iii), (B)-(ii), (C)-(i), (D)-(iv)
(d) (A)-(iv), (B)-(ii), (C)-(i), (D)-(iii)

47. Chosse the **correct** option relating wavelengths of different parts of electromagnetic wave spectrum : **[Sep. 04, 2020 (I)]**
(a) $\lambda_{\text{visible}} < \lambda_{\text{micro waves}} < \lambda_{\text{radio waves}} < \lambda_{X-\text{rays}}$
(b) $\lambda_{\text{radio waves}} > \lambda_{\text{micro waves}} > \lambda_{\text{visible}} > \lambda_{x-\text{rays}}$
(c) $\lambda_{x-\text{rays}} < \lambda_{\text{micro waves}} < \lambda_{\text{radio waves}} < \lambda_{\text{visible}}$
(d) $\lambda_{\text{visible}} > \lambda_{x-\text{rays}} > \lambda_{\text{radio waves}} > \lambda_{\text{micro waves}}$

48. Given below in the left column are different modes of communication using the kinds of waves given in the right column. **[10 April 2019, I]**

A. Optical Fibre Communication	P. Ultrasound
B. Radar	Q. Infrared Light
C. Sonar	R. Microwaves
D. Mobile Phones	S. Radio Waves

From the options given below, find the most appropriate match between entries in the left and the right column.

(a) A – Q, B – S, C – R, D – P
(b) A – S, B – Q, C – R, D – P
(c) A – Q, B – S, C – P, D – R
(d) A – R, B – P, C – S, D – Q

49. Arrange the following electromagnetic radiations per quantum in the order of increasing energy : **[2016]**

A : Blue light B : Yellow light
C : X-ray D : Radiowave.

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

50. Microwave oven acts on the principle of : **[Online April 9, 2016]**

(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

51. Match List - I (Electromagnetic wave type) with List - II (Its association/application) and select the correct option from the choices given below the lists: **[2014]**

List 1		List 2	
1.	Infrared waves	(i)	To treat muscular strain
2.	Radio waves	(ii)	For broadcasting
3.	X-rays	(iii)	To detect fracture of bones
4.	Ultraviolet rays	(iv)	Absorbed by the ozone layer of the atmosphere

	1	2	3	4
(a)	(iv)	(iii)	(ii)	(i)
(b)	(i)	(ii)	(iv)	(iii)
(c)	(iii)	(ii)	(i)	(iv)
(d)	(i)	(ii)	(iii)	(iv)

52. 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 ? **[Online April 19, 2014]**

(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

53. Match the List-I (Phenomenon associated with electromagnetic radiation) with List-II (Part of electromagnetic spectrum) and select the correct code from the choices given below this lists: **[Online April 11, 2014]**

List I		List II	
I	Doublet of sodium	(A)	Visible radiation
II	Wavelength corresponding to temperature associated with the isotropic radiation filling all space	(B)	Microwave
III	Wavelength emitted by atomic hydrogen in interstellar space	(C)	Short radio wave
IV	Wavelength of radiation arising from two close energy levels in hydrogen	(D)	X-rays

(a) (I)-(A), (II)-(B), (III)-(B), (IV)-(C)
(b) (I)-(A), (II)-(B), (III)-(C), (IV)-(C)
(c) (I)-(D), (II)-(C), (III)-(A), (IV)-(B)
(d) (I)-(B), (II)-(A), (III)-(D), (IV)-(A)

54. Match List I (Wavelength range of electromagnetic spectrum) with List II (Method of production of these waves) and select the correct option from the options given below the lists. **[Online April 9, 2014]**

List I		List II	
(1)	700 nm to 1 mm	(i)	Vibration of atoms and molecules.
(2)	1 nm to 400 nm	(ii)	Inner shell electrons in atoms moving from one energy level to a lower level.
(3)	$< 10^{-3}$ nm	(iii)	Radioactive decay of the nucleus.
(4)	1 mm to 0.1 m	(iv)	Magnetron valve.

(a) (1)-(iv), (2)-(iii), (3)-(ii), (4)-(i)
(b) (1)-(iii), (2)-(iv), (3)-(i), (4)-(ii)
(c) (1)-(ii), (2)-(iii), (3)-(iv), (4)-(i)
(d) (1)-(i), (2)-(ii), (3)-(iii), (4)-(iv)

55. Photons of an electromagnetic radiation has an energy 11 keV each. To which region of electromagnetic spectrum does it belong ? **[Online April 9, 2013]**

(a) X-ray region (b) Ultra violet region
(c) Infrared region (d) Visible region

56. The frequency of X-rays; γ-rays and ultraviolet rays are respectively a, b and c then **[Online May 26, 2012]**

(a) $a < b; b > c$ (b) $a > b ; b > c$
(c) $a < b < c$ (d) $a = b = c$

Hints & Solutions

1. **(a)** Relation between electric field E_0 and magnetic field B_0 of an electromagnetic wave is given by

$c = \frac{E_0}{B_0}$ (Here, c = Speed of light)

$\Rightarrow E_0 = B_0 \times c = 1.2 \times 10^{-7} \times 3 \times 10^8 = 36$

As the wave is propagating along x-direction, magnetic field is along z-direction

and $(\hat{E} \times \hat{B}) \parallel \hat{C}$

$\therefore \vec{E}$ should be along y-direction.

So, electric field $\vec{E} = E_0 \sin \vec{E} \cdot (x, t)$

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

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

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

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

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

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

3. **(a)** $\vec{E} = E_0(\hat{x} + \hat{y})\sin(kz - \omega t)$

Direction of propagation of em wave $= +\hat{k}$

Unit vector in the direction of electric field, $\hat{E} = \frac{\hat{i} + \hat{j}}{\sqrt{2}}$

The direction of electromagnetic wave is perpendicular to both electric and magnetic field.

$\therefore \hat{k} = \hat{E} \times \hat{B}$

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

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

4. **(d)** Given : $\overline{B} = 3 \times 10^{-8} \sin[200\pi(y + ct)]\hat{i}T$

$\therefore B_0 = 3 \times 10^{-8}$

$E_0 = CB_0 \Rightarrow E_0 = 3 \times 10^8 \times 3 \times 10^{-8} = 9$ V/m

Directiono f wave propagation

$(\overline{E} \times \overline{B}) \parallel \overline{C}$

$\hat{B} = \hat{i}$ and $\hat{C} = -\hat{j}$ $\therefore \hat{E} = -\hat{k}$

$\therefore \overline{E} = E_0 \sin[200\pi(y + ct)](-\hat{k})$ V/m

or, $\overline{E} = -9\sin[200\pi(y + ct)]\hat{k}$ V/m

5. **(c)** Relation between electric field and magnetic field for an electromagnetic wave in vacuum is $B_0 = \frac{E_0}{c}$.

In free space, its speed $c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}$

Here, μ_0 = absolute permeability, ε_0 = absolute permittivity

$\therefore B_0 = \frac{E_0}{c} = \frac{E_0}{1/\sqrt{\mu_0\varepsilon_0}} = E_0\sqrt{\mu_0\varepsilon_0}$

As the electromagnetic wave is propagating along x direction and electric field is along y direction.

$\therefore \hat{E} \times \hat{B} \parallel \hat{C}$ (Here, $\hat{C}$ = direction of propagation of wave)

$\therefore \vec{B}$ should be in $\hat{k}$ direction.

$\therefore$ B = $E_0\sqrt{\mu_0\varepsilon_0}$ cos (ωt – kx) $\hat{k}$

At t = 0

B = $E_0\sqrt{\mu_0\varepsilon_0}$ cos (kx) $\hat{k}$

6. **(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

7. **(a)** Electromagnetic wave will propagate perpendicular to the direction of Electric and Magnetic fields

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

Here unit vector $\hat{C}$ is perpendicular to both $\hat{E}$ and $\hat{B}$

Given, $\overline{E} = \hat{k}, \overline{B} = 2\hat{i} - 2\hat{j}$

$\therefore \hat{C} = \hat{E} \times \hat{B} = \frac{1}{\sqrt{2}}\begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ 0 & 0 & 1 \\ 1 & -1 & 0 \end{vmatrix} = \frac{\hat{i} + \hat{j}}{\sqrt{2}}$

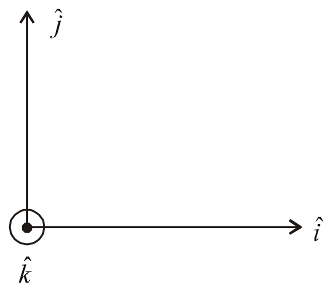
$\Rightarrow \hat{C} = \frac{\hat{i} + \hat{j}}{\sqrt{2}}$

8. **(d)** Given: $\vec{E}_1 = E_0\hat{j}\cos(\omega t - kx)$

i.e., Travelling in $+ve$ x-direction $\vec{E}\times\vec{B}$ should be in x-direction

$\therefore$ $\vec{B}$ is in $\hat{K}$

$\therefore$ $\vec{B}_1 = \frac{E_0}{C}\cos(\omega t - kx)\hat{k}$ $\left(\because B_0 = \frac{E_0}{C}\right)$



$\vec{E}_2 = E_0\hat{k}\cos(\omega t - ky)$

$\vec{B}_2 = \frac{E_0}{C}\hat{i}\cos(\omega t - ky)$

$\therefore$ Travelling in $+ve$ y-axis

$\vec{E}\times\vec{B}$ should be in y-axis

$\therefore$ Net force $\vec{F} = q\vec{E} + q(\vec{v}\times\vec{B})$

$q(\vec{E}_1 + \vec{E}_2) + q(0.8c\hat{j}\times(\vec{B}_1 + \vec{B}_2))$

If t = 0 and x = y = 0

$\vec{E}_1 = E_0\hat{j}$ $\qquad \vec{E}_2 = E_0\hat{k}$

$\vec{B}_1 = \frac{E_0}{c}\hat{k}$ $\qquad \vec{B}_2 = \frac{E_0}{c}\hat{i}$

$\therefore \vec{F}_{\text{net}} = qE_0(\hat{j}+\hat{k}) + q\times 0.8c\times\frac{E_0}{C}\hat{j}\times(\hat{k}+\hat{i})$

$= qE_0(\hat{j}+\hat{k}) + 0.8qE_0(\hat{i}-\hat{k})$

$= qE_0(0.8\hat{i}+\hat{j}+0.2\hat{k})$

9. **(a)** Direction of polarisation = $\hat{E} = \hat{k}$

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

But $\vec{E}.\vec{B} = 0$ $\therefore$ $\hat{B} = \frac{\hat{i}-\hat{j}}{\sqrt{2}}$

10. **(d)** Amplitude of electric field (E) and Magnetic field (B) of an electromagnetic wave are related by the relation

$\frac{E}{B} = c$

$\Rightarrow E = Bc$

$\Rightarrow E = 5\times 10^{-8}\times 3\times 10^{8} = 15\ N/C$

$\Rightarrow \vec{E} = 15\hat{i}\ V/m$

11. **(b)** Given, $\vec{B} = 3\times 10^{-8}\sin(1.6\times 10^{3}x + 48\times 10^{10}\ \text{t})$

Using, $E_0 = B_0\times C = 3\times 10^{-8}\times 3\times 10^{8} = 9\ V/m$

$\therefore$ Electric field,

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

12. **(c)** At $t = 0, z = \frac{\pi}{k}$

$\therefore$ $\vec{E} = \frac{E_0}{\sqrt{2}}(\hat{i}+\hat{j})\cos[\pi] = -\frac{E_0}{\sqrt{2}}(\hat{i}+\hat{j})$

$\vec{F}_E = q\vec{E}$

Force due to electric field will be in the direction $\frac{-(\hat{i}+\hat{j})}{\sqrt{2}}$

Force due to magnetic field is in direction

$q(\vec{v}\times\vec{B})$ and $\vec{v}\parallel\vec{k}$. Therefore, it is parallel to $\vec{E}$.

$\Rightarrow$ $\vec{F}_{\text{net}} = \vec{F}_E + \vec{F}_B$ is antiparallel to $\frac{\hat{i}+\hat{j}}{\sqrt{2}}$

13. **(c)** $\hat{S} = \frac{6\hat{j}+8\hat{k}}{\sqrt{6^2+8^2}} = \frac{-3\hat{j}+4\hat{k}}{5}$

14. **(b)** $B_0 = \frac{E_0}{C} = \frac{60}{3\times 10^{8}}$

$= 20\times 10^{-8}\ \text{T} = 2\times 10^{-7}\ \text{T}$

$K = \frac{\omega}{v} = \frac{2\pi f}{v} = \frac{2\pi\times 23.9\times 10^{9}}{3\times 10^{8}} = 500$

Therefore, $\vec{B} = B_0\sin(kz - \omega t)$

$= 2\times 10^{-7}\ \sin(0.5\times 10^{3}z - 1.5\times 10^{11}t)i$

15. **(a)**

$\frac{\text{E}_0}{\text{B}_0} = \text{C}$

$\Rightarrow \text{B}_0 = \frac{\text{E}_0}{\text{C}}$

Given that $\vec{\text{E}} = \text{E}_0\cos(\text{kz})\cos(\omega\,\text{t})\hat{\text{i}}$

$\vec{\text{E}} = \frac{\text{E}_0}{2}\left[\cos(\text{kz}-\omega\text{t})\hat{\text{i}} - \cos(\text{kz}+\omega\text{t})\hat{\text{i}}\right]$

Correspondingly

$\vec{\text{B}} = \frac{\text{B}_0}{2}\left[\cos(\text{kz}-\omega\text{t})\hat{\text{j}} - \cos(\text{kz}+\omega\text{t})\hat{\text{j}}\right]$

$\vec{\text{B}} = \frac{\text{B}_0}{2}\times 2\sin\text{kz}\sin\omega\text{t}$

$\vec{\text{B}} = \left(\frac{\text{E}_0}{\text{C}}\sin\text{kz}\sin\omega\text{t}\right)\hat{\text{j}}$

16. **(c)** Pressure, $P = \frac{I}{C}$

$\Rightarrow \frac{F}{A} = \frac{I}{C}$

$\Rightarrow F = \frac{IA}{C} = \frac{\Delta p}{\Delta t}$

$\Rightarrow \Delta p = \frac{I}{C} A\Delta t$

$= \frac{(25\times 25)\times 10^4 \times 10^{-4} \times 40 \times 60}{3\times 10^8}$ N-s

$= 5 \times 10^{-3}$ N-s

17. **(a)** $B_0 = \sqrt{B_0^2 + B_1^2} = \sqrt{30^2 + 2^2} \times 10^{-6}$

$= 30 \times 10^{-6}$ T

$\therefore E_0 = CB = 3\times 10^8 \times 30 \times 10^{-6}$

$= 9 \times 10^3$ V/m

$\frac{E_0}{V_2} = \frac{9}{\sqrt{2}} \times 10^3 V/m$

Force on the charge,

$F = EQ = \frac{9}{\sqrt{2}} \times 10^3 \times 10^{-4} \simeq 0.64N$

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

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

19. **(b)** $F = (1+r)\frac{IA}{C}$

$= \frac{(1+0.25)\times 50\times 1}{3\times 10^8}$

$\simeq 20\times 10^{-8}$ N

20. **(a)** The relation between amplitudes of electric and magnetic field in free space is given by

$B_0 = \frac{E_0}{c} = \frac{6}{3\times 10^8} = 2\times 10^{-8} T$

Propagation direction $= \hat{E}\times\hat{B}$

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

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

$\therefore$ The magnetic field component will be along z direction.

21. **(c)** $E_0 = cB_0 = 3 \times 10^8 \times 1.6 \times 10^{-6} = 4.8 \times 10^2$ V/m

Also $\overrightarrow{S} \Rightarrow \overrightarrow{E}\times\overrightarrow{B}$

or $-\overrightarrow{K} \Rightarrow \overrightarrow{E}\times(2\hat{i}+\hat{j})$

Therefore direction of $\overrightarrow{E} \rightarrow \left(-\hat{i}+2\hat{j}\right)$

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

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

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

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

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

Which is closest to 10^{-4}.

23. **(c)** The speed of electromagnetic wave in free space is given by

$C = \frac{1}{\sqrt{\mu_0 \epsilon_0}}$ ...(i)

In medium, $v = \frac{1}{\sqrt{k\epsilon_0\mu_0}}$ ...(ii)

Dividing equation (i) by (ii), we get

$\therefore \frac{C}{V} = \sqrt{k} = n$

$\frac{1}{2}\epsilon_0 E_0^2 C = \text{intensity} = \frac{1}{2}\epsilon_0 kE^2 v$

$\therefore E_0^2 C = kE^2 v$

$\Rightarrow \frac{E_0^2}{E^2} = \frac{kV}{C} = \frac{n^2}{n} \Rightarrow \frac{E_0}{E} = \sqrt{n}$

similarly

$\frac{B_0^2 C}{2\mu_0} = \frac{B^2 v}{2\mu_0} \Rightarrow \frac{B_0}{B} = \frac{1}{\sqrt{n}}$

24. **(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]

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

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

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

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

$= 3 \times 10^4$ N/C

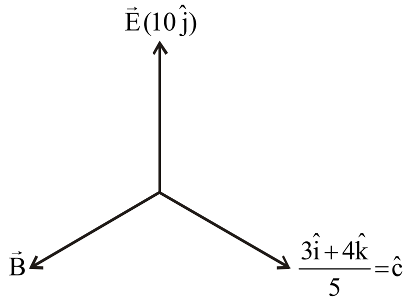
Here we assumed that

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

26. **(b)** $\vec{E} = 10\hat{j}\cos\left[\left(6\hat{i}+8\hat{k}\right).\left(x\hat{i}+z\hat{k}\right)\right]$

$= 10\hat{j}\cos\left[\vec{K}.\vec{r}\right]$

$\therefore \vec{K} = 6\hat{i}+8\hat{K}$; direction of waves travel i. e. direction of 'c'.



$\hat{C}\times\hat{E}=\frac{-4\hat{i}+3\hat{k}}{5}$

$\vec{B}=\frac{E}{C}=\frac{10}{C}$

$\therefore\ \vec{B}\frac{10}{C}\left(\frac{-4\hat{i}+3\hat{k}}{5}\right)=\left(\frac{-8\hat{i}+6\hat{k}}{C}\right)$

or, magnetic field $\vec{B}(x,z,t)=\frac{1}{C}$

$\left(6\hat{k}-8\hat{i}\right)\cos(6x+8z-10ct)$

27. **(c)** Velocity of EM wave is given by $v=\frac{1}{\sqrt{\mu\in}}$

Velocity in air $=\frac{\omega}{k}=C$

Velocity in medium $=\frac{C}{2}$

Here, $\mu_1=\mu_2=1$ as medium is non-magnetic

$$\therefore\quad \frac{\frac{1}{\sqrt{\in_{r_1}}}}{\frac{1}{\sqrt{\in_{r_2}}}}=\frac{C}{\left(\frac{C}{2}\right)}=2\quad\Rightarrow\quad \frac{\in_{r_1}}{\in_{r_2}}=\frac{1}{4}$$

28. **(d)** Average energy density of magnetic field,

$u_B=\frac{B_0^2}{4\mu_0}$.

Average energy density of electric field,

$u_E=\frac{\varepsilon_0E_0^2}{4}$

Now, $E_0=CB_0$ and $C^2=\frac{1}{\mu_0\in_0}$

$$u_E=\frac{\varepsilon_0}{4}\times C^2B_0^2=\frac{\varepsilon_0}{4}\times\frac{1}{\mu_0\varepsilon_0}\times B_0^2=\frac{B_0^2}{4\mu_0}=u_B$$

$\therefore u_E=u_B$

Since energy density of electric and magnetic field is same, so energy associated with equal volume will be equal i.e. $u_E=u_B$

29. **(c)** If E_0 is magnitude of electric field then

$\frac{1}{2}\varepsilon_0E^2\times C=1\Rightarrow E_0=\sqrt{\frac{2I}{C\varepsilon_0}}$

$E_0=\frac{E_0}{C}$

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

30. **(c)** $\hat{E}\times\hat{B}$ should give the direction of wave propagation

$$\Rightarrow\quad \hat{K}\times\hat{B}\,||\,\frac{\hat{i}\times\hat{j}}{\sqrt{2}}\Rightarrow\hat{K}\times\left(\frac{\hat{i}+\hat{j}}{\sqrt{2}}\right)=\frac{\hat{j}-(-\hat{i})}{\sqrt{2}}=\frac{\hat{i}+\hat{j}}{\sqrt{2}}\,||\,\frac{\hat{i}+\hat{j}}{\sqrt{2}}$$

Option (a), option (b) and option (d) does not satisfy.

Wave propagation vector $\hat{K}$ should along $\frac{\hat{i}+\hat{j}}{\sqrt{2}}$.

31. **(c)** Given, Electric field component of monochromatic radiation, $(\vec{E})=2E_0\hat{i}\cos kz\cos\omega t$

We know that, $\frac{dE}{dz}=-\frac{dB}{dt}$

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

$dB=+2E_0k\sin kz\cos\omega t\,dt$ ..... (i)

Integrating eq^n (i), we have

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

Magnetic field is given by,

$=+2E_0\frac{k}{\omega}\sin kz\sin\omega t$

We also know that,

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

Magnetic field vector,

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

32. **(a)** Speed of EM wave in force space (c) $=\frac{E_0}{B_0}$

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

33. **(d)** Wave in X-direction means E and B should be function of x and t.

$\hat{y}-\hat{z}\perp\hat{y}+\hat{z}$

34. **(b)** As we know, $\vec{E}.\vec{B}=0\because[\vec{E}\perp\vec{B}]$

and $\vec{E}\times\vec{B}$ should be along Z direction

As $(-2\hat{i}-3\hat{j})\times(3\hat{i}-2\hat{j})=5\hat{k}$

Hence option (b) is the correct answer.

35. **(d)** As we know,

$B_0=\frac{E_0}{C}=\frac{27}{3\times10^8}=9\times10^{-8}$ tesla

Oscillation of B can be only along $\hat{j}$ or $\hat{k}$ direction.
$\omega = 2\pi f = 2\pi \times 2 \times 10^{14}$ Hz

$\therefore\ \vec{B}(x,t) = (9\times10^{-8}T)\hat{k}\sin[2\pi(1.5\times10^{-6}\times -2\times10^{4}t)]$

36. **(c)** $E_0 = CB_0$ and $C = \dfrac{1}{\sqrt{\mu_0\varepsilon_0}}$

Electric energy density $= \dfrac{1}{2}\varepsilon_0 E_0^{\,2} = \mu_E$

Magnetic energy density $= \dfrac{1}{2}\dfrac{Bo^2}{\mu_0} = \mu_B$

Thus, $\mu_E = \mu_B$
Energy is equally divided between electric and magnetic field.

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

Intensity $I = \dfrac{\text{Power}}{\text{Area}}$

$$= \frac{100\times(3/100)}{4\pi(5)^2} = \frac{3}{100\pi}\text{Wm}^{-2}$$

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

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

or $E_0 = \sqrt{\dfrac{2I}{\varepsilon_0 C}}$

$$= \sqrt{\frac{2\times\left(\frac{3}{100}\pi\right)}{\left(\frac{1}{4\pi\times9\times10^9}\right)\times\left(3\times10^8\right)}}$$

$$= \sqrt{\frac{6}{25}\times30} = \sqrt{7.2}$$

$\therefore\ E_0 = 2.68$ V / m

38. **(c)** **Given:** Amplitude of electric field,
$E_0 = 4$ v/m
Absolute permitivity,
$\varepsilon_0 = 8.8 \times 10^{-12}$ c^2/N-m^2
Average energy density u_E = ?
Applying formula,

Average energy density $u_E = \dfrac{1}{4}\varepsilon_0 E^2$

$$\Rightarrow\ u_E = \frac{1}{4}\times8.8\times10^{-12}\times(4)^2$$
$$= 35.2 \times 10^{-12}\ \text{J/m}^3$$

39. **(b)** From question,
$B_0 = 20\,nT = 20 \times 10^{-9}T$
($\because$ velocity of light in vacuum $C = 3 \times 10^8$ ms^{-1})
$\vec{E}_0 = \vec{B}_0 \times \vec{C}$
$|\vec{E}_0| = |\vec{B}|\cdot|\vec{C}| = 20\times10^{-9}\times3\times10^8$
$= 6$ V/m.

40. **(b)**

41. **(d)** Electromagnetic waves do not required any medium to propagate. They can travel in vacuum. They are transverse in nature like light. They carry both energy and momentum.
A changing electric field produces a changing magnetic field and vice-versa. Which gives rise to a transverse wave known as electromagnetic wave.

42. **(b)** $\because$ The E.M. wave are transverse in nature *i.e.*,

$$= \frac{\vec{k}\times\vec{E}}{\mu} = \vec{H} \quad \ldots\text{(i)}$$

where $\vec{H} = \dfrac{\vec{B}}{\mu}$

and $\dfrac{\vec{k}\times\vec{H}}{\omega\varepsilon} = -\vec{E}$ …(ii)

$\vec{k}$ is $\perp$ $\vec{H}$ and $\vec{k}$ is also $\perp$ to $\vec{E}$

The direction of wave propagation is parallel to $\vec{E}\times\vec{B}$.
The direction of polarization is parallel to electric field.

43. **(c)** In an electromagnetic wave electric field and magnetic field are perpendicular to the direction of propagation of wave. The vector equation for the electric field is

$$\vec{E} = E_0\cos\left(\omega t - \frac{2\pi}{\lambda}y\right)\hat{z}$$

44. **(a)** Frequency remains unchanged during refraction
Velocity of EM wave in vacuum

$$V_{\text{vacuum}} = \frac{1}{\sqrt{\mu_0 \epsilon_0}} = C$$

$$v_{\text{med}} = \frac{1}{\sqrt{\mu_0 \epsilon_0 \times 4}} = \frac{c}{2}$$

$$\frac{\lambda_{\text{med}}}{\lambda_{\text{vacuum}}} = \frac{v_{\text{med}}}{v_{\text{vacuum}}} = \frac{c/2}{c} = \frac{1}{2}$$

$\therefore$ Wavelength is halved and frequency remains unchanged

45. **(a)** The phenomenon of polarisation is shown only by transverse waves. The vibration of electromagnetic wave are restricted through polarization in a direction perpendicular to wave propagation.

46. **(d)** Energy sequence of radiations is

$E_{\gamma\text{-Rays}} > E_{\text{X-Rays}} > E_{\text{microwave}} > E_{\text{AM Radiowaves}}$

$\therefore\ \lambda_{\gamma\text{-Rays}} < \lambda_{\text{X-Rays}} < \lambda_{\text{microwave}} < \lambda_{\text{AM Radiowaves}}$

From the above sequence, we have

(a) Microwave $\to 10^{-3}$ m (iv)

(b) Gamma Rays $\to 10^{-15}$ m (ii)

(c) AM Radio wave $\to 100$ m (i)

(d) X-Rays $\to 10^{-10}$ m (iii)

47. **(b)** The orderly arrangement of different parts of EM wave in decreasing order of wavelength is as follows:

$$\lambda_{\text{radiowaves}} > \lambda_{\text{microwaves}} > \lambda_{\text{visible}} > \lambda_{\text{X-rays}}$$

48. **(c)** Optical Fibre Communication – Infrared Light

Radar – Radio Waves

Sonar – Ultrasound

Mobile Phones – Microwaves

49. **(c)** $\xrightarrow{\text{E, Decreases}}$

γ-rays X-rays uv-rays Visible rays VIBGYOR IR rays Microwaves Radio waves

Radio wave < yellow light < blue light < X-rays

(Increasing order of energy)

50. **(c)** Microwave oven acts on the principle of giving vibrational energy to water molecules.

51. **(d)**

(1) Infrared rays are used to treat muscular strain because these are heat rays.

(2) Radio waves are used for broadcasting because these waves have very long wavelength ranging from few centimeters to few hundred kilometers.

(3) X-rays are used to detect fracture of bones because they have high penetrating power but they can't penetrate through denser medium like dones.

(4) Ultraviolet rays are absorbed by ozone of the atmosphere.

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

53. **(d)** Wavelength emitted by atomic hydrogen in interstellar space - Part of short radio wave of electromagnetic spectrum.

Doublet of sodium - visible radiation.

54. **(d)** Vibration of atoms and molecules 700 nm to 1 mm

Radioactive decay of the nucleus < 10^{-3} nm

Magnetron valve 1 mm to 0.1 m

55. **(a)** $E = \frac{hc}{\lambda} \Rightarrow \lambda = \frac{hc}{E}$

$$\Rightarrow \lambda = \frac{6.6 \times 10^{-34} \times 3 \times 10^{8}}{11 \times 1000 \times 1.6 \times 10^{-19}}$$

$= 12.4$ Å

Increasing order of frequency →

x-rays u-v rays visible Infrared

wavelength range of visible region is 4000Å to 7800Å.

56. **(a)** Frequency range of γ-ray,

$b = 10^{18} - 10^{23}$ Hz

Frequency range of X-ray,

$a = 10^{16} - 10^{20}$ Hz

Frequency range of ultraviolet ray,

$c = 10^{15} - 10^{17}$ Hz

$\therefore\ a < b;\ b > c$