Electromagnetic Waves

1. 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 is $x \times 10^{-8}\hat{k}$. Find the value of x.
2. If the magnetic field of a plane electromagnetic wave is given by (The speed of light $= 3 \times 10^{8}$ 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 (in N/C) associated with it is:
3. A 27 mW laser beam has a cross-sectional area of $10\ \mathrm{mm}^2$. The magnitude of the maximum electric field (in kV/m) 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]
4. The mean intensity of radiation on the surface of the Sun is about $10^{8}\ \mathrm{W/m^2}$. The rms value of the corresponding magnetic field (in tesla) is :
5. 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 $B_0 = 3 \times 10^{-5}$ T and $B_1 = 2 \times 10^{-6}$ T. The rms value of the force (in newton) experienced by a stationary charge $Q = 10^{-4}$C at $z = 0$ is :
6. $50\ \mathrm{W/m^2}$ 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 (in newton) exerted on $1\ \mathrm{m^2}$ surface area will be ($c = 3 \times 10^{8}$ m/s):
7. A light beam travelling in the x-direction is described by the electric field $E_y = 300 \sin \omega\left(t - \frac{x}{c}\right)$. An electron is constrained to move along the y-direction with a speed of 2.0×10^{7} m/s. Find the maximum electric force (in newton) on the electron.
8. A laser beam has intensity $2.5 \times 10^{14} \frac{\mathrm{W}}{\mathrm{m}^2}$. Find the amptitude of electric field (in V/m) in the beam.
9. 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 (in Ns) transferred to the surface in 40 min time duration will be:
10. In a wave $E_0 = 100\mathrm{Vm}^{-1}$. Find the magnitude of Poynting's vector in watt m^{-2}.
11. The magnetic field in a travelling electromagnetic wave has a peak value of 20 nT. The peak value of electric field strength (in volt m^{-1}) is
12. A new system of unit is evolved in which the values of μ_0 and ϵ_0 are 2 and 8 respectively. Then the speed of light in this system will be
13. A plane electromagnetic wave of wave intensity $10\ \mathrm{W/m^2}$ strikes a small mirror of area $20\ \mathrm{cm}^2$, held perpendicular to the approaching wave. The radiation force (in newton) on the mirror will be
14. Radiations of intensity $0.5\ \mathrm{W/m^2}$ are striking on a perfectly reflecting metal plate. The pressure (in $\mathrm{N/m^2}$) on the plate is
15. 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(in metre $^{-1}$) is

SOLUTIONS

1. **(2.1)** As we know,

$$|\vec{B}| = \frac{|\vec{E}|}{C} = \frac{6.3}{3\times10^8} = 2.1\times10^{-8}\,\text{T}$$

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 $\vec{B} = 2.1\times10^{-8}\hat{k}\text{T}$

2. **(3 × 10⁴ N/C)** 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

3. **(1.4)** 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]

$$\Rightarrow \frac{27\times10^{-3}}{10\times10^{-6}} = \frac{1}{2}\times9\times10^{-12}\times E_0^2\times3\times10^8$$

$$\Rightarrow E_0 = \sqrt{2}\times10^3\,\text{kV/m} = 1.4\,\text{kV/m}$$

4. **(6 × 10⁻⁴)** $I = \frac{B_0^2}{2\mu_0}\cdot C$

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

$$= \sqrt{\frac{10^8\times4\pi\times10^{-7}}{3\times10^8}} \simeq 6\times10^{-4}\,\text{T}$$

5. **(0.64)** $B_0 = \sqrt{B_0^2 + B_1^2} = \sqrt{30^2+2^2}\times10^{-6}$

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

$\therefore E_0 = cB = 3\times10^8\times30\times10^{-6}$

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

$$E_{rms} = \frac{E_0}{\sqrt{2}} = \frac{9}{\sqrt{2}}\times10^3 V/m$$

Force on the charge,

$$F = E_{rms}Q = \frac{9}{\sqrt{2}}\times10^3\times10^{-4} \simeq 0.64N$$

6. **(20×10^{-8})** $F = (1+r)\frac{IA}{C}$

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

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

7. **(4.8×10^{-7})** $E_0 = 300$ V/m,

$$\therefore\ B_0 = \frac{E_0}{C} = \frac{300}{3\times 10^{8}} = 1\times 10^{-6}\ \text{N/A-m}$$

The maximum electric force,

$$F_0 = E_0 q = 300 \times 1.6 \times 10^{-19}$$
$$= 4.8 \times 10^{-7}\,\text{N.}$$

8. **(4.3×10^{8})** The intensity is given by

$$I = \frac{1}{2}\epsilon_0 E^2 C$$

$$\text{or } 2.5 \times 10^{14} = \frac{1}{2}\times(8.86\times 10^{-12})\times E_0^2 \times (3\times 10^{8})$$

$$\therefore E_0 = 4.3 \times 10^{8}\ \text{V/m}$$

9. **(5×10^{-3})** Pressure, $P = \frac{I}{C}$

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

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

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

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

10. **(26.5)** $|\vec{S}| = \frac{EB}{\mu_0} = \frac{E^2}{C\mu_0} = \frac{10^4}{3\times 10^{8}\times 4\pi\times 10^{-7}} = 26.5\ \text{Wm}^{-2}$

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

12. **(0.25)** The speed of light

$$C = \frac{1}{\sqrt{\mu_0 \varepsilon_0}} = \frac{1}{\sqrt{2\times 8}} = \frac{1}{4} = 0.25$$

13. **(1.33×10^{-10})**

14. **(0.332×10^{-8})**

15. **(2)** On comparing the given equation to

$$\vec{E} = a_0\hat{i}\cos(\omega t - kz),\ \omega = 6 \times 10^{8},\ k = \frac{2p}{1} = \frac{w}{c}$$

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