Chapter

8 ELECTROMAGNETIC WAVES

1. The current $\varepsilon_0 \frac{d\phi_E}{dt} = i$ is a new term and is due to Changing electric field, therefore called

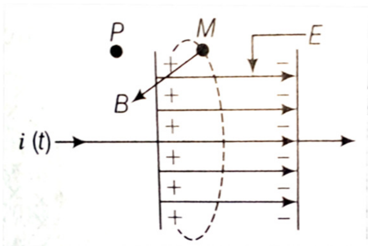
   (a) conduction current

   (b) induced current

   (c) Both (a) and (b)

   (d) Maxwell's displacement current

2. In the given figure, a magnetic field (say at point *M*) between the plates of the capacitor to be the same as that just



   (a) outside at *P* (b) between the plates

   (c) above the plates (d) down the plates

3. The charge of a parallel plate capacitor is varying as $q = q_0 \sin 2\pi ft$. The plates are very large and close together$(Area = A, separation = d)$ Neglecting edge effects, the displacement current through the capacitor is

   (a) $\frac{d}{A\varepsilon_0}$ (b) $\frac{d}{\varepsilon_0} sin\, 2\pi ft$

   (c) $2\pi f q_0 \cos 2\pi ft$ (d) $\frac{2\pi f q_0}{\varepsilon_0} \cos 2\pi ft$

4. You are given a parallel plate capacitor having capacitance of $2\mu F$. How would you establish an instantaneous displacement current of 1 mA in the space between its plates?

   (a) 550 Vs^{-1} (b) 500 Vs^{-1}

   (c) 525 Vs^{-1} (d) 475 Vs^{-1}

5. Which is the most important prediction to emerge from Maxwell's equations?

   (a) Existence of magnetic waves

   (b) Existence of electrical waves

   (c) Existence of radio waves

   (d) Existence of electromagnetic waves

6. Find magnetic field on circular loop of radius r, placed between circular plates of capacitor of radius R having displacement current $i_d, r < R$

   (a) $\frac{\mu_0 i_d r}{2\pi R^2}$ (b) $\frac{\mu_0 i_d}{2\pi R}$

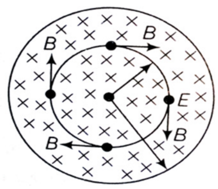
   (c) $\frac{\mu_0 i_d}{2\pi r}$ (d) zero

7. An expression for the magnetic field strength B at the point between the capacitor plates in terms of the rate of change of the electric field strength i.e., *dE/dt* between the plates is

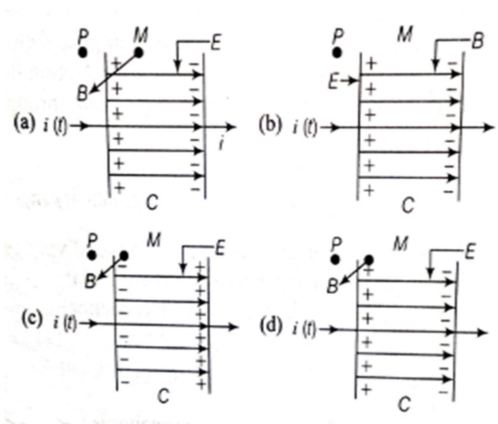
   (a) $\frac{\mu_0 i}{2\pi r}$ (b) $\frac{\varepsilon_0 \mu_0 r}{2} \frac{dE}{dt}$

   (c) zero (d) $\frac{\mu_0 i}{2r}$

8. Consider cross-sectional view of the given figure



   Now choose the correct option



9. Electromagnetic waves can be deflected by

   (a) only electric field (b) only magnetic field

   (c) Both (a) and (b) (d) None of these

10. The direction of k describes

(a) direction of propagate on of the wave

(b) opposite direction of propagation of the wave

(c) direction of propagation of the wave (ω/k)

(d) opposite direction of propagation of the wave (ω/k)

11. What will be the magnetic energy density, in the magnetic field B?

(a) $B^2/2\mu_0$ (b) $B/2\mu_0$

(c) $2B/\mu_0$ (d) $2B^2\mu_0$

12. During the propagation or electromagnetic waves in a medium.

(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

13. Out of the following options which one can be used to produce a propagating electromagnetic wave?

(a) A stationary charge

(b) A charge less particle

(c) An accelerating charge

(d) A charge moving at constant velocity

14. A plane electromagnetic wave of frequency 25 MHz travels in free space along the x-direction. At a particular point in space and time, $E = 6.3\hat{J}V/m$

What is B at this point?

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

(c) $3.5 \times 10^{6}\hat{k}T$ (d) $3.0 \times 10^{5}\hat{k}T$

15. Suppose that the electric field amplitude of an electromagnetic wave is $E_0 = 120NC^{-1}$ and its frequency is $v = 50.0MHz$. The expressions for E will be (if wave travels along X)

(a) $[(120\,NC^{-1})\,sin\{(1.05radm^{-1})x - (3.14 \times 10^8 rads^{-1})t\}]\hat{\imath}$

(b) $[(120\,NC^{-1})sin\{(1.05\,radm^{-1})x - (3.14 \times 10^8 rads^{-1})t\}]\hat{k}$

(c) $[(120NC^{-1})sin\{(1.05radm^{-1})x - (3.14 \times 10^8 rads^{-1})t\}]\hat{\jmath}$

(d) $[(120\,NC^{-1})cos\{(1.05radm^{-1})x - (3.14 \times 10^8 rads^{-1})t\}]\hat{\jmath}$

16. Light having an energy flux of 40 Wcm^{-2} falls on non-reflecting surface at normal incidence. If the surface has an area of $20cm^2$, the total momentum delivered (for complete absorption) during 10 min is

(a) 24×10^{-5}kg ms^{-1}

(b) $24 \times 10^{-4}\,kg\,ms^{-1}$

(c) $102 \times 10^{4}\,kgms^{-1}$

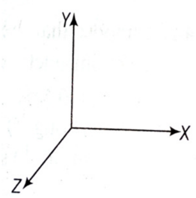
(d) $1.03 \times 10^{7}\,kgms^{-1}$

17. If ε_0 and μ_0 are the electric permittivity and magnetic permeability of free space and ε and μ are the corresponding quantities in the medium, the index of refraction of the medium in terms of above parameter is

(a) $\frac{\varepsilon\mu}{\varepsilon_0\mu_0}$ (b) $\left(\frac{\varepsilon\mu}{\varepsilon_0\mu_0}\right)^{1/2}$

(c) $\left(\frac{\varepsilon_0\mu_0}{\varepsilon\mu}\right)$ (d) $\left(\frac{\varepsilon_0\mu_0}{\varepsilon\mu}\right)^{1/2}$

18 Light wave is travelling along *y*-direction. If the corresponding *E* vector at any time is along the *X*-axis, the direction of *B* vector at that time is along



(a) y-axis (b) *X*-axis

(c) +Z-axis (d) $-Z$-axis

19. The electric field associated with an electro magnetic wave in vacuum is give by

$E = i\,40\,cos\,(kz - 6 \times 10^8\,t)$, where E, z and t are in Vm^{-1} , meter and second respectively. The value of wave vector k is

(a) $2m^{-1}$ (b) $0.5m^{-1}$ (c) 6 m^{-1} (d) 3 m^{-1}

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

(a) 3 Vm^{-1} (b) $6Vm^{-1}$

(c) 9 Vm^{-1} (d) 12 Vm^{-1}

21. The magnetic field component of intensity of electromagnetic wave is $4I_0$. What is the electric field component of intensity?

(a) $2I_0$ (b) $4I_0$ (c) I_0 (d) $\frac{I_0}{4}$

22. At the Maxwell predicted the existence of electromagnetic waves , which was the more familiar electromagnetic waves at that time?

(a) X-rays

(b) y-rays

(c) Visible light waves

(d) Radiowaves

23. Arrange the following electromagnetic radiations in the order of increasing energy.

I . Blue light II. Yellow light

III. X-ray IV. Radio wave

(a) IV, II, I, III

(b) I, II, IV,III

(c) III, I,II, IV

(d) II, I, IV,III

24. UV radiation is absorbed by

(a) ordinary glass

(b) Prism

(c) black glass

(d) Both (b) and (c)

25. The energy of the EM waves is of the order of 1 keV. To which part of the spectrum does it belong?

(a) X-ray (b) Infrared rays

(c) Ultraviolet rays (d) Y-rays

26. A linearly polarized electromagnetic wave given as $E = E_0\hat{\imath}cos(kz - \omega t)$ is incident normally on a perfectly reflecting infinite wall at $z = a$. Assuming that the material of the wall is optically inactive, the reflected wave will be given as

(a) $E_r = E_0\hat{\imath}(kz - \omega t)$

(b) $E_r = E_0\hat{\imath}cos(kz + \omega t)$

(c) $E_r = -E_0\hat{\imath}\, cos(kz + \omega t)$

(d) $E_r = E_0\hat{\imath}sin(kz - \omega t)$

27. Light with an energy flux of 20 W cm^{-2} falls on a non-reflecting surface at normal incidence. If the surface has an area of $30cm^2$, the total momentum delivered (for complete absorption) during 30 min is

(a) $36 \times 10^{-5}\ kg\text{-}ms^{-1}$

(b) $36 \times 10^{-4}\ kg\text{-}ms^{-1}$

(c) $108 \times 10^{4}\ kgms^{-1}$

(d) $1.08 \times 10^{7}\ kg\text{-}ms^{-1}$

28. The ratio of contributions made by the electric field and magnetic field components to the intensity of an EM wave is

(a) c : 1 (b) $c^2 : 1$ (c) 1:1 (d) $\sqrt{c} : 1$

29. An electromagnetic wave travels in vacuum along z-direction $E = (E_1\hat{\imath} - E_2\hat{\jmath})cos(kz - \omega t)$. Choose the correct options from the following.

(a) The associated magnetic field is given as

$$B = \frac{1}{c}(E_1\hat{\imath} - E_2\hat{\jmath})\cos(kz - \omega t)$$

(b) The associated magnetic field is given as

$$B = \frac{1}{c}(E_1\hat{\imath} - E_2\hat{\jmath})cos(kz - \omega t)$$

(c) The given electromagnetic field is circularly polarized

(d) The given electromagnetic wave is plane polarized

30. The magnetic field of a beam emerging from a filter facing a floodlight is given by

$B_0 = 12 \times 10^{-8} sin(1.20 \times 10^{7}z - 3.60 \times 10^{15}t)T$.

What is the average intensity of the beam?

(a) $1.91Wm^{-2}$ (b) $1.71Wm^{-2}$

(c) $200Wm^{-2}$ (d) $1.5Wm^{-2}$

Hints and explanations

1. (d)

2. (a)

3. (c)

The displacement through the capacitor

i.e, $i = \frac{dq}{dt} = \frac{d}{dt}(q_0 sin2\pi ft) = q_0 2\pi f \cos 2\pi ft.$

4. (b)

$C = 2\mu F = 2 \times 10^{-6} F$

i_d(displacement current)= $1mA = 10^{-3} A$

As, $i_d = \frac{dq}{dt} = \frac{d}{dt}(CV) = C\frac{dV}{dt}$,

$\frac{dV}{dt} = \left(\frac{1}{C}\right) i_d = \left(\frac{1}{2\times10^{-6}F}\right)(10^{-3}A) = 500\, Vs^{-1}$

5. (d)

The most important prediction to emerge from Maxwell's equations is the existence of electromagnetic waves, which are (coupled) time-varying electric and magnetic fields that propagate in space. The speed of the waves, according to these equations, turned out to be very close to the speed of light($3 \times 10^8 ms^{-1}$), obtained from optical measurement. This led to the remarkable conclusion that light is an electromagnetic waves.

6. (a)

Consider a loop of radius $r(< R)$ between the two circular plates, placed coaxially with them. The area of the loop= πr^2

By symmetry, magnetic field is equal in magnitude at all points on the loop. If $i_d$is the displacement current crossing the loop and i_d is the total displacement current between

plates $i_d = \frac{i_d}{\pi R^2} \times \pi r^2$

Using Ampere-Maxwell's law

B$.dl = \mu_0 i_d$ or $B.\, 2\pi r = \mu_0 i_d \frac{\pi r^2}{\mu R^2}$ $or\ B = \frac{\mu_0 i_d r}{2\pi R^2}$

7. (b)

Magnetic field strength B between the parallel plates capacitor i.e, $B. = \mu_0 i_d$

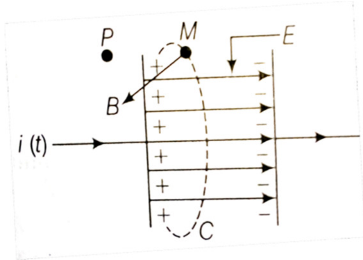
$B = \frac{\mu_0 2i_d}{4\pi r} = \frac{\mu_0}{4\pi}\frac{2i_d}{r} = \frac{\mu_0}{4\pi}\frac{2}{r} \times \varepsilon_0 \frac{d\phi_E}{dt}\left(\because i_d = \varepsilon_0 \frac{d\phi_E}{dt}\right)$

$(\because d\phi_E = dE.A = dE\,\pi r^2)$

$= \frac{\mu_0 \varepsilon_0 \pi r^2 dE}{2\pi r\, dt} = \frac{\mu_0 \varepsilon_0 r}{2}\frac{dE}{dt}$

8. (a)

In parallel plate capacitor, electric field E is perpendicular to the surfaces. It has the same magnitude over the area A of the capacitor plates and vanishes outside it.



9. (d)

In electromagnetic waves, the rest mass of a particle is zero, then net force exerted on a particle is zero. So, there is no deflection shown by a particle.

10 .(a)

11. (a)

12. (c)

13. (c)

14. (a)

According to Maxwell equation, the magnitude of the electric and magnetic fields in an electromagnetic wave are related as.

$B = \frac{E}{c} = \frac{6.3Vm^{-1}}{3\times10^8 ms^{-1}} = 2.1 \times 10^{-8}\hat{k}T$

15. (c)

Given, $E_0 = 120NC^{-1}, v = 50.0MHz = 50 \times 10^6 Hz$. As, we know, magnetic field

$$B_0 = \frac{E_0}{c} = \frac{120NC^{-1}}{3\times10^8 ms^{-1}}$$

$$= 4\times 10^{-7}\, T = 400nT$$

$$\omega = 2\pi v = (2 \times 3.14\, rad)(50 \times 10^6 Hz)$$

$$= \quad 3.14 \times 10^8 rads^{-1}$$

16. (b)

energy flux, $\phi = 40\, Wcm^{-2}$, surface area $(A) = 20cm^2, time(t) = 10min = 10 \times 60\ s$

Total energy falling on the surface in time t is

$$U = \phi At = 40 \times 20 \times (10 \times 60)\, J$$

Momentum of the incident light

$$(P) = \frac{U}{c} = \frac{40\times20\times(10\times60)}{3\times10^8}$$

$$= \ 24 \times 10^{-4}\ kgs^{-1}$$

Momentum of the reflected light $= 0$

∴ Momentum delivered to the surface

$$= 24 \times 10^{-4} - 0$$

$$= 24 \times 10^{-4}\ kg\ ms^{-1}$$

17. (b)

Velocity of light in vacuum $c = \frac{1}{\sqrt{\mu_0\varepsilon_0}}$

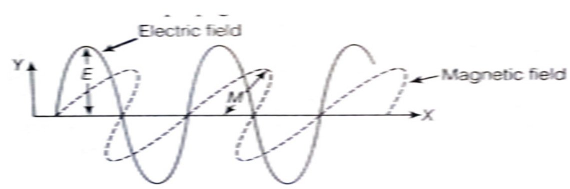
Velocity of light in medium $v = \frac{1}{\sqrt{\mu\varepsilon}}$

So, $\mu = \frac{c}{v} = \left(\frac{\mu\varepsilon}{\mu_0\varepsilon_0}\right)^{1/2}$

18. (c)

Electromagnetic radiation is a self propagating wave in space with electric and magnetic components.

These components oscillate at right angles to each other and to the direction of propagation.



Hence, B is along the Z-axis at that time.

19. (a)

Electromagnetic wave equation

$$E = E_0 \cos(kz - \omega t) \qquad ...(i)$$

Speed of electromagnetic wave $v = \frac{\omega}{k}$

Given, equation

$$E = \hat{\imath}40 \cos(kz - 6 \times 10^8 t) \qquad ...(ii)$$

Comparing Eqs. (i) and (ii), we get

$$\omega = 6 \times 10^8 \quad and\ \ E_0 = 40\hat{\imath}$$

Here, wave factor k $= \frac{\omega}{v} = \frac{6\times10^8}{3\times10^8} = 2m^{-1}$

20. (b)

E $= B \times c$

E = electric field, B = magnetic field

$$c = \ \ speed\ of\ EM\ wave$$

On putting the values of electric field

$$|E| = |B||c|$$

$$= 20 \times 10^{-9} \times 3 \times 10^{-8} = 6Vm^{-1}$$

21. (b)

I_E (intensity due to electric field) $= \frac{1}{2} c\varepsilon_0 E^2$

I_B (intensity due to magnetic field)$= \frac{cB^2}{2\mu_0}$

$$\frac{I_E}{I_B} = \frac{\frac{1}{2c\varepsilon_0 E^2}}{\frac{cB^2}{2\mu_0}} = (\varepsilon_0\mu_0)\left(\frac{E}{B}\right)^2 = \left(\frac{1}{c^2}\right)(c^2) = 1$$

$$\Rightarrow \quad I_E = I_B = 4I_0$$

$$\left(as\ c = \frac{1}{\sqrt{\varepsilon_0\mu_0}}\ andE\ /B = c\right)$$

22. (c)

23. (a)

24 (a)

UV-radiation is absorbed by ordinary glass.

25. (a)

Energy of EM waves is of the order of 15 keV

i.e., $E = hv = h \times \frac{c}{\lambda}$

$\Rightarrow \quad \lambda = \frac{h \times c}{E} = \frac{6.624\times10^{-34}\times3\times10^{18}}{15\times10^{3}\times1.6\times10^{-19}}$

$= \frac{1.3248\times10^{-29}}{1.6\times10^{-19}} = 0.828 \times 10^{-10}\text{m}$

$\lambda = 0.828\,\text{Å} \quad (\therefore 1\,\text{Å} = 10^{-10}m)$

This spectrum is a part of X - rays.

26. (b)

The incident electromagnetic wave is,

$E = E_0\hat{\imath}cos(kz - \omega t)$

The reflected electromagnetic wave is given by

$E_r = E_0(\hat{\imath})cos[k(-z) - \omega t + \pi]$

$= -E_0\hat{\imath}\,cos[-(kz + \omega t) + \pi]$

$= E_0\hat{\imath}cos[-(kz + \omega t) = E_{0i}\hat{\imath}cos(kz + \omega t)]$

27. (b)

Given, energy flux $\phi = 20Wcm^{-2}$

$A = 30cm^2, t = 30\,min = 30 \times 60\,s$

total energy falling on the surface in time t is,

$U = \phi At = 20 \times 30 \times (30 \times 60)J$

Momentum of the incident light $= \frac{U}{c}$

$= \frac{20\times30\times(30\times60)J}{3\times10^8} = 36 \times 10^{-4}\,kg\text{-}ms^{-1}$

Momentum of the reflected light $= 0$

∴ Momentum delivered to the surface

$36 \times 10^{-4} - 0 = 36 \times 10^{-4}\,kg\text{-}ms^{-1}$

28. (c)

Intensity in terms of electric field, $U_{av} = \frac{1}{2}\varepsilon_0 E_0^2$

Now taking the intensity in terms of electric field.

$(U_{av})electric\ field = \frac{1}{2}\varepsilon_0 E_0^2 = \frac{1}{2}\varepsilon_0(cB_0)^2$

$(\therefore E_0 = cB_0)$

$= \frac{1}{2}\varepsilon_0 \times c^2{B_0}^2$

But, $\quad c = \frac{1}{\sqrt{\mu_0\varepsilon_0}}$

$\therefore (U_{av})\ eletric\ field = \frac{1}{2}\varepsilon_0 \times \frac{1}{\mu_0\varepsilon_0}B_0^2 = \frac{1B_0^2}{2\mu_0}$

$= (U_{av})$ magnetic field

Thus, the energy in electromagnetic wave is divided equally between electric field vector and magnetic field vector.

Therefore, the ratio of contributions by the electric field and magnetic field and magnetic field components to the intensity of an electromagnetic wave is 1 :1.

29. (d)

Electromagnetic wave, the electric field vector is given as,

$E = (E_1\hat{\imath} + E_2\hat{\jmath})\,cos(kz - \omega t)$

In electromagnetic wave, the associated magnetic field vector.

$B = \frac{E}{c} = \frac{E_1\hat{\imath}+E_2\hat{\jmath}}{c}\,cos(kz - \omega t)$

Also, E and **B** are perpendicular to each other and the propagation of electromagnetic wave is perpendicular to **E** as well as B, so the given electromagnetic wave is plane polarized.

30. (b)

Magnetic field $\quad B = B_0 \sin \omega t$

$B = 12 \times 10^{-8}\,sin(1.20 \times 10^7\,z - 3.60 \times 10^{15}\,t)T.$

On comparing this equation with standard equation, we get

$B_0 = 12 \times 10^{-8}$

The average intensity of the beam $I_{av} = \frac{1B_0^2}{2\mu_0}.c$

$= \frac{1}{2} \times \frac{(12\times10^{-8})^2\times3\times10^8}{4\pi\times10^{-7}} = 1.71\,W/m^2$