

Chapter Eight

ELECTROMAGNETIC WAVES



MCQ I

8.1 One requires 11eV of energy to dissociate a carbon monoxide molecule into carbon and oxygen atoms. The minimum frequency of the appropriate electromagnetic radiation to achieve the dissociation lies in

- (a) visible region.
- (b) infrared region.
- (c) ultraviolet region.
- (d) microwave region.

8.2 A linearly polarized electromagnetic wave given as $\mathbf{E} = E_o \hat{\mathbf{i}} \cos(kz - \omega t)$ 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) $\mathbf{E}_r = -E_o \hat{\mathbf{i}} \cos(kz - \omega t)$.
- (b) $\mathbf{E}_r = E_o \hat{\mathbf{i}} \cos(kz + \omega t)$.

 Exemplar Problems-Physics

- (c) $\mathbf{E}_r = -E_0 \hat{\mathbf{i}} \cos(kz + \omega t)$.
- (d) $\mathbf{E}_r = E_0 \hat{\mathbf{i}} \sin(kz - \omega t)$.
- 8.3** 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 30 cm^2 , the total momentum delivered (for complete absorption) during 30 minutes is
- (a) $36 \times 10^{-5} \text{ kg m/s}$.
 (b) $36 \times 10^{-4} \text{ kg m/s}$.
 (c) $108 \times 10^4 \text{ kg m/s}$.
 (d) $1.08 \times 10^7 \text{ kg m/s}$.
- 8.4** The electric field intensity produced by the radiations coming from 100 W bulb at a 3 m distance is E . The electric field intensity produced by the radiations coming from 50 W bulb at the same distance is
- (a) $\frac{E}{2}$.
 (b) $2E$.
 (c) $\frac{E}{\sqrt{2}}$.
 (d) $\sqrt{2}E$.
- 8.5** If $\mathbf{E}$ and $\mathbf{B}$ represent electric and magnetic field vectors of the electromagnetic wave, the direction of propagation of electromagnetic wave is along
- (a) $\mathbf{E}$.
 (b) $\mathbf{B}$.
 (c) $\mathbf{B} \times \mathbf{E}$.
 (d) $\mathbf{E} \times \mathbf{B}$.
- 8.6** 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) $\sqrt{c} : 1$
- 8.7** An EM wave radiates outwards from a dipole antenna, with E_0 as the amplitude of its electric field vector. The electric field E_0 which

transports significant energy from the source falls off as

- (a) $\frac{1}{r^3}$
- (b) $\frac{1}{r^2}$
- (c) $\frac{1}{r}$
- (d) remains constant.

MCQ II

8.8 An electromagnetic wave travels in vacuum along z direction: $\mathbf{E} = (E_1 \hat{\mathbf{i}} + E_2 \hat{\mathbf{j}}) \cos(kz - \omega t)$. Choose the correct options from the following:

(a) The associated magnetic field is given as

$$\mathbf{B} = \frac{1}{c} (E_1 \hat{\mathbf{i}} - E_2 \hat{\mathbf{j}}) \cos(kz - \omega t).$$

(b) The associated magnetic field is given as

$$\mathbf{B} = \frac{1}{c} (E_1 \hat{\mathbf{i}} + E_2 \hat{\mathbf{j}}) \cos(kz - \omega t).$$

(c) The given electromagnetic field is circularly polarised.

(d) The given electromagnetic wave is plane polarised.

8.9 An electromagnetic wave travelling along z-axis is given as: $\mathbf{E} = \mathbf{E}_0 \cos(kz - \omega t)$. Choose the correct options from the following:

(a) The associated magnetic field is given as $\mathbf{B} = \frac{1}{c} \hat{\mathbf{k}} \times \mathbf{E} = \frac{1}{\omega} (\hat{\mathbf{k}} \times \mathbf{E})$.

(b) The electromagnetic field can be written in terms of the associated magnetic field as $\mathbf{E} = c (\mathbf{B} \times \hat{\mathbf{k}})$.

(c) $\hat{\mathbf{k}} \cdot \mathbf{E} = 0, \hat{\mathbf{k}} \cdot \mathbf{B} = 0$.

(d) $\hat{\mathbf{k}} \times \mathbf{E} = 0, \hat{\mathbf{k}} \times \mathbf{B} = 0$.

8.10 A plane electromagnetic wave propagating along x direction can have the following pairs of $\mathbf{E}$ and $\mathbf{B}$

(a) E_x, B_y .

(b) E_y, B_z .

(c) B_x, E_y .

(d) E_z, B_y .

 Exemplar Problems-Physics

- 8.11** A charged particle oscillates about its mean equilibrium position with a frequency of 10^9 Hz. The electromagnetic waves produced:
- will have frequency of 10^9 Hz.
 - will have frequency of 2×10^9 Hz.
 - will have a wavelength of 0.3 m.
 - fall in the region of radiowaves.
- 8.12** The source of electromagnetic waves can be a charge
- moving with a constant velocity.
 - moving in a circular orbit.
 - at rest.
 - falling in an electric field.
- 8.13** An EM wave of intensity I falls on a surface kept in vacuum and exerts radiation pressure p on it. Which of the following are true?
- Radiation pressure is I/c if the wave is totally absorbed.
 - Radiation pressure is I/c if the wave is totally reflected.
 - Radiation pressure is $2I/c$ if the wave is totally reflected.
 - Radiation pressure is in the range $I/c < p < 2I/c$ for real surfaces.

VSA

- 8.14** Why is the orientation of the portable radio with respect to broadcasting station important?
- 8.15** Why does microwave oven heats up a food item containing water molecules most efficiently?
- 8.16** The charge on a parallel plate capacitor varies as $q = q_0 \cos 2\pi vt$. The plates are very large and close together (area = A , separation = d). Neglecting the edge effects, find the displacement current through the capacitor?
- 8.17** A variable frequency a.c source is connected to a capacitor. How will the displacement current change with decrease in frequency?
- 8.18** The magnetic field of a beam emerging from a filter facing a floodlight is given by
 $B_0 = 12 \times 10^{-8} \sin (1.20 \times 10^7 z - 3.60 \times 10^{15} t) \text{ T}$.
 What is the average intensity of the beam?
- 8.19** Poynting vectors $\mathbf{S}$ is defined as a vector whose magnitude is equal to the wave intensity and whose direction is along the direction of wave propagation. Mathematically, it is given by $\mathbf{S} = \frac{1}{\mu_0} \mathbf{E} \times \mathbf{B}$. Show the nature of S vs t graph.

- 8.20** Professor C.V Raman surprised his students by suspending freely a tiny light ball in a transparent vacuum chamber by shining a laser beam on it. Which property of EM waves was he exhibiting? Give one more example of this property.

SA

- 8.21** Show that the magnetic field B at a point in between the plates of a parallel-plate capacitor during charging is $\frac{\epsilon_0 \mu_r}{2} \frac{dE}{dt}$ (symbols having usual meaning).
- 8.22** Electromagnetic waves with wavelength
- (i) λ_1 is used in satellite communication.
 - (ii) λ_2 is used to kill germs in water purifiers.
 - (iii) λ_3 is used to detect leakage of oil in underground pipelines.
 - (iv) λ_4 is used to improve visibility in runways during fog and mist conditions.
- (a) Identify and name the part of electromagnetic spectrum to which these radiations belong.
 - (b) Arrange these wavelengths in ascending order of their magnitude.
 - (c) Write one more application of each.
- 8.23** Show that average value of radiant flux density 'S' over a single period 'T' is given by $S = \frac{1}{2c\mu_0} E_0^2$.
- 8.24** You are given a $2\mu\text{F}$ parallel plate capacitor. How would you establish an instantaneous displacement current of 1mA in the space between its plates?
- 8.25** Show that the radiation pressure exerted by an EM wave of intensity I on a surface kept in vacuum is I/c .
- 8.26** What happens to the intensity of light from a bulb if the distance from the bulb is doubled? As a laser beam travels across the length of a room, its intensity essentially remains constant.

Exemplar Problems-Physics

What geometrical characteristic of LASER beam is responsible for the constant intensity which is missing in the case of light from the bulb?

- 8.27** Even though an electric field $\mathbf{E}$ exerts a force $q\mathbf{E}$ on a charged particle yet the electric field of an EM wave does not contribute to the radiation pressure (but transfers energy). Explain.

LA

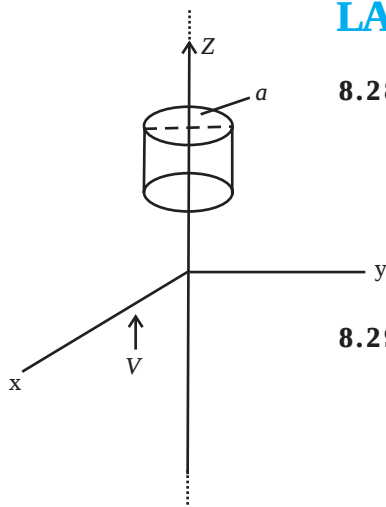


Fig. 8.1

- 8.28** An infinitely long thin wire carrying a uniform linear static charge density λ is placed along the z -axis (Fig. 8.1). The wire is set into motion along its length with a uniform velocity $\mathbf{v} = v \hat{\mathbf{k}}_z$. Calculate

the poynting vector $\mathbf{S} = \frac{1}{\mu_0} (\mathbf{E} \times \mathbf{B})$.

- 8.29** Sea water at frequency $\nu = 4 \times 10^8$ Hz has permittivity $\epsilon \approx 80 \epsilon_0$, permeability $\mu \approx \mu_0$ and resistivity $\rho = 0.25 \Omega\text{-m}$. Imagine a parallel plate capacitor immersed in sea water and driven by an alternating voltage source $V(t) = V_0 \sin(2\pi \nu t)$. What fraction of the conduction current density is the displacement current density?

- 8.30** A long straight cable of length l is placed symmetrically along z -axis and has radius a ($a \ll l$). The cable consists of a thin wire and a co-axial conducting tube. An alternating current $I(t) = I_0 \sin(2\pi \nu t)$ flows down the central thin wire and returns along the co-axial conducting tube. The induced electric field at a distance s from

the wire inside the cable is $\mathbf{E}(s, t) = \mu_0 I_0 \nu \cos(2\pi \nu t) \ln\left(\frac{s}{a}\right) \hat{\mathbf{k}}$.

- Calculate the displacement current density inside the cable.
- Integrate the displacement current density across the cross-section of the cable to find the total displacement current I^d .
- Compare the conduction current I_0 with the displacement current I_0^d .

- 8.31** A plane EM wave travelling in vacuum along z direction is given by $\mathbf{E} = E_0 \sin(kz - \omega t) \hat{\mathbf{i}}$ and $\mathbf{B} = B_0 \sin(kz - \omega t) \hat{\mathbf{j}}$.

- Evaluate $\oint \mathbf{E} \cdot d\mathbf{l}$ over the rectangular loop 1234 shown in Fig 8.2.
- Evaluate $\int \mathbf{B} \cdot d\mathbf{s}$ over the surface bounded by loop 1234.

(iii) Use equation $\oint \mathbf{E} \cdot d\mathbf{l} = \frac{-d\phi_B}{dt}$ to prove $\frac{E_0}{B_0} = c$.

(iv) By using similar process and the equation

$$\oint \mathbf{B} \cdot d\mathbf{l} = \mu_0 I + \varepsilon_0 \frac{d\phi_E}{dt}, \text{ prove that } c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}$$

8.32 A plane EM wave travelling along z direction is described by $\mathbf{E} = E_0 \sin(kz - \omega t)\hat{\mathbf{i}}$ and $\mathbf{B} = B_0 \sin(kz - \omega t)\hat{\mathbf{j}}$. Show that

(i) The average energy density of the wave is given by

$$u_{av} = \frac{1}{4} \varepsilon_0 E_0^2 + \frac{1}{4} \frac{B_0^2}{\mu_0}.$$

(ii) The time averaged intensity of the wave is given by

$$I_{av} = \frac{1}{2} c \varepsilon_0 E_0^2.$$

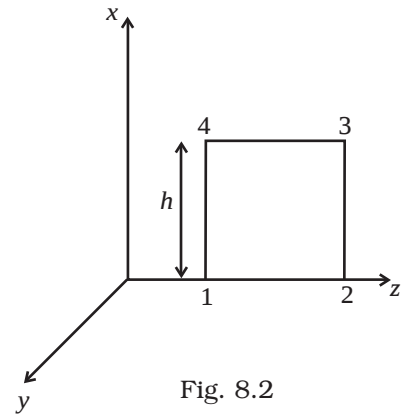


Fig. 8.2