Electromagnetic Waves

Case Study Based Questions

Case Study 1

The spectrum of electromagnetic radiation contains a part known as microwaves. These waves have frequency and energy smaller than visible light and wavelength larger than it.

All food items such as fruits, vegetables, meat, cereals, etc., contain water as a constituent. Now, what does it mean when we say that a certain object has become warmer? When the temperature of a body rises, the energy of the random motion of atoms and molecules increases and the molecules travel or vibrate or rotate with higher energies. The frequency of rotation of water molecules is about 300 crore hertz, which is 3 gigahertz (GHz). If water receives microwaves of this frequency, its molecules absorb this radiation, which is equivalent to heating up water. These molecules share this energy with neighbouring food molecules, heating up the food.

One should use porcelain vessels and not metal containers in a microwave oven because of the danger of getting a shock from accumulated electric charges. Metals may also melt from heating. The porcelain container remains unaffected and cool, because its large molecules vibrate and rotate with much smaller frequencies, and thus cannot absorb microwaves. Hence, they do not get heated up.

Thus, the basic principle of a microwave oven is to generate microwave radiation of appropriate frequency in the working space of the oven where we keep food. This way energy is not wasted in heating up the vessel. In the conventional heating method, the vessel on the burner gets heated first, and then the food inside gets heated because of transfer of energy from the vessel. In the microwave oven, on the other hand, energy is directly delivered to water molecules which is shared by the entire food.

Read the given passage carefully and give the answer of the following questions:

Q1. Which of the following electromagnetic radiations have the longest wavelength?

a. X-rays b. γ-rays

c. Microwaves d. Radio waves

Q2. Why does a microwave oven heat up a food item containing water molecules most efficiently?

a. Microwaves are heat waves, so always produce heat.

b. Infrared waves produce heating in a microwave oven.

c. Energy from the microwaves is transferred efficiently to the kinetic energy of water

molecules at their resonant frequency.

d. The frequency of microwaves has no relation with natural frequency of water molecules.

Q3. Microwaves are:

a. transverse electromagnetic waves

b. longitudinal electromagnetic waves

c. stationary waves

d. None of the above

Q4. Microwaves are used in:

a. RADAR system for aircraft navigation

b. long-distance communication systems via geostationary satellites

c. microwave ovens

d. All of the above

Solutions

1. (d) Radio waves

2. (c) Energy from the microwaves is transferred efficiently to the kinetic energy of water molecules at their resonant frequency.

3. (a) transverse electromagnetic waves

4. (d) All of the above

Case Study 2

A major report on mobile phones and health advises limits of their use by children, the BBC understands.

While the Stewart Report has found no clear evidence that mobiles can damage the health of either adults or children, scientists suggest that there may be some effect on the human body.

Children may be advised to cut phone use

And it recommends that mobile phone companies should not aim their advertising at children. The report was commissioned in response to fears that mobile use could be linked to memory loss, and even Alzheimer's disease.

Some studies have suggested that children are more vulnerable to the effects of microwave radiation emissions because their nervous systems are not fully developed and their skull is thinner than adults, providing less protection.

"A growing number of children have access to mobile phones, and they are a great source of comfort and security for parents, knowing they can find out where their children are and can keep in touch with them."

The radiation emitted by mobile phones is not X-ray radiation, but microwave radiation, and some scientists were concerned that it might actually be heating and damaging brain cells because the phone is held so close to the head.

Read the given passage carefully and give the answer of the following questions:

Q1. What type of electromagnetic waves do mobile phones emit?

a. Heat waves b. X-rays

c. UV rays d. Microwaves

Q2. Why are mobile phones more likely to cause damage to young people's brain cells?

a. Because they don't know, how to use mobile phones properly

b. Because they use mobile phones for longer time

c. Because their nervous system is not fully developed and their skull is thinner than adults.

d. Because mobile phone causes memory loss in young people

Q3. Which of the following are fundamentally different from the others?

a. Gamma rays   b. Microwaves

c. Sound waves   d. Light waves

Q4. The main difference between microwaves and light waves is:

a. speed   b. wavelength

c. nature   d. None of these

Solutions

1. (d) Microwaves

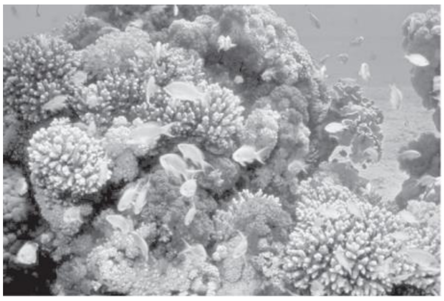
2. (c) Because their nervous system is not fully developed and their skull is thinner than adults.

3. (c) Sound waves

4. (b) wavelength

Case Study 3

The beauty of a coral reef, the warm radiance of sunshine, the sting of sunburn, the X-ray revealing a broken bone, even microwave popcorn, all are brought to us by electromagnetic waves.



It is worth noting at the outset that the general phenomenon of electromagnetic waves was predicted by theory before it was realised that light is a form of electromagnetic wave. The prediction was made by James Clerk Maxwell in the mid-19th century when he formulated a single theory combining all the electric and magnetic effects known by scientists at that time.

"Electromagnetic waves" was the name he gave to the phenomena he predicted.

An electromagnetic wave has a frequency 'ν' and a wavelength 'λ' associated with it and travels at the speed of light 'c'. The relationship among these wave characteristics is

$$c = \nu\lambda.$$

Thus, for all electromagnetic waves, the greater the frequency, the smaller the wavelength. Electromagnetic waves are classified into categories such as radio waves, infrared rays, ultraviolet rays, and so on, so that we can understand some of their similarities as well as some of their differences.

Read the given passage carefully and give the answer of the following questions:

Q1. Which of the following electromagnetic radiations have the shortest wavelength?

a. X-rays b. β-rays

c. Microwaves d. Gamma rays

Q2. If a source is transmitting electromagnetic waves of frequency 8.2×10^6 Hz, the wavelength of electromagnetic wave transmitted from the source is:

a. 36.5 m b. 18.8 m

c. 42.8 m d. 58 m

Q3. Light can travel in vacuum due to its:

a. transverse nature b. electromagnetic nature

c. longitudinal nature d. Both a. and c.

Q4. We consider the radiation emitted by the human body. Which one of the following statements is true?

a. The radiation emitted is in the infrared region

b. The radiation emitted only during the day

c. The radiation is emitted during the summers and absorbed during winters

d. The radiation emitted lies in the ultraviolet region and hence is not visible

Solutions

1. (d) Gamma rays
2. (a) 36.5 m

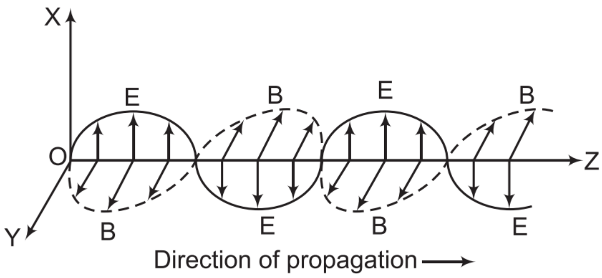
   Given, frequency, $\nu = 8.2 \times 10^6$ Hz

   Wavelength, $\lambda = \frac{c}{\nu} = \frac{3 \times 10^8}{8.2 \times 10^6}$

   $= 36.5$ m
3. (b) electromagnetic nature
4. (a) The radiation emitted is in the infrared region

Case Study 4

A stationary charge produces only an electrostatic field while a charge in uniform motion produces a magnetic field, that does not change with time. An oscillating charge is an example of accelerating charge. It produces an oscillating magnetic field, which in turn produces an oscillating electric fields and so on. The oscillating electric and magnetic fields regenerate each other as a wave which propagates through space.



Read the given passage carefully and give the answer of the following questions:

Q 1. Magnetic field in a plane electromagnetic wave is given by $\vec{B} = B_0 \sin(kx + \omega t)\hat{j}$ T. What will be the expression for corresponding electric field?

Q 2. The electric field component of monochromatic radiation is given by $\vec{E} = 2E_0\, k \sin kz \cdot \cos \omega t$. What will be its magnetic field component?

Q 3. A plane electromagnetic wave of frequency 25 MHz travels in a free space along X-direction. At a particular point in space and time, $E = (6.3\,\hat{j})$ V/m. What is magnetic field at that time?

Q 4. A plane electromagnetic wave travelling along the *X*-direction has a wavelength of 3 mm. The variation in the electric field occurs in the *Y*-direction with an amplitude 66 V m^{-1}. Write the equations for the electric and magnetic fields as a function of *x* and *t*.

Solutions

1. Given, $\vec{\mathrm{B}} = B_0 \sin(kx + \omega t)\hat{\mathrm{j}}\,\mathrm{T}$

The relation between electric and magnetic fields is,

$C = \dfrac{E}{B}$ or $E = cB$

The electric field component is perpendicular to the direction of propagation and the direction of magnetic field. Therefore, the electric field component along *Z*-axis is obtained as $\vec{E} = cB_0 \sin(kx + \omega t)\,\hat{k}\,\mathrm{kV/m}$.

2. Since, $\dfrac{dE}{dz} = -\dfrac{dB}{dt}$

$$\frac{dE}{dz} = -2E_0 k \sin kz \cos \omega t = -\frac{dB}{dt}$$

$$dB = +2\,E_0 k \sin kz \cos \omega t\, dt$$

$$\mathrm{B} = +2E_0 k \sin kz \int \cos \omega t\, dt = +2\,E_0 \frac{k}{\omega} \sin kz \sin \omega t$$

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

$$\therefore \quad B = \frac{2E_0}{c} \sin kz \sin \omega t$$

Thus, magnetic field component,

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

3. Given, $E = 6.3\ \hat{\mathrm{j}}\ \mathrm{V/m}$, $c = 3 \times 10^8\ \mathrm{m/s}$

The magnitude of magnetic field,

$$B_z = \frac{E}{c} = \frac{6.3}{3 \times 10^8} = 2.1 \times 10^{-8}\ \mathrm{T} = 0.021\,\mu\mathrm{T}$$

4. Given, $E_0 = 66\ \mathrm{Vm}^{-1}$, $E_y = 66 \cos \omega \left(t - \frac{x}{c}\right)$,

$$\lambda = 3\ \mathrm{mm} = 3 \times 10^{-3}\ \mathrm{m},\ k = \frac{2\pi}{\lambda}$$

$$\frac{\omega}{k} = c \Rightarrow \omega = ck = 3 \times 10^{8} \times \frac{2\pi}{3 \times 10^{-3}}$$

$$\text{or} \quad \omega = 2\pi \times 10^{11}\ \mathrm{rad/s}$$

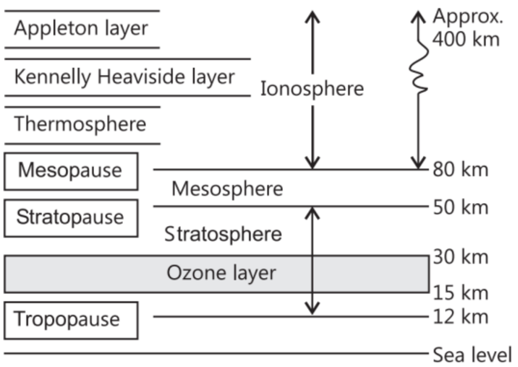
$$\therefore \quad E_y = 66 \cos 2\pi \times 10^{11} \left(t - \frac{x}{c}\right)$$

$$B_z = \frac{E_y}{c} = \left(\frac{66}{3 \times 10^{8}}\right) \cos 2\pi \times 10^{11} \left(t - \frac{x}{c}\right)$$

$$= 2.2 \times 10^{-7} \cos 2\pi \times 10^{11} \left(t - \frac{x}{c}\right)$$

Case Study 5

Radio waves are produced by the accelerated motion of charges in conducting wires. Microwaves are produced by special vacuum tubes. Infrared waves are produced by hot bodies and molecules and also known as heat waves. UV rays are produced by special lamps and very hot bodies like sun.



Read the given passage carefully and give the answer of the following questions:

Q1. What is the cause of greenhouse effect?

Q2. Ozone is present in which layer?

Q3. What is the biological importance of ozone layer?

Q4. Earth's atmosphere is richest in which radiation?

Solutions

1. Greenhouse effect is due to infrared rays.

2. Ozone lies in stratosphere.

3. Ozone layer absorbs the harmful ultraviolet radiations coming from the sun.

4. Earth's atmosphere is richest in infrared radiations.

The earth emits huge amount of infrared radiation and thereby makes the atmosphere richest in infrared rays.

Solutions for Questions 6 to 12 are Given Below

Case Study 6

Directions of Electromagnetic Waves

In an electromagnetic wave both the electric and magnetic fields are perpendicular to the direction of propagation, that is why electromagnetic waves are transverse in nature. Electromagnetic waves carry energy as they travel through space and this energy is shared equally by the electric and magnetic fields. Energy density of an electromagnetic waves is the energy in unit volume of the space through which the wave travels.

(i) The electromagnetic waves propagated perpendicular to both $\vec{E}$ and $\vec{B}$. The electromagnetic waves travel in the direction of

(a) $\vec{E} \cdot \vec{B}$ (b) $\vec{E} \times \vec{B}$

(c) $\vec{B} \cdot \vec{E}$ (d) $\vec{B} \times \vec{E}$

(ii) Fundamental particle in an electromagnetic wave is

(a) photon (b) electron

(c) phonon (d) proton

(iii) Electromagnetic waves are transverse in nature is evident by

(a) polarisation (b) interference

(c) reflection (d) diffraction

(iv) For a wave propagating in a medium, identify the property that is independent of the others.

(a) velocity (b) wavelength

(c) frequency (d) all these depend on each other

(v) The electric and magnetic fields of an electromagnetic waves are

(a) in opposite phase and perpendicular to each other

(b) in opposite phase and parallel to each other

(c) in phase and perpendicular to each other

(d) in phase and parallel to each other.

Case Study 7

Speed of Electromagnetic Wave

Maxwell showed that the speed of an electromagnetic wave depends on the permeability and permittivity of the medium through which it travels. The speed of an electromagnetic wave in free space is given by $c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}$. The fact led Maxwell to predict that light is an electromagnetic wave. The emergence of the speed of light from purely electromagnetic considerations is the crowning achievement of Maxwell's electromagnetic theory. The speed of an electromagnetic wave in any medium of permeability μ and permittivity ε will be $\frac{c}{\sqrt{K\mu_r}}$ where K is the dielectric constant of the medium and μ_r is the relative permeability.

(i) The dimensions of $\frac{1}{2}\varepsilon_0 E^2$ (ε_0 : permittivity of free space; E = electric field) is

(a) MLT^{-1} (b) ML^2T^{-2} (c) $ML^{-1}T^{-2}$ (d) ML^2T^{-1}

(ii) Let $[\varepsilon_0]$ denote the dimensional formula of the permittivity of the vacuum. If M = mass, L = length, T = time and A = electric current, then

(a) $[\varepsilon_0] = M^{-1}L^{-3}T^2A$ (b) $[\varepsilon_0] = M^{-1}L^{-3}T^4A^2$

(c) $[\varepsilon_0] = MLT^{-2}A^{-2}$ (d) $[\varepsilon_0] = ML^2T^{-1}$

(iii) An electromagnetic wave of frequency 3 MHz passes from vacuum into a dielectric medium with permittivity $\varepsilon = 4$. Then

(a) wavelength and frequency both remain unchanged
(b) wavelength is doubled and the frequency remains unchanged
(c) wavelength is doubled and the frequency becomes half
(d) wavelength is halved and the frequency remains unchanged.

(iv) Which of the following are not electromagnetic waves?

(a) cosmic rays (b) γ-rays (c) β-rays (d) X-rays

(v) The electromagnetic waves travel with

(a) the same speed in all media
(b) the speed of light $c = 3 \times 10^8$ m s^{-1} in free space
(c) the speed of light $c = 3 \times 10^8$ m s^{-1} in solid medium
(d) the speed of light $c = 3 \times 10^8$ m s^{-1} in fluid medium.

Case Study 8

Momentum and Pressure of an Electromagnetic Wave

An electromagnetic wave transports linear momentum as it travels through space. If an electromagnetic wave transfers a total energy U to a surface in time t, then total linear momentum delivered to the surface is $p = \frac{U}{c}$. When an electromagnetic wave falls on a surface, it exerts pressure on the surface. In 1903, the American scientists Nichols and Hull succeeded in measuring radiation pressures of visible light where other had failed, by making a detailed empirical analysis of the ubiquitous gas heating and ballistic effects.

(i) The pressure exerted by an electromagnetic wave of intensity I (W m^{-2}) on a non-reflecting surface is (c is the velocity of light)

(a) Ic (b) Ic^2 (c) I/c (d) I/c^2

(ii) Light with an energy flux of 18 W/cm^2 falls on a non-reflecting surface at normal incidence. The pressure exerted on the surface is

(a) 2 N/m^2 (b) 2×10^{-4} N/m^2
(c) 6 N/m^2 (d) 6×10^{-4} N/m^2

(iii) Radiation of intensity 0.5 W m^{-2} are striking a metal plate. The pressure on the plate is

(a) 0.166×10^{-8} N m^{-2} (b) 0.212×10^{-8} N m^{-2}
(c) 0.132×10^{-8} N m^{-2} (d) 0.083×10^{-8} N m^{-2}

(iv) A point source of electromagnetic radiation has an average power output of 1500 W. The maximum value of electric field at a distance of 3 m from this source (in V m^{-1}) is

(a) 500 (b) 100 (c) $\frac{500}{3}$ (d) $\frac{250}{3}$

(v) The radiation pressure of the visible light is of the order of

(a) 10^{-2} N m^2 (b) 10^{-4} N/m (c) 10^{-6} N/m^2 (d) 10^{-8} N

Case Study 9

Electromagnetic Spectrum

All the known radiations from a big family of electromagnetic waves which stretch over a large range of wavelengths. Electromagnetic wave include radio waves, microwaves, visible light waves, infrared rays, UV rays, X-rays and gamma rays. The orderly distribution of the electromagnetic waves in accordance with their wavelength or frequency into distinct groups having widely differing properties is electromagnetic spectrum.

(i) Which wavelength of the Sun is used finally as electric energy?

(a) radio waves (b) infrared waves
(c) visible light (d) microwaves

(ii) Which of the following electromagnetic radiations have the longest wavelength?

(a) X-rays (b) γ-rays
(c) microwaves (d) radiowaves

(iii) Which one of the following is not electromagnetic in nature?

(a) X-rays (b) gamma rays
(c) cathode rays (d) infrared rays

(iv) Which of the following has minimum wavelength ?

(a) X-rays (b) ultraviolet rays
(c) γ-rays (d) cosmic rays

(v) The decreasing order of wavelength of infrared, microwave, ultraviolet and gamma rays is

(a) microwave, infrared, ultraviolet, gamma rays
(b) gamma rays, ultraviolet, infrared, microwave
(c) microwave, gamma rays, infrared, ultraviolet
(d) infrared, microwave, ultraviolet, gamma rays.

Case Study 10

Radiations by Electromagnetic Waves

Electrons oscillating in a circuit give rise to radiowaves. A transmitting antenna radiates most effectively the radiowaves of wavelength equal to the size of the antenna. The infrared waves incident on a substance set into oscillation all its electrons, atoms and molecules. This increases the internal energy and hence the temperature of the substance.

(i) If v_g, v_X and v_m are the speeds of gamma rays, X-rays and microwaves respectively in vacuum, then

(a) $v_g > v_X > v_m$ (b) $v_g < v_X < v_m$ (c) $v_g > v_X > v_m$ (d) $v_g = v_X = v_m$

(ii) Which of the following will deflect in electric field?

(a) X-rays (b) γ-rays (c) cathode rays (d) ultraviolet rays

(iii) γ-rays are detected by

(a) point contact diodes (b) thermopiles (c) ionization chamber (d) photocells

(iv) The frequency of electromagnetic wave, which best suited to observe a particle of radius 3×10^{-4} cm is the order of

(a) 10^{15} Hz (b) 10^{14} Hz (c) 10^{13} Hz (d) 10^{12} Hz

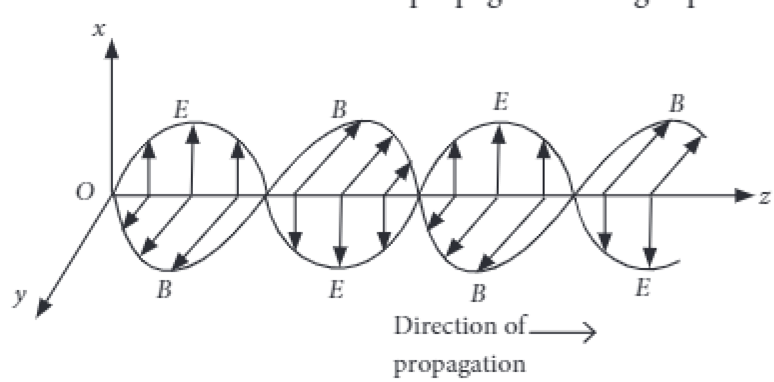
(v) We consider the radiation emitted by the human body. Which one of the following statements is true?

(a) The radiation emitted is in the infrared region.
(b) The radiation is emitted only during the day.
(c) The radiation is emitted during the summers and absorbed during the winters.
(d) The radiation emitted lies in the ultraviolet region and hence it is not visible.

Case Study 11

Oscillating Charge

A stationary charge produces only an electrostatic field while a charge in uniform motion produces a magnetic field, that does not change with time. An oscillating charge is an example of accelerating charge. It produces an oscillating magnetic field, which in turn produces an oscillating electric fields and so on. The oscillating electric and magnetic fields regenerate each other as a wave which propagates through space.



(i) 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.)

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

(ii) 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

(a) $\frac{2E_0}{c}\hat{j} \cos kz \cos \omega t$ (b) $\frac{2E_0}{c}\hat{j} \sin kz \cos \omega t$ (c) $\frac{2E_0}{c}\hat{j} \sin kz \sin \omega t$ (d) $-\frac{2E_0}{c}\hat{j} \sin kz \sin \omega t$

(iii) A plane em wave of frequency 25 MHz travels in a free space along x-direction. At a particular point in space and time, $E = (6.3\ \hat{j})$ V/m. What is magnetic field at that time?

(a) 0.095 μT (b) 0.124 μT (c) 0.089 μT (d) 0.021 μT

(iv) A plane electromagnetic wave travelling along the x-direction has a wavelength of 3 mm. The variation in the electric field occurs in the y-direction with an amplitude 66 V m^{-1}. The equations for the electric and magnetic fields as a function of x and t are respectively

(a) $E_y = 33 \cos \pi \times 10^{11}\left(t - \frac{x}{c}\right)$, $B_z = 1.1 \times 10^{-7} \cos \pi \times 10^{11}\left(t - \frac{x}{c}\right)$

(b) $E_y = 11 \cos 2\pi \times 10^{11}\left(t - \frac{x}{c}\right)$, $B_y = 11 \times 10^{-7} \cos 2\pi \times 10^{11}\left(t - \frac{x}{c}\right)$

(c) $E_x = 33 \cos \pi \times 10^{11}\left(t - \frac{x}{c}\right)$, $B_x = 11 \times 10^{-7} \cos \pi \times 10^{11}\left(t - \frac{x}{c}\right)$

(d) $E_y = 66 \cos 2\pi \times 10^{11}\left(t - \frac{x}{c}\right)$, $B_z = 2.2 \times 10^{-7} \cos 2\pi \times 10^{11}\left(t - \frac{x}{c}\right)$

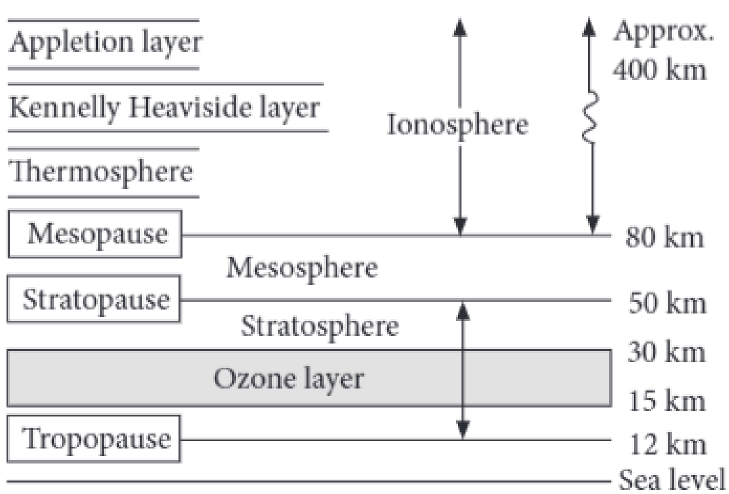
(v) A plane electromagnetic wave travels in free space along x-axis. At a particular point in space, the electric field along y-axis is 9.3 V m^{-1}. The magnetic induction (B) along z-axis is

(a) 3.1×10^{-8} T (b) 3×10^{-5} T (c) 3×10^{-6} T (d) 9.3×10^{-6} T

Case Study 12

Sources of Electromagnetic Waves

Radio waves are produced by the accelerated motion of charges in conducting wires. Microwaves are produced by special vacuum tubes. Infrared waves are produced by hot bodies and molecules also known as heat waves. UV rays are produced by special lamps and very hot bodies like Sun.



(i) Solar radiation is
   (a) transverse electromagnetic wave
   (b) longitudinal electromagnetic waves
   (c) both longitudinal and transverse electromagnetic waves
   (d) none of these.

(ii) What is the cause of greenhouse effect?
   (a) Infrared rays (b) Ultraviolet rays (c) X-rays (d) Radiowaves

(iii) Biological importance of ozone layer is
   (a) it stops ultraviolet rays (b) It layer reduces greenhouse effect
   (c) it reflects radiowaves (d) none of these.

(iv) Ozone is found in
   (a) stratosphere (b) ionosphere (c) mesosphere (d) troposphere

(v) Earth's atmosphere is richest in
   (a) ultraviolet (b) infrared (c) X-rays (d) microwaves

HINTS & EXPLANATIONS

6. **(i) (b):** Electromagnetic waves propagate in the direction of $\vec{E}\times\vec{B}$.

(ii) (a): Photon is the fundamental particle in an electromagnetic wave.

(iii) (a): Polarisation establishes the wave nature of electromagnetic waves.

(iv) (c): Frequency υ remains unchanged when a wave propagates from one medium to another. Both wavelength and velocity get changed.

(v) (c): The electric and magnetic fields of an electromagnetic wave are in phase and perpendicular to each other.

7. **(i) (c):** $\frac{1}{2}\varepsilon_0 E^2 = \text{energy density} = \frac{\text{Energy}}{\text{Volume}}$

$$\therefore \left[\frac{1}{2}\varepsilon_0 E^2\right] = \frac{\text{ML}^2\text{T}^{-2}}{\text{L}^3} = [\text{ML}^{-1}\text{T}^{-2}]$$

(ii) (b): As $\varepsilon_0 = \frac{q_1 q_2}{4\pi F R^2}$ (from Coulomb's law)

$$\varepsilon_0 = \frac{\text{C}^2}{\text{Nm}^2}\ \frac{[\text{AT}]^2}{\text{MLT}^{-2}\text{L}^2} = \text{M}^{-1}\text{L}^{-3}\text{T}^4\text{A}^2$$

(iii) (d): The frequency of the electromagnetic wave remains same when it passes from one medium to another.

Refractive index of the medium, $n = \sqrt{\frac{\varepsilon}{\varepsilon_0}} = \sqrt{\frac{4}{1}} = 2$

Wavelength of the electromagnetic wave in the medium,

$$\lambda_{\text{med}} = \frac{\lambda}{n} = \frac{\lambda}{2}$$

(iv) (b): β-rays consists of electrons which are not electromagnetic in nature.

(v) (b): The velocity of electromagnetic waves in free space (vacuum) is equal to velocity of light in vacuum (*i.e.*, 3×10^8 m s^{-1}).

8. **(i) (c):** Pressure exerted by an electromagnetic radiation, $P = \frac{I}{c}$

(ii) (d): $P_{\text{rad}} = \frac{\text{Energy flux}}{\text{Speed of light}} = \frac{18\ \text{W/cm}^2}{3\times10^8\ \text{m/s}}$

$$= \frac{18\times10^4\ \text{W/m}^2}{3\times10^8\ \text{m/s}} = 6\times10^{-4}\ \text{N/m}^2$$

(iii) (a): $P = \frac{I}{c} = \frac{0.5}{3\times10^8} = 0.166\times10^{-8}\ \text{N m}^{-2}$

(iv) (b): Intensity of EM wave is given by $I = \frac{P}{4\pi R^2}$

$$V_{av} = \frac{1}{2}\varepsilon_0 E_0^2 \times c$$

$$\Rightarrow E_0 = \sqrt{\frac{P}{2\pi R^2 \varepsilon_0 c}} = \sqrt{\frac{1500}{2\times3.14(3)^2\times8.85\times10^{-12}\times3\times10^8}}$$

$$= \sqrt{10,000} = 100\ \text{V m}^{-1}$$

(v) (c) : The radiation pressure of visible light
$= 7 \times 10^{-6}$ N/m^2

9. (i) (b): Infrared rays can be converted into electric energy as in solar cell.

(ii) (d): Radiowaves have longest wavelength.

(iii) (c) : Cathode rays are invisible fast moving streams of electrons emitted by the cathode of a discharge tube which is maintained at a pressure of about 0.01 mm of mercury.

(iv) (c) : γ-rays have minimum wavelength.

(v) (a): $\lambda_{micro} > \lambda_{infra} > \lambda_{ultra} > \lambda_{gamma}$

10. (i) (d): All electromagnetic waves travel in vacuum with the same speed.

(ii) (c) : Cathode rays (beam of electrons) get deflected in an electric field.

(iii) (c) : γ-rays are detected by ionization chamber.

(iv) (b): Size of particle $= \lambda = \dfrac{c}{\upsilon}$

$$\upsilon = \frac{c}{\lambda} = \frac{3\times10^{10} \text{ cm s}^{-1}}{3\times10^{-4} \text{ cm}} = 3\times10^{14} \text{ Hz}$$

(v) (a): Every body at a temperature $T > 0$ K emits radiation in the infrared region.

11. (i) (d): Given : $\vec{B} = B_0 \sin(kx + \omega t)\hat{j}$ T

The relation between electric and magnetic field is,

$c = \dfrac{E}{B}$ or $E = cB$

The electric field component is perpendicular to the direction of propagation and the direction of magnetic field. Therefore, the electric field component along z-axis is obtained as $\vec{E} = cB_0 \sin(kx + \omega t)\hat{k}$ V/m

(ii) (c) : $\dfrac{dE}{dz} = -\dfrac{dB}{dt}$

$$\frac{dE}{dz} = -2E_0 k \sin kz \cos\omega t = -\frac{dB}{dt}$$

$$dB = +2E_0 k \sin kz \cos\omega t\, dt$$

$$B = +2E_0 k \sin kz \int \cos\omega t\, dt = +2E_0 \frac{k}{\omega} \sin kz \sin\omega t$$

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

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

E is along y-direction and the wave propagates along x-axis.

$\therefore$ B should be in a direction perpendicular to both x-and y-axis.

(iii) (d): Here, $E = 6.3\hat{j}$; $c = 3 \times 10^8$ m/s

The magnitude of B is

$$B_z = \frac{E}{c} = \frac{6.3}{3\times10^8} = 2.1\times10^{-8} \text{ T} = 0.021\ \mu\text{T}$$

(iv) (d): Here : $E_0 = 66$ V m^{-1}, $E_y = 66 \cos \omega(t - \dfrac{x}{c})$,

$\lambda = 3$ mm $= 3 \times 10^{-3}$ m, $k = \dfrac{2\pi}{\lambda}$

$$\frac{\omega}{k} = c \Rightarrow \omega = ck = 3 \times 10^8 \times \frac{2\pi}{3\times10^{-3}}$$

or $\omega = 2\pi \times 10^{11}$

$$\therefore \quad E_y = 66 \cos 2\pi \times 10^{11}(t - \frac{x}{c})$$

$$B_z = \frac{E_y}{c} = \left(\frac{66}{3\times10^8}\right)\cos 2\pi\times10^{11}\left(t - \frac{x}{c}\right)$$

$$= 2.2 \times10^{-7} \cos 2\pi \times 10^{11} (t - \frac{x}{c})$$

(v) (a): At a particular point, $E = 9.3$ V m^{-1}

$\therefore$ Magnetic field at the same point $= \dfrac{9.3}{3\times10^8}$
$= 3.1 \times 10^{-8}$ T

12. (i) (a)

(ii) (a): Greenhouse effect is due to infrared rays.

(iii) (a): Ozone layer absorbs the harmful ultraviolet radiations coming from the sun.

(iv) (a): Ozone layer lies in stratosphere.

(v) (b): The atmosphere of earth is richest in infrared radiation.