CHAPTER - 8
ELECTROMAGNETIC WAVES - ADDITIONAL EXER-CISE SOLUTIONS

Question 8.11:

Suppose that the electric field part of an electromagnetic wave in vacuum is E = {(3.1 N/C) cos [(1.8 rad/m) y + (5.4 × 10^6 rad/s)t]} $\hat{i}$.

(a) What is the direction of propagation?

(b) What is the wavelength λ?

(c) What is the frequency v?

(d) What is the amplitude of the magnetic field part of the wave?

(e) Write an expression for the magnetic field part of the wave.

Answer

(a) From the given electric field vector, it can be inferred that the electric field is directed along the negative x direction. Hence, the direction of motion is along the negative y direction i.e., $-\hat{j}$.

(b) It is given that,

$$\vec{E} = 3.1\ \text{N/C} \cos\left[(1.8\ \text{rad/m})y + (5.4\times10^{8}\ \text{rad/s})t\right]\hat{i} \qquad ...(1)$$

The general equation for the electric field vector in the positive x direction can be written as:

$$\vec{E} = E_0 \sin(kx - \omega t)\ \hat{i} \qquad ...(2)$$

On comparing equations (1) and (2), we get

Electric field amplitude, E_0 = 3.1 N/C

Angular frequency, ω = 5.4 × 10^8 rad/s

Wave number, k = 1.8 rad/m

Wavelength, $\lambda = \frac{2\pi}{1.8}$ = 3.490 m

(c) Frequency of wave is given as:

$$\nu = \frac{\omega}{2\pi}$$

$$= \frac{5.4\times10^8}{2\pi} = 8.6\times10^7 \text{ Hz}$$

(d) Magnetic field strength is given as:

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

Where,

c = Speed of light = 3 × 10^8 m/s

$$\therefore B_0 = \frac{3.1}{3\times10^8} = 1.03\times10^{-7} \text{ T}$$

(e) On observing the given vector field, it can be observed that the magnetic field vector is directed along the negative z direction. Hence, the general equation for the magnetic field vector is written as:

$$\vec{B} = B_0 \cos(ky+\omega t)\,\hat{k}$$

$$= \left\{\left(1.03\times10^{-7}\text{ T}\right)\cos\left[\left(1.8\text{ rad/m}\right)y+\left(5.4\times10^6\text{ rad/s}\right)t\right]\right\}\hat{k}$$

Question 8.12:

About 5% of the power of a 100 W light bulb is converted to visible radiation. What is the average intensity of visible radiation (a) at a distance of 1 m from the bulb?

(b) at a distance of 10 m?

Assume that the radiation is emitted isotropically and neglect reflection.

Answer

Power rating of bulb, P = 100 W

It is given that about 5% of its power is converted into visible radiation.

∴ Power of visible radiation,

$$P' = \frac{5}{100}\times100 = 5 \text{ W}$$

Hence, the power of visible radiation is 5W.

(a) Distance of a point from the bulb, d = 1 m

Hence, intensity of radiation at that point is given as:

$$I = \frac{P'}{4\pi d^2}$$
$$= \frac{5}{4\pi (1)^2} = 0.398 \text{ W / m}^2$$

(b) Distance of a point from the bulb, d_1 = 10 m

Hence, intensity of radiation at that point is given as:

$$I = \frac{P'}{4\pi (d_1)^2}$$
$$= \frac{5}{4\pi (10)^2} = 0.00398 \text{ W/m}^2$$

Question 8.13:

Use the formula λ_m T= 0.29 cm K to obtain the characteristic temperature ranges for different parts of the electromagnetic spectrum. What do the numbers that you obtain tell you?

Answer

A body at a particular temperature produces a continous spectrum of wavelengths. In case of a black body, the wavelength corresponding to maximum intensity of radiation is given according to Planck's law. It can be given by the relation,

$$\lambda_m = \frac{0.29}{T} \text{ cm K}$$

Where,

λ_m = maximum wavelength

T = temperature

Thus, the temperature for different wavelengths can be obtained as:

For λ_m = 10^{-4} cm; $T = \frac{0.29}{10^{-4}} = 2900\ ^{o}K$

For λ_m = 5 $\times 10^{-5}$ cm; $T = \frac{0.29}{5\times10^{-5}} = 5800\ ^{o}K$

For λ_m = 10^{-6} cm; $T = \frac{0.29}{10^{-6}} = 290000\ ^{o}K$ and so on.

The numbers obtained tell us that temperature ranges are required for obtaining radiations in different parts of an electromagnetic spectrum. As the wavelength decreases, the corresponding temperature increases.

Question 8.14:

Given below are some famous numbers associated with electromagnetic radiations in different contexts in physics. State the part of the electromagnetic spectrum to which each belongs.

(a) 21 cm (wavelength emitted by atomic hydrogen in interstellar space).

(b) 1057 MHz (frequency of radiation arising from two close energy levels in hydrogen; known as Lamb shift).

(c) 2.7 K [temperature associated with the isotropic radiation filling all space-thought to be a relic of the 'big-bang' origin of the universe].

(d) 5890 Å - 5896 Å [double lines of sodium]

(e) 14.4 keV [energy of a particular transition in ^{57}Fe nucleus associated with a famous high resolution spectroscopic method (Mössbauer spectroscopy)].

Answer

(a) Radio waves; it belongs to the short wavelength end of the electromagnetic spectrum.

(b) Radio waves; it belongs to the short wavelength end.

(c) Temperature, T = 2.7 °K λ_m is given by Planck's law as:

$$\lambda_m = \frac{0.29}{2.7} = 0.11 \text{ cm}$$

This wavelength corresponds to microwaves.

(d) This is the yellow light of the visible spectrum.

(e) Transition energy is given by the relation,

E = hv Where,

h = Planck's constant = 6.6×10^{-34} Js

v = Frequency of radiation

Energy, E = 14.4 K eV

$$\therefore \nu = \frac{E}{h}$$

$$= \frac{14.4 \times 10^3 \times 1.6 \times 10^{-19}}{6.6 \times 10^{-34}}$$

$$= 3.4 \times 10^{18} \text{ Hz}$$

This corresponds to X-rays.

Question 8.15:

Answer the following questions:

(a) Long distance radio broadcasts use short-wave bands. Why?

(b) It is necessary to use satellites for long distance TV transmission. Why?

(c) Optical and radio telescopes are built on the ground but X-ray astronomy is possible only from satellites orbiting the earth. Why?

(d) The small ozone layer on top of the stratosphere is crucial for human survival. Why? (e) If the earth did not have an atmosphere, would its average surface temperature be higher or lower than what it is now?

(f) Some scientists have predicted that a global nuclear war on the earth would be followed by a severe 'nuclear winter' with a devastating effect on life on earth. What might be the basis of this prediction?

Answer

(a) Long distance radio broadcasts use shortwave bands because only these bands can be refracted by the ionosphere.

(b) It is necessary to use satellites for long distance TV transmissions because television signals are of high frequencies and high energies. Thus, these signals are not reflected by the ionosphere. Hence, satellites are helpful in reflecting TV signals. Also, they help in long distance TV transmissions.

(c) With reference to X-ray astronomy, X-rays are absorbed by the atmosphere. However, visible and radio waves can penetrate it. Hence, optical and radio telescopes are built on the ground, while X-ray astronomy is possible only with the help of satellites orbiting the Earth.

(d) The small ozone layer on the top of the atmosphere is crucial for human survival because it absorbs harmful ultraviolet radiations present in sunlight and prevents it from reaching the Earth’s surface.

(e) In theabsenceof an atmosphere, there would be no greenhouse effect on the surface of the Earth. As a result, the temperature of the Earth would decrease rapidly, making it chilly and difficult for human survival.

(f) A global nuclear war on the surface of the Earth would have disastrous consequences.

Post-nuclear war, the Earth will experience severe winter as the war will produce clouds of smoke that would cover maximum parts of the sky, thereby preventing solar light form reaching the atmosphere. Also, it will lead to the depletion of the ozone layer.