

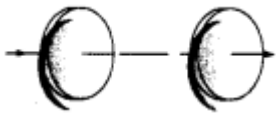
NCERT Solutions for Class 12 Physics

Chapter 8 Electromagnetic Waves

Question 1.

Figure shows a capacitor made of two circular plates each of radius 12 cm and separated by 5.0 cm. The capacitor is being charged by an external source (not shown in figure). The charging current is constant and equal to 0.15 A.

- (a) Calculate the capacitance and the rate of change of potential difference between the plates.
 (b) Obtain the displacement current across the plates.
 (c) Is Kirchoffs first rule valid at each plate of the capacitor ? Explain.



Answer:

(a) Using $C = \frac{\epsilon_0 A}{d}$ we get

$$C = \frac{8.854 \times 10^{-12} \times \pi r^2}{d}$$

$$= \frac{8.854 \times 10^{-12} \times 3.14 \times (12 \times 10^{-2})^2}{5 \times 10^{-2}}$$

$$= 800.7 \times 10^{-14} = 8 \text{ pF.}$$

Now using

$$V = \frac{Q}{C} \text{ we get } \frac{dV}{dt} = \frac{1}{C} \frac{dQ}{dt}$$

$$\text{or } \frac{dV}{dt} = \frac{I}{C} = \frac{0.15}{8 \times 10^{-12}}$$

$$= 1.875 \times 10^{10} \text{ V s}^{-1}.$$

(b) Displacement Current

$$I_d = \epsilon_0 \frac{d\phi_E}{dt} = \epsilon_0 \frac{d(EA)}{dt} = \epsilon_0 A \frac{dE}{dt}$$

$$= \frac{\epsilon_0 A}{d} \frac{dV}{dt} = C \frac{dV}{dt}$$

$$= (8 \times 10^{-12}) (1.875 \times 10^{10})$$

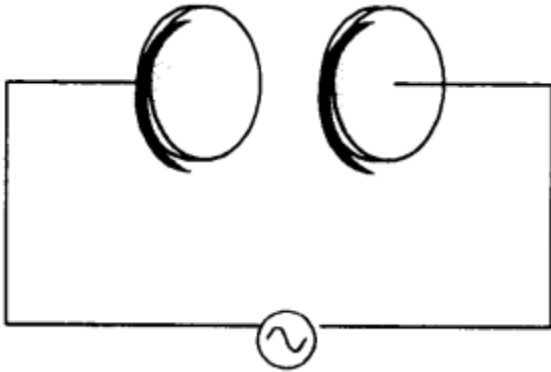
$$= 0.15 \text{ A.}$$

Yes. Because conduction current entering one plate is equal to the displacement current leaving that plate.

Question 2.

A parallel plate capacitor (shown in the figure) made of circular plates each of radius $R = 6.0 \text{ cm}$ has a capacitance $C = 100 \text{ pF}$. The capacitor is connected to a 230 V a.c. supply with an (angular) frequency of 300 rad s^{-1} .

- (a) What is the r.m.s. value of the conduction current?
- (b) Is the conduction current equal to the displacement current?
- (c) Determine the amplitude of \vec{B} at a point 3.0 cm from the axis between the plates.



Answer:

Here $V_{\text{rms}} = 230 \text{ V}$, $C = 100 \text{ pF}$
 $= 100 \times 10^{-12} = 10^{-10} \text{ F}$
 $\omega = 300 \text{ rad s}^{-1}$

(a) Using $I_{\text{rms}} = \frac{V_{\text{rms}}}{X_C}$, we get,

$$I_{\text{rms}} = \frac{V_{\text{rms}}}{\frac{1}{C\omega}} = V_{\text{rms}} \times C\omega$$

$$= 230 \times 10^{-10} \times 300$$

$$= 69 \times 10^{-7} = 6.9 \mu\text{A}.$$

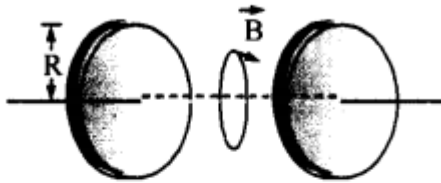
(b) Yes, because

$$I_d = \epsilon_0 \frac{d\phi_E}{dt} = \frac{\epsilon_0 d(EA)}{dt} = \frac{\epsilon_0 A dV}{d dt} = C \frac{dV}{dt}$$

$$\left(\because C = \frac{\epsilon_0 A}{d} \right)$$

But $\frac{dV}{dt} = \frac{I_C}{C} \therefore I_d = C \times \frac{I_C}{C}$
 $= I_C$ (Conduction Current)

(c) Consider the figure given below



Using Ampere's Circuital law we get

$$\oint \vec{B} \cdot d\vec{l} = \epsilon_0 \mu_0 \oint \frac{\partial \vec{E}}{\partial t} \cdot d\vec{S}$$

$$\text{or } B \times 2\pi r = \mu_0 \epsilon_0 \frac{dE}{dt} \pi r^2$$

$$\therefore B = \frac{\mu_0 \epsilon_0 r}{2} \frac{dE}{dt} \quad \dots(i)$$

But $E = \frac{\sigma}{\epsilon_0} = \frac{q}{A \epsilon_0}$

$$\therefore \frac{dE}{dt} = \frac{dq}{dt} = \frac{I}{\pi R^2 \epsilon_0}$$

where I is the r.m.s. value of current

$$\therefore B = \frac{\mu_0 \epsilon_0 r}{2} \times \frac{I}{\pi R^2 \epsilon_0} = \frac{\mu_0 r I}{2\pi R^2}$$

$$\Rightarrow \text{Amplitude, } B_0 = \frac{\mu_0 r}{2\pi R^2} I_0$$

$$\text{i.e. } B_0 = \frac{\mu_0 r \sqrt{2} I}{2\pi R^2} \quad (\because I_0 = \sqrt{2} I)$$

$$= \frac{(4\pi \times 10^{-7})(3 \times 10^{-2})1.414(6.9 \times 10^{-6})}{2\pi \times (6 \times 10^{-2})^2}$$

$$= 1.626 \times 10^{-11} \text{ T.}$$

Question 3.

What physical quantity is the same for X-rays of wavelength 10^{-10} m, the red light of wavelength 6800 Å, and radio waves of wavelength 500 m?

Answer:

The speed in a vacuum is the same for all are $c = 3 \times 10^8 \text{ ms}^{-1}$. (Electromagnetic waves)

Question 4.

A plane electromagnetic wave travels in a vacuum along Z-direction. What can you say about the directions of its electric and magnetic field vectors? If the frequency of the wave is 30 MHz, what is its wavelength?

Answer:

The electric field vector \vec{E} and magnetic field vector \vec{B} are in xy plane. They are normal to each other.

Using $c = \lambda\nu$, we get $\lambda = \frac{c}{\nu}$

i.e. $\lambda = \frac{3 \times 10^8}{30 \times 10^6} = 10 \text{ m}$

Question 5.

A radio can tune into any station in the 7.5 MHz to 12 MHz band. What is the corresponding wavelength band ?

Answer:

Using $c = \lambda\nu$, we get $\lambda = \frac{c}{\nu}$

i.e. $\lambda = \frac{3 \times 10^8}{30 \times 10^6} = 10 \text{ m}$

=> The corresponding wavelength band is 40 m to 25 m.

Question 6.

A charged particle oscillates about its mean equilibrium position with a frequency of 10^9 Hz. What is the frequency of the electromagnetic waves produced by the oscillator?

Answer:

The frequency of the electromagnetic waves produced is the same as that of the oscillating charged particle. Hence the frequency of the electromagnetic waves produced is, $\nu = 10^9$ Hz.

Question 7.

The amplitude of the magnetic field part of a harmonic electromagnetic wave in a vacuum is $B_0 = 510 \text{ nT}$. What is the electromagnetic waves produced by the oscillator?

Answer:

Using $\frac{E_0}{B_0} = c$ we get $E_0 = B_0 c$

i.e. $E = (510 \times 10^{-9})(3 \times 10^8)$
 $= 153 \text{ N C}^{-1}$.

Question 8.

Suppose that the electric field amplitude of an electromagnetic wave is $E_0 = 120 \text{ N/C}$ and that its frequency is $\nu = 50.0 \text{ MHz}$.

- (a) Determine, B_0 , ω , k and λ .
- (b) Find expressions for E and B .

Answer:

(a) (i) Using $\frac{E_0}{B_0} = c$, we get

$$B_0 = \frac{E}{c} = \frac{120}{3 \times 10^8}$$

$$= 4 \times 10^{-7} \text{ T}$$

i.e. $B_0 = 400 \text{ nT}$.

(ii) $\omega = 2\pi\nu$
 $= 2 \times \pi \times 50 \times 10^6$
 $= 3.14 \times 10^8 \text{ rad s}^{-1}$

(iii) $c = \lambda\nu$

i.e. $\lambda = \frac{c}{\nu} = \frac{3 \times 10^8}{50 \times 10^6} = 6 \text{ m}$

(iv) $k = \frac{\omega}{c} = \frac{3.14 \times 10^8}{3 \times 10^8}$
 $= 1.05 \text{ rad m}^{-1}$

(b) $\vec{E} = E_0 \sin(kx - \omega t) \hat{j}$
 $= 120 \sin(1.05x - 3.14 \times 10^8 \times t) \hat{j}$,

with usual units and

$$\vec{B} = B_0 \times \sin(kx - \omega t) \hat{k}$$

$$= 400 \times 10^{-7} \sin(1.05x - 3.14 \times 10^8 \times t) \hat{k}$$

with usual units.

Question 9.

The terminology of different parts of the electromagnetic spectrum is given in the text. Use the formula $E = h\nu$ (for the energy of a quantum of radiation: photon) and obtain the photon energy in units of eV for different parts of the electromagnetic spectrum. In what way are the different scales of photon energies that you obtain related to the sources of electromagnetic radiation?

Answer:

Using the relation for photon energy,

$$E = h\nu \text{ we get } E = \frac{hc}{\lambda}$$

For $\lambda = 1 \text{ m}$, we get

$$\begin{aligned} E &= \frac{(6.63 \times 10^{-34})(3 \times 10^8)}{1 \times 1.6 \times 10^{-19}} \\ &= 1.24 \times 10^{-6} \text{ eV.} \end{aligned}$$

\Rightarrow Energy for other wavelengths can be worked out from the relation

$$E_{\lambda} = \frac{1.24 \times 10^{-6}}{\lambda} \text{ eV}$$

(a) For γ -rays, let $\lambda = 10^{-12} \text{ m}$, then

$$\begin{aligned} E &= \frac{1.24 \times 10^{-6}}{10^{-12}} = 1.24 \times 10^6 \text{ eV} \\ &= 1.24 \text{ MeV} \end{aligned}$$

(b) For X-rays, let $\lambda = 1 \text{ nm} = 10^{-9} \text{ m}$, then

$$\begin{aligned} E &= \frac{1.24 \times 10^{-6}}{10^{-9}} = 1.24 \times 10^3 \text{ eV} \\ &= 1240 \text{ eV} \end{aligned}$$

(c) For visible light, let $\lambda = 1 \mu\text{m} = 10^{-6} \text{ m}$, then

$$E = \frac{1.24 \times 10^{-6}}{10^{-6}} = 1.24 \text{ eV}$$

(d) For microwaves, let $\lambda = 1 \text{ cm} = 10^{-2} \text{ m}$, then

$$E = \frac{1.24 \times 10^{-6}}{10^{-2}} = 1.24 \times 10^{-4} \text{ eV}$$

(e) For radiowaves, let $\lambda = 1 \text{ km} = 1000 \text{ m}$, then

$$E = \frac{1.24 \times 10^{-6}}{1000} = 1.24 \times 10^{-9} \text{ eV.}$$

Conclusion. The above result indicates that the different wavelengths in the electromagnetic spectrum can be obtained by multiplying roughly the powers often.

The visible wavelengths are spaced by a few eV.
 The nuclear energy levels (from γ rays) are spaced about 1 MeV.

Question 10.

In-plane electromagnetic wave, the electric field oscillates sinusoidally at a frequency of 2.0×10^{10} Hz and amplitude 48 Vm^{-1} .
 (a) What is the wavelength of the wave?
 (b) What is the amplitude of the oscillating magnetic field?
 (c) Show that the average energy density of the E field equals the average energy density of the B field. [$c = 3 \times 10^8 \text{ ms}^{-1}$].

Answer:

(a) Using $c = \lambda\nu$, we get

$$\lambda = \frac{c}{\nu} = \frac{3 \times 10^8}{2 \times 10^{10}} = 1.5 \times 10^{-2} \text{ m}$$

(b) Using $c = \frac{E_0}{B_0}$, we get

$$B_0 = \frac{E_0}{c} = \frac{48}{3 \times 10^8} = 1.6 \times 10^{-7} \text{ T}$$

(c) Average energy density of the electric field,

$$U_E = \frac{1}{4} \epsilon_0 E_0^2$$

and average energy density of the magnetic field,

$$U_B = \frac{B_0^2}{4\mu_0}$$

Also $c = \frac{E_0}{B_0}$ and $c = \frac{1}{\sqrt{\mu_0 \epsilon_0}}$

i.e. $\frac{E_0}{B_0} = \frac{1}{\sqrt{\mu_0 \epsilon_0}}$

Then $\frac{U_E}{U_B} = \frac{\mu_0 \epsilon_0 E_0^2}{B_0^2} = \frac{\mu_0 \epsilon_0}{\mu_0 \epsilon_0} = 1$

or $U_E = U_B$

Question 11.

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

(a) What is the direction of propagation?

- (b) What is the wavelength λ ?
- (c) What is the frequency ν ?
- (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:

Here $\vec{E} = 3.1 \cos(1.8y + 5.4 \times 10^6 t) \hat{i}$

Comparing it with standard equation

$\vec{E} = [E_0 \cos(ky + \omega t)] \hat{i}$, we get the following answers

(a) $-\hat{j}$ direction *i.e.* wave travels along negative y direction.

(b) $k = 1.8$ or $\frac{2\pi}{\lambda} = 1.8$ or $\lambda = \frac{2\pi}{1.8}$
 $= 3.5 \text{ m}$

(c) $\omega = 5.4 \times 10^6$ or $2\pi\nu = 5.4 \times 10^6$

or $\nu = \frac{5.4 \times 10^6}{2\pi} = 0.86 \text{ MHz}$

(d) $c = \frac{E_0}{B_0}$ or $B_0 = \frac{E_0}{c} = \frac{3.1}{3 \times 10^8}$
 $= 10 \text{ nT}$

(e) Using $\vec{B} = [B_0 \cos(ky + \omega t)] \hat{k}$
 $= 10 \text{ nT} \cos(1.8y \text{ rad m}^{-1} + 5.4 \times 10^6 \text{ rad s}^{-1}) \hat{k}$

Question 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:

(a) Visible power = 5 W

∴ Average intensity of radiation at 1 m

$$= \frac{\text{Power}}{4\pi r^2} = \frac{5}{4 \times \pi \times 1} = 0.4 \text{ W m}^{-2}$$

(b) Average intensity of radiation at 10 m

$$= \frac{\text{Power}}{4\pi r'^2} = \frac{5}{4 \times \pi \times 10^2}$$

$$= 0.004 \text{ W m}^{-2}$$

Question 13.

Use the formula $\lambda_m T = 0.29 \text{ cm K}$ to obtain the characteristic temperature ranges for different parts of the electromagnetic spectrum. What do the numbers that you obtain tell you?

Answer:

Using $\lambda_m T = 0.29 \text{ cm K}$ we get

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

$$T = 0.29 \text{ K for } \lambda_m = 1 \text{ cm.}$$

(a) For $\lambda_m = 10^{-10} \text{ cm}$, we get

$$T = \frac{0.29}{10^{-10}} = 2.9 \times 10^9 \text{ K.}$$

(b) For $\lambda_m = 1 \text{ nm} = 10^{-7} \text{ cm}$, we get

$$T = \frac{0.29}{\lambda_m} = \frac{0.29}{10^{-7}} = 2.9 \times 10^6 \text{ K.}$$

(c) For $\lambda_m = 1 \mu\text{m} = 10^{-4} \text{ cm}$, we get

$$T = \frac{0.29}{10^{-4}} = 2.9 \times 10^3 = 2900 \text{ K}$$

(d) For $\lambda_m = 1 \text{ m} = 100 \text{ cm}$, we get

$$T = \frac{0.29}{100} = 2.9 \times 10^{-3} \text{ K}$$

(e) For $\lambda_m = 1 \text{ km} = 10^5 \text{ cm}$, we get

$$T = \frac{0.29}{10^5} = 2.9 \times 10^{-6} \text{ K}$$

These numbers tell us the range of temperature required to obtain the different parts of the spectrum. For example, to obtain a wavelength of 1 μm , a temperature of 2900 K is required.

Question 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 ⁵⁷Fe nucleus associated with a famous high-resolution spectroscopic method (Mossbauer spectroscopy).]

Answer:

- (a) Radio waves (short-wavelength end)
- (b) Radio waves (short-wavelength end)
- (c)

$$\lambda_m T = 0.29$$

$$\text{or } \lambda_m = \frac{0.29}{T} = \frac{0.29}{2.7}$$

$$= 0.09 \text{ cm} = 0.0009 \text{ m}$$

Wavelength is of the order of 10^{-4} m *i.e.* microwave.

- (d) Given wavelength is of the order of 10^{-7} m *i.e.* visible radiations(yellow light)

Question 15.

Answer the following questions:

1. Long-distance radio broadcasts use shortwave bands. Why? (C.B.S.E. 2005)
2. It is necessary to use satellites for long-distance TV transmission. Why? (C.B.S.E. 2005)
3. Optical and radio telescopes are built on the ground but X-ray astronomy is possible only from satellites orbiting the earth. Why? (C.B.S.E. 2009)
4. The small ozone layer on top of the stratosphere is crucial for human survival. Why?(C.B.S.E. 2005, 2009)
5. If the earth did not have an atmosphere, would its average surface temperature be higher or lower than what it is now?
6. 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? (C.B.S.E. 1995)

Answer:

1. The ionosphere reflects waves in these bands.
2. Television signals are of >30 MHz penetrate the ionosphere. Therefore, reflection is effected by satellites.
3. The atmosphere absorbs X-rays. while visible and radio waves can penetrate it.

4. It absorbs ultraviolet radiation from the sun and prevents it from reaching the earth's surface and causing damage to life.
5. The temperature of the earth would be lower because the Greenhouse effect of the atmosphere would be absent.
6. The clouds produced by global nuclear war would perhaps cover substantial parts of the sky preventing solar light from reaching many parts of the globe. This would cause a 'winter'. against which life on earth cannot withstand.