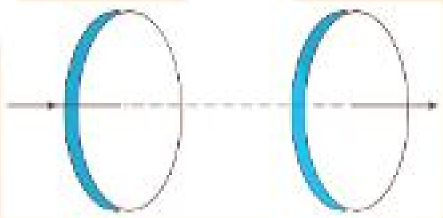
NCERT Solutions for Class 12

Physics

Chapter 8 – Electromagnetic Waves

EXERCISE

1. Figure drawn below 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 the 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.

Ans: Radius of each circular plates, $r = 12\text{ cm} = 0.12\text{ m}$

Distance between the given plates, $d = 5\text{ cm} = 0.05\text{ m}$

Charging current, $I = 0.15\text{A}$

The permittivity of free space, $\varepsilon_0 = 8.85\times10^{-12}\,C^2N^{-1}m^{-2}$

Capacitance between the two plates can be given as: $C = \frac{\varepsilon_0 A}{d}$

Where, $A = \pi r^2$. Hence,

$$C = \frac{\varepsilon_0 \pi r^2}{d}$$

$$= \frac{8.85\times10^{-12}\times(0.12)^2}{0.05}$$

$= 8.0032 \times 10^{-12} F$

$= 80.032 pF$

Charge on each plate is given as, $q = CV$, where,

V = Potential difference across the plates

Differentiating both sides with respect to time (t), we get:

$$\frac{dq}{dt} = C\frac{dV}{dt}$$

As, $\frac{dq}{dt} = I$, so, the rate of change of potential difference between the plates can be given as:

$$\frac{dV}{dt} = \frac{I}{C} = \frac{0.15}{80.032 \times 10^{-12}}$$

$$\therefore \frac{dV}{dt} = 1.87 \times 10^{9} V/s$$

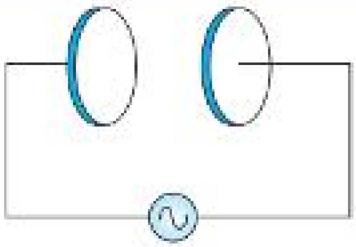
(b)Obtain the displacement current across the plates.

Ans: The displacement current across the plates would be same as the conduction current. Hence, the displacement current, I_d would be 0.15 A.

(c) **Is Kirchhoff's first rule (junction rule) valid at each plate of the** capacitor? Explain.

Ans: Yes, Kirchhoff's first rule would be valid at each plate of the capacitor, provided that sum of conduction and displacement currents, i.e., $I = I_c + I_d$ (junction rule of Kirchhoff's law).

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



(a) What is the rms value of the conduction current?

Ans: Radius of each circular plate, $R = 6.0\text{ cm} = 0.06\text{ m}$

Capacitance of a parallel plate capacitor, $C = 100\text{ pF} = 100 \times 10^{-12}\text{ F}$

Supply voltage, $V = 230\text{ V}$

Angular frequency, $\omega = 300\,\text{rad}\,\text{s}^{-1}$

Rms value of conduction current can be given as: $I = \dfrac{V}{X_c}$.

Where, X_c = capacitive currant $= \dfrac{1}{\omega C}$

$\therefore I = V \times \omega C$

$= 230 \times 300 \times 100 \times 10^{-12}$

$= 6.9 \times 10^{-6}$

$= 6.9\mu A$

Therefore, the rms value of conduction current will be $6.9\mu A$.

(b) Is the conduction current equal to the displacement current?

Ans: Yes, conduction current will be equal to displacement current.

(c) Determine the amplitude of B at a point 3.0 cm from the axis between the plates.

Ans: Magnetic field is given as: $B = \dfrac{\mu_0 r}{2\pi R^2} I_0$

Where,

μ_0 = Free space permeability $= 4\pi \times 10^{-7} NA^{-2}$

I_0 = Maximum value of current = $\sqrt{2}I$

r = Distance between the plates from the axis = $3.0cm = 0.03cm$.

$$\therefore B = \frac{4\pi \times 10^{-7} \times 0.03 \times \sqrt{2} \times 6.9 \times 10^{-6}}{2\pi \times (0.06)^2}$$

$$= 1.63 \times 10^{-11} T$$

Therefore, the magnetic field at that point will be $1.63 \times 10^{-11} T$.

3. What physical quantity is the same for X-rays of wavelength $10^{-10} m$, red light of wavelength $6800 \mathring{A}$ and radio waves of wavelength $500\ m$?

Ans: The speed of light $(3 \times 10^8 m/s)$ is independent of the wavelength in the vacuum. Hence, it is same for all wavelengths in vacuum.

4. A plane electromagnetic wave travels in 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 $30MHz$, what is its wavelength?

Ans: The electromagnetic wave is travelling along the z-direction, in a vacuum. The electric field (E) and the magnetic field (H) will lie in the x-y plane and they will be mutually perpendicular.

Frequency of the wave, $\nu = 30\ MHz = 30 \times 10^6 s^{-1}$

Speed of light in a vacuum, $c = 3 \times 10^8 m/s$

Wavelength, λ of the wave can be given as: $\lambda = \frac{c}{\nu}$

$$\therefore \lambda = \frac{3\times10^8}{30\times10^6} = 10m$$

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

Ans: A radio can tune to minimum frequency, $v_1 = 7.5\text{ MHz} = 7.5\times10^6\text{ Hz}$

Maximum frequency, $v_2 = 12\text{ MHz} = 12\times10^6\text{ Hz}$

Speed of light, $c = 3\times10^8 m/s$

Wavelength for frequency, v_1 can be calculated as:

$$\lambda_1 = \frac{c}{v_1}$$

$$= \frac{3\times10^8}{7.5\times10^6}$$

$$= 40m$$

Wavelength for frequency, v_2 can be calculated as:

$$\lambda_2 = \frac{c}{v_2}$$

$$= \frac{3\times10^8}{12\times10^6}$$

$$= 25m$$

Therefore, the corresponding wavelength band would be between 40m to 25m.

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?

Ans: The frequency of an electromagnetic wave produced by the oscillator will be equal to the frequency of charged particle oscillating about its mean position i.e., $10^9\,\text{Hz}$.

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

Ans: Amplitude of magnetic field of an electromagnetic wave in a vacuum, is:

$B_0 = 510\text{nT} = 510 \times 10^{-9}\,\text{T}$

Speed of light in a vacuum, $c = 3 \times 10^8\,\text{m/s}$

Amplitude of electric field of the electromagnetic wave can be given as:

$E = cB = 3 \times 10^8 \times 510 \times 10^{-9} = 153\,\text{N/C}$.

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.

Ans: Electric field amplitude, $E_0 = 120\,\text{N/C}$

Frequency of source, $\nu = 50.0\text{MHz} = 50 \times 10^6\,\text{Hz}$

Speed of light, $c = 3 \times 10^8\,\text{m/s}$

Magnetic field strength can be given as:

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

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

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

$= 400\text{nT}$

Angular frequency of source can be given as:

$\omega = 2\pi\nu$

$= 2\pi(50 \times 10^6)$

$= 3.14 \times 10^8 \text{ rad / s}$

Propagation constant can be given as:

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

$= \frac{3.14 \times 10^8}{3 \times 10^8}$

$= 1.05 \text{rad / m}$

Wavelength of wave can be given as:

$\lambda = \frac{c}{\nu}$

$= \frac{3 \times 10^8}{50 \times 10^6}$

$= 6.0\text{m}$

(b) Find expressions for E and B.

Ans: If the wave propagates in the positive x direction. Then, the electric field vector would be in the positive y direction and the magnetic field vector will lie in the positive z direction. This is because all three vectors are mutually perpendicular.

Equation of electric field vector can be given as:

$\vec{E} = E_0 \sin(kx - \omega t)\hat{j}$

$= 120\sin\left[1.05x - 3.14 \times 10^8 t\right]\hat{j}$

And, magnetic field vector can be given as:

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

$$= (4\times10^{-7})\sin\left[1.05x - 3.14\times10^{8}t\right]\hat{k}$$

9. The terminology of different parts of the electromagnetic spectrum is given in the text. Use the formula $E = h\nu$ (for 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?

Ans: The energy of photon can be given as:

$$E = h\nu = \frac{hc}{\lambda}$$

Where,

h = Planck's constant $= 6.6\times10^{-34}$ Js

c = speed of light $= 3\times10^{8}$ m / s

λ = wavelength of radiation

$$\therefore E = \frac{6.6\times10^{-34}\times3\times10^{8}}{\lambda} J$$

$$= \frac{19.8\times10^{-26}}{\lambda} J$$

$$= \frac{19.8\times10^{-26}}{\lambda\times1.6\times10^{-19}} eV$$

$$= \frac{12.375\times10^{-7}}{\lambda} eV$$

For different values of in an electromagnetic spectrum, photon energies are listed in below table:

$\lambda(m)$	$E(eV)$
10^3	12.375×10^{-10}
1	12.375×10^{-7}
10^{-3}	12.375×10^{-4}
10^{-6}	12.375×10^{-1}
10^{-8}	12.375×10^{1}
10^{-10}	12.375×10^{3}
10^{-12}	12.375×10^{5}

10. In a plane electromagnetic wave, the electric field oscillates sinusoidally at a frequency of $2\times10^{10}\,Hz$ and amplitude $48\ Vm^{-1}$.

(a) What is the wavelength of the wave?

Ans: Frequency of the electromagnetic wave, $\nu = 2.0\times10^{10}\,Hz$

Electric field amplitude, $E_0 = 48\ Vm^{-1}$

Speed of light, $c = 3\times10^8\,m/s$

Wavelength of wave can be given as:

$$\lambda = \frac{c}{\nu}$$

$$= \frac{3\times10^8}{2\times10^{10}}$$

$$= 0.015m$$

(b) What is the amplitude of the oscillating magnetic field?

Ans: Magnetic field strength can be given as:

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

$$= \frac{48}{3\times10^8}$$

$$= 1.6\times10^{-7}\,T$$

(c) Show that the average energy density of the E field equals the average energy density of the B field. $[c = 3\times10^8 m/s]$

Ans: Energy density of the electric field is given as:

$$U_E = \frac{1}{2}\epsilon_0 E^2$$

Energy density of the magnetic field can be given as:

$$U_B = \frac{1}{2\mu_0}B^2$$

Where,

ϵ_0 = Permittivity of free space

μ_0 = Permeability of free space

The relation between E and B can be given as:

$$E = cB \quad ....(1)$$

Where,

$$c = \frac{1}{\sqrt{\epsilon_0 \mu_0}} \quad ....(2)$$

Substituting equation (2) in equation (1), we get:

$$E = \frac{1}{\sqrt{\epsilon_0 \mu_0}}B$$

Squaring both the sides, we get:

$$E^2 = \frac{1}{\epsilon_0 \mu_0} B^2$$

$$E^2 \epsilon_0 = \frac{B^2}{\mu_0}$$

$$\frac{1}{2} E^2 \epsilon_0 = \frac{1}{2} \frac{B^2}{\mu_0}$$

$$\Rightarrow U_E = U_B.$$

11.Suppose that the electric field part of an electromagnetic wave in vacuum is $\acute{E} = \{(3.1 N/C)\cos\left[(1.8 rad/m)y + (5.4\times10^6 rad/s)t\right]\}\hat{i}$.

(a) What is the direction of propagation?

Ans: From the given electric field vector, we can say that the electric field will be directed along the negative x direction. Hence, the direction of motion will be along the negative y direction i.e., $-j$.

(b) What is the wavelength λ?

Ans: The general equation for electric field in the positive x direction is given as: $\acute{E} = E_0 \sin(kx - \omega t)\hat{i}$. By comparing the given equation, $\acute{E} = \{(3.1 N/C)\cos\left[(1.8 rad/m)y + (5.4\times10^6 rad/s)t\right]\}\hat{i}$ with general equation, we get:

Electric field amplitude, $E_0 = 3.1 N/C$

Wave number, $k = 1.8 rad/m$

Angular frequency, $\omega = 5.4\times10^6 rad/s$

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

(c) What is the frequency ν?

Ans: The frequency, ν of the wave can be given as: $\nu = \frac{\omega}{2\pi}$

$= \frac{5.4 \times 10^8}{2\pi} = 8.6 \times 10^7 \text{ Hz}$.

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

Ans: Magnetic field strength can be given as:

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

$$\therefore B_0 = \frac{3.1}{3 \times 10^8} = 1.03 \times 10^{-7} \text{ T}.$$

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

Ans: We can observe that the magnetic field vector will be directed along the negative z direction. Hence, the general equation for the magnetic field vector is written as: $\vec{B} = B_0 \cos(ky + \omega t)\hat{k}$, hence $\vec{B} = \{(1.03 \times 10^{-7} \text{ T})\cos\left[(1.8 \text{ rad/m})y + (5.4 \times 10^6 \text{ rad/s})t\right]\}\hat{k}$.

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? Assume that the radiation is emitted isotropically and neglect reflection.

Ans: Power rating of bulb, $P = 100 \text{ W}$

About 5% of its power has been converted into visible radiation.

Therefore, power of visible radiation is given as:

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

Average intensity at distance, $d = 1\text{m}$ can be given as:

$$I = \frac{P'}{A} = \frac{P'}{4\pi d^2}$$

$$= \frac{5}{4 \times 3.14 \times (1)^2} = 0.398 W/m^2$$

(b)at a distance of 10 m? Assume that the radiation is emitted isotropically and neglect reflection.

Ans: Power of visible radiation can be given as:

$$P' = \frac{5}{100} \times 100 = 5W.$$

Average intensity at distance, $d = 10m$ can be given as:

$$I = \frac{P'}{A} = \frac{P'}{4\pi d^2}$$

$$= \frac{5}{4 \times 3.14 \times (10)^2} = 0.00398 W/m^2$$

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

Ans: At a particular temperature, a body produces a continuous spectrum of wavelengths. In case of a black body, the wavelength corresponding to maximum intensity of radiation is given by Planck's law. It can be represented as:

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

Where,

λ_m = maximum wavelength

T = temperature

Therefore, the temperature for different wavelengths can be given as:

For, $\lambda_m = 10^{-4}\text{cm}$, $T = \frac{0.29}{10^{-4}} = 2900\ K$

For, $\lambda_m = 5\times10^{-5}\text{cm}$, $T = \frac{0.29}{5\times10^{-5}} = 5800\ K$

For, $\lambda_m = 10^{-6}\text{cm}$, $T = \frac{0.29}{10^{-6}} = 290000´K$

We can see that, as the maximum wavelength decreases, the corresponding temperature increases. At lower temperature, wavelength produced will not have maximum intensity.

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).

Ans: Wavelength of 21 cm belongs to short radio wave, which is present at the end of electromagnetic spectrum.

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

Ans: Frequency of 1057MHz belongs to radio waves. As, radio waves generally belong to the frequency range of 500kHz to 1000MHz. The range of wavelength for radio waves is, $>0.1\text{m}$.

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

Ans: Given, temperature, $T = 2.7\text{K}$.

According to Planck's law, $\lambda = 0.29(\text{cm})T(\text{K})$

Substituting the value of temperature, we get: $\lambda = \frac{0.29}{2.7} = 0.11\text{cm}$.

Now, $\lambda = 0.11\text{cm}$ belongs to the Microwave region of the electromagnetic spectrum.

(d) $5890\,\text{Å} - 5896\,\text{Å}$ [double lines of sodium]

Ans: This wavelength belongs to yellow light of visible spectrum.

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

Ans: Given: 14.4keV

The transition energy can be given as: $E = h\nu$.

Where,

h is Planck's constant $6.6 \times 10^{-34}\text{Js}$,

ν is frequency radiation.

Substituting the values, we get:

$$\nu = \frac{E}{h} = \frac{14.4 \times 10^{3} \times 1.6 \times 10^{-19}}{6.6 \times 10^{-34}} = 3.4 \times 10^{18}\text{Hz}.$$

Now, $3.4 \times 10^{18}\text{Hz}$ belongs to range of X-ray frequencies. As frequency of X-ray lies between $1016\text{Hz} - 1020\text{Hz}$.

15.Answer the following questions:

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

Ans: Short wave bands are used for long distance broadcasting because, after getting reflected from ionosphere present in our environment, these waves can reach to longer distances.

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

Ans: Yes, for long-distance TV transmission, it is compulsory to use satellites, because TV signal contains very high frequency of range $54\text{MHz} - 890\text{MHz}$, and this much high frequency does not get reflected by ionosphere, and communication does not get stablished. Hence, we need to use satellites for TV transmission, over long distance.

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

Ans: Light and radio waves used in optical and radio telescopes respectively, penetrate through the atmosphere but X-rays used in X-ray astronomy, are absorbed by the atmosphere. Hence, optical and radio telescopes are built on earth's surface and for X-ray astronomy, satellites orbiting the earth are necessary.

(d) The small ozone layer on top of the stratosphere is crucial for human survival. Why?

Ans: The ozone layer, present on the top of the stratosphere layer is essential for human survival because it prevents the harmful radiations, (like, ultraviolet rays, γ rays, cosmic rays) coming from the sun to earth's atmosphere, which can cause many diseases like cancer and genetic damage in cells and plants. The ozone layer also traps the infrared radiations and maintains earth's warmth.

(e) If the earth did not have an atmosphere, would its average surface temperature be higher or lower than what it is now?

Ans: If the earth would not have any atmosphere, then there will not be any greenhouse effect. And if greenhouse effect would not be present, then infrared radiations and CO_2 would not retain in the atmosphere. The infrared radiations and CO_2 gets reflected from the atmosphere and keep the earth's surface warm. But in the absence of atmosphere, this would not be possible and average surface temperature of earth would become lower.

(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?

Ans: A global nuclear war on the earth would be followed by a severe 'nuclear winter', as the nuclear weapons would create clouds of smoke and dust, which would stop the solar light to reach the earth's surface and would stop the greenhouse effect. This would cause extreme winter conditions.