NCERT SOLUTIONS

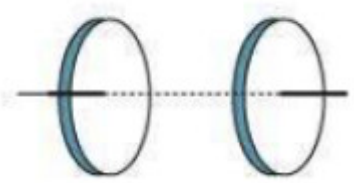
CLASS - 12th



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Class : 12th
Subject : Physics
Chapter : 8
Chapter Name : Electromagnetic Waves

Q8.1 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 the figure). The charging current is constant and equal to 0.15A. (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 Kirchhoff's first rule (junction rule) valid at each plate of the capacitor? Explain.



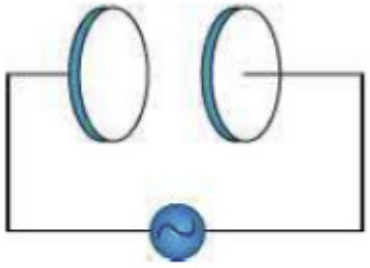
Answer. Radius of each circular plate, r = 12 cm = 0.12 m
Distance between the plates, d = 5 cm = 0.05 m
Charging current, I = 0.15 A
Permittivity of free space, $\varepsilon_0 = 8.85 \times 10^{-12} \mathrm{C}^2\mathrm{N}^{-1}\mathrm{m}^{-2}$
(a) Capacitance between the two plates is given by the relation,
$c^{=\frac{\varepsilon_0 \mathrm{A}}{d}}$
Where,
A = Area of each plate = πr^2
$C = \frac{\mathcal{E}_0 \pi r^2}{d}$
$= \frac{8.85 \times 10\pi^2 \times 0.84}{0.05}$
$= 8.0032 \times 10^{-12}\mathrm{F} = 80.032\mathrm{pF}$
Charge on each plate, q = CV
Where,
V = Potential difference across the plates
Differentiation on both sides with respect to time (t) gives:
$\frac{dq}{dt} = C\frac{dV}{dt}$
But, $\frac{dq}{dt} = \text{ current } (I)$
$\therefore \frac{dV}{dt} = \frac{I}{C}$
$\Rightarrow \frac{0.15}{80.032 \times 10^{-12}} = 1.87 \times 10^9 \mathrm{V/s}$
Therefore, the change in potential difference between the plates is $1.87 \times 10^9 \mathrm{V/s}$.

(b) The displacement current across the plates is the same as the conduction current. Hence, the displacement current, $\dot{I}_d$ is 0.15 A.

(c) Yes ,Kirchhoff's first rule is valid at each plate of the capacitor provided that we take the sum of conduction and displacement for current.

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Q8.2 A parallel plate capacitor 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?(b) Is the conduction current equal to the displacement current? (c) Determine the amplitude of B at a point 3.0 cm from the axis between the plates



Answer. Radius of each circular plate, R = 6.0 cm = 0.06 m
Capacitance of a parallel plate capacitor, $C = 100\text{pF} = 100 \times 10^{-12}\text{F}$
Supply voltage, V = 230 V
Angular frequency, $\omega = 300\text{rads}^{-1}$
(a) Rms value of conduction current, $_I = \frac{V}{X_C}$
Where
$X_C =$ Capacitive resistance
$= \frac{1}{\omega C}$
$\therefore I = v \times \omega C$
$= 230 \times 300 \times 100 \times 10^{-12}$
$= 6.9 \times 10^{-6}\text{A}$
$= 6.9\mu\text{A}$
Hence, the rms value of conduction current is 6.9 μA.
(b) Yes, conduction current is equal to displacement current.
(c) Magnetic field is given as:
$= \frac{\mu_0 r}{2\pi R^2} I_0$
Where,
μ_0 = Free space permeability $= 4\pi \times 10^{-7}\text{NA}^{-2}$
I_0 = Maximum value of current = $\sqrt{2}I$
r = Distance between the plates from the axis = 3.0 cm = 0.03 m
$= \frac{4\pi \times 10^{-7} \times 0.03 \times \sqrt{2} \times 6.9 \times 10^{-6}}{2\pi \quad \times (06)^2}$

$= 1.63 \times 10^{-11}\mathrm{T}$
Hence, the magnetic field at that point is $1.63 \times 10^{-11}\mathrm{T}$.

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Q8.3 What physical quantity is the same for X-rays of wavelength $10^{-10}\mathrm{m}$ red light of wavelength 6800 Å and radiowaves of wavelength 500m?

Answer. The speed of light $\left(3 \times 10^{3}\mathrm{m/s}\right)$ in a vacuum is the same for all wavelengths. It is independent of the wavelength in the vacuum.

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Q8.4 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 30 MHz, what is its wavelength?

Answer. The electromagnetic wave travels in a vacuum along the z-direction. The electric field (E) and the magnetic field (H) are in the x-y plane. They are mutually perpendicular.
Frequency of the wave, v = 30 MHz = $30 \times 10^{6} s^{-1}$
Speed of light in a vacuum, $c = 3 \times 10^{8}\mathrm{m/s}$
Wavelength of a wave is given as:
$\lambda = \frac{c}{v}$
$= \frac{3 \times 10^{8}}{30 \times 10^{6}} = 10\mathrm{m}$

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Q8.5 A radio can tune in to any station in the 7.5 MHz to 12 MHz band. What is the corresponding wavelength band?

Answer. A radio can tune to minimum frequency, $v_1 = 7.5\mathrm{MHz} = 7.5 \times 10^{6}\mathrm{Hz}$
Maximum frequency, $v_2 = 12\mathrm{MHz} = 12 \times 10^{6}\mathrm{Hz}$
Speed of light, $c = 3 \times 10^{8}\mathrm{m/s}$
Corresponding wavelength for can be calculated as:
$$\lambda_1 = \frac{c}{v_1}$$
$$= \frac{3 \times 10^{8}}{7.5 \times 10^{6}} = 40\mathrm{m}$$
Corresponding wavelength for V2 can be calculated as:
$$\lambda_2 = \frac{c}{v_2}$$
$$= \frac{3 \times 10^{8}}{12 \times 10^{6}} = 25\mathrm{m}$$

Thus, the wavelength band of the radio is 40 m to 25 m.
The photon energies for the different parts of the spectrum of a source indicate the spacing of the relevant energy levels of the source.

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Q8.10 In a plane electromagnetic wave, the electric field oscillates sinusoidally at a frequency of 2.0×10^{10} Hz and amplitude 48 V m^{-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. [$c = 3 \times 10^8 \mathrm{ms}^{-1}$]

Answer. Frequency of the electromagnetic wave, v = $v = 2.0 \times 10^{10} \mathrm{Hz}$
Electric field amplitude, $E_0 = 48 \mathrm{Vm}^{-1}$
Speed of light, $c = 3 \times 10^8 \mathrm{m/s}$
(a) Wavelength of a wave is given as:

$$\lambda = \frac{c}{v}$$
$$= \frac{3 \times 10^8}{2 \times 10^{10}} = 0.015 \mathrm{m}$$

(b) Magnetic field strength is given as:

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

(c) Energy density of the electric field is given as:
$U_E = \frac{1}{2} \epsilon_0 E^2$
And, energy density of the magnetic field is given as:
$U_n = \frac{1}{2\mu_0} B^2$
Where,
ϵ_0 = Permittivity of free space
μ_0 = Permeability of free space
We have the relation connecting E and B as:
E = cB ... (1)
Where,
$c = \frac{1}{\sqrt{\epsilon_0 \mu_0}}$....(2)
Putting equation (2) in equation (1), we get
$E = \frac{1}{\sqrt{\epsilon_0 \mu_0}} B$
Squaring both sides, we get
$E^2 = \frac{1}{\epsilon_0 \mu_0} B^2$
$\epsilon_0 E^2 = \frac{B^2}{\mu_0}$

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

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Q8.11 Suppose that the electric field part of an electromagnetic wave in vacuum is $E = \{(3.1\mathrm{N/C})\cos\left[(1.8\mathrm{rad/m})y + \left(5.4\times10^6\mathrm{rad/s}\right)t\right]\}\hat{i}.$
(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. (a) from the given electric field vector, it can be inferred that the elkctric field is directed along the negative x direction. Hence , the direction of the motion is along the negative y direction i.e. $-\hat{j}$
(b) It is given that,
$\vec{E} = 3.1\mathrm{N/C}\cos[(1.8\mathrm{rad/m})y + (5.4\times10^{\mathrm{s}}\mathrm{rad/s})\,t]\hat{i}$ .. (1)
The general equation for the electric field vector in the positive x direction can be written as:
$\vec{E} = E_0\sin(kx-\omega t)\hat{i}$..... (2)
On comparing equations (1) and (2), we get
Electric field amplitude,$E_0 = 3.1\mathrm{N/C}$
Angular frequency, $\omega = 5.4\times10^8\mathrm{rad/s}$
Wave number, k = 1.8 rad/m
Wavelength,$\lambda = \frac{2\pi}{1.8} = 3.490\mathrm{m}$
(c) Frequency of wave is given as:
$v = \dfrac{\omega}{2\pi}$
$= \dfrac{5.4\times10^8}{2\pi} = 8.6\times10^7\mathrm{Hz}$
(d) Magnetic field strength is given as:
$B_0 = \frac{E_0}{c}$
Where,
C = Speed of light = $3\times10^8\mathrm{m/s}$
$\therefore B_0 = \frac{3.1}{3\times10^8} = 1.03\times10^{-7}\mathrm{T}$
(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:
$\vec{B} = B_0\cos(ky+\omega t)\hat{k}$
$= \left\{\left(1.03\times10^{-7}\mathrm{T}\right)\cos\left[(1.8\mathrm{rad/m})y + \left(5.4\times10^6\mathrm{rad/s}\right)t\right]\right\}\hat{k}$

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Q8.12 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 1m 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, $P' = \frac{5}{100} \times 100 = 5\text{w}$
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:

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

(b) Distance of a point from the bulb, d_1 = 10 m
Hence, intensity of radiation at that point is given as:

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

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Q8.13 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,
$\lambda_\text{m} = \frac{0.29}{\text{T}}\text{cmK}$
Where,
λ_m = maximum wavelength
T = temperature
Thus, the temperature for different wavelengths can be obtained as:
$\lambda_\text{m} = 10^{-4}\text{cm}; T = \frac{0.29}{10^{-4}} = 2900^\circ\text{K}$
$\lambda_m = 5 \times 10^{-5}\text{cm}_i \quad T = \frac{0.29}{5\times10^{-5}} = 5800^\circ\text{K}$
$\lambda_\text{m} = 10^{-6}\text{cm}_i^{T=\frac{0.29}{10^{-6}}} = 290000^\circ\text{K}$ 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.

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Q8.14 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 (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.
$(\mathrm{c})\ \text{Temperature, T } = 2.7^{\circ}\mathrm{K}\lambda_{\mathrm{m}}$ is given by Planck's law as:

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

This wavelength corresponds to microwaves.

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

(e) Transition energy is given by the relation,

$\mathrm{E} =$ hv Where, $\mathrm{h} =$ Planck's constant $= 6.6 \times 10^{-34}\mathrm{Js}$

$v =$ Frequency of radiation

$\text{Energy, E} = 14.4\mathrm{KeV}$

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

$= \frac{14.4\times10^{3}\times1.6\times10^{-19}}{6.6\times10^{-34}}$

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

This corresponds to X -rays.

Q8.15 Answer the following questions:
(a) Long distance radio broadcasts use shortwave 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 the absence of 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.

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