NCERT SOLUTIONS
CLASS-XII PHYSICS
CHAPTER-8
ELECTROMAGNETIC WAVES

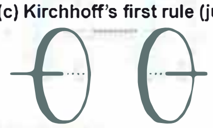
Electromagnetic Waves

Q 8.1) Two circular plates having radius of 12 cm each and separated by 5 cm are used to make a capacitor as shown in the Figure 8.6. An external source charges this capacitor. 0.15 A is the charging current which remains constant.

(a) Determine the capacitance and the rate of charge of potential difference between the two capacitiveplates.

(b) Calculate the displacement current across the capacitive plates.

(c) Kirchhoff's first rule (junction rule) is applicable to each plate of the capacitor. Yes or No. Give Reasons.



Answer 8.1:

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, $\varepsilon_0 = 8.85 \times 10^{-12}\ C^2 N^{-1} m^{-2}$

(a) Capacitance between the two plates is given by the relation,

$C = \frac{\varepsilon_0 A}{d}$

Where,

A = Area of each plate = πr^2

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

= $\frac{8.85 \times 10^{-12} \times \pi (0.12)^2}{0.05}$

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

= 80.032 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, $\frac{dq}{dt}$ = Current (I)

$\therefore \frac{dV}{dt} = \frac{I}{C}$

=> $\frac{0.15}{80.032 \times 10^{-12}} = 1.87 \times 10^9\ V/s$

Therefore, the change in potential difference between the plates is $1.87 \times 10^9\ V/s$.

(b) The displacement current across the plates is the same as the conduction current.Hence, the displacement current, id is 0.15 A.

(c) Yes

Kirchhoff's first rule is valid at each plate of the capacitor provided that we take the sum ofconduction and displacement for current.

Q 8.2) Circular plates each of radius 6.0 cm having acapacitance of 100 pF is used to make a parallel plate capacitor (Fig. 8.7). The capacitor is connected to a 230 V ac supply with a (angular) frequency of 300 rad s^{-1}.

(a) Determine RMS value of the conduction current

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

(c) At a point 3.0 cm find out the amplitude of B from the axis between the plates.

Answer 8.2:

Radius of each circular plate, R = 6.0 cm = 0.06 m

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

Supply voltage, V = 230 V

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

(a) Rms value of conduction current, I = $\frac{V}{X_c}$

Where,

X_c = Capacitive reactance

= $\frac{1}{\omega C}$

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

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

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

= $6.9\ \mu A$

Hence, the rms value of conduction current is $6.9\ \mu A$.

(b) Yes, conduction current is equivalent to displacement current.

(c) Magnetic field is given as:

$B = \frac{\mu_0 r}{2\pi R^2} I_0$

Where,

μ_0 = Permeability of free space = $4\pi \times 10^{-7}\ N\ A^{-2}$

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

r = Distance between the plates from the axis = 3.0 cm = 0.03 m

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

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

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

Q 8.3) For X-rays of wavelength 10^{-10}m, red light of wavelength6800 Å and radiowaves of wavelength 500 m, what physical quantity could be the same?

Answer 8.3:

The speed of light (3×10^8 m/s) in a vacuum is the same for all wavelengths. It is independentof the wavelength in the vacuum.

Q 8.4) What can be understood about the directions of magnetic and electric field vectors of a plane electromagnetic wave travelling in vacuum along z-direction. What is the wavelength of the electromagnetic wave when its frequency is 30 MHz?

Answer 8.4:

The electromagnetic wave travels in a vacuum along the z-direction. The electric field (E) andthe 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 vacuum, C = 3×10^8 m/s

Wavelength of a wave is given a:

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

= $\frac{3 \times 10^8}{30 \times 10^6}$ = 10 m

Q 8.5) What is the wavelength band of a radio that can tune in to any station in the 7.5 MHz to 12 MHz band?

Answer 8.5:

A radio can tune to minimum frequency, $v_1 = 7.5\ MHz = 7.5 \times 10^6\ Hz$

Maximum frequency, $v_2 = 12\ MHz = 12 \times 10^6\ Hz$

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

Corresponding wavelength for v_1 can be calculated as:

$\lambda_1 = \frac{c}{v_1} \frac{3\times10^3}{7.5\times10^6} = 40\ m$

Corresponding wavelength for v_2 can be calculated as:

$\lambda_2 = \frac{c}{v_2} \frac{3\times10^3}{12\times10^6} = 25\ m$

Thus, the wavelength band of the radio is 40 m to 25 m.

Q 8.6) What is the frequency of the electromagnetic waves produced by the oscillator which oscillates a charged particle about its mean equilibrium position with a frequency of 10^9 Hz?

Answer 8.6:

The frequency of an electromagnetic wave produced by the oscillator is the same as that of a charged particle oscillating about its mean position i.e., 10^9 Hz.

Q 8.7) What is the amplitude of the electric field part of the harmonic electromagnetic wave whose amplitude of the magnetic field part in vacuum is $B_0 = 510\ nT$?

Answer 8.7:

Amplitude of magnetic field of an electromagnetic wave in a vacuum,

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

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

Amplitude of electric field of an electromagnetic wave is given by the relation,

$E = cB_0 = 3 \times 10^8 \times 510 \times 10^{-9} = 153\ N/C$

Therefore, the electric field part of the wave is 153 N/C.

Q 8.8)Determine, (a) $B_0,\ \omega,\ k\ and\ \lambda$ supposing that the electric field amplitude of an electromagnetic wave is $E_0 = 120\ N/C$ and that its frequency is v = 50 MHz. (b) Also find expressions for E and B.

Answer 8.8:

Electric field amplitude, $E_0 = 120\ N/C$

Frequency of source, v = 50 MHz = 50×10^6 Hz

Speed of light, c = 3×10^8 m/s

(a) Magnitude of magnetic field strength is given as:

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

= $\frac{120}{3\times10^8}$

= $4 \times 10^{-7}\ T = 400\ nT$

Angular frequency of source is given by:

$\omega = 2nv = 2n \times 50 \times 10^6$

= 3.14×10^8 rad/s

Propagation constant is given as:

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

= $\frac{3.14\times10^8}{3\times10^8} = 1.05\ rad/m$

Wavelength of wave is given by:

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

= $\frac{3\times10^8}{50\times10^6}$ = 6.0 m

(b) Suppose the wave is propagating in the positive x direction. Then, the electric field vectorwill be in the positive y direction and the magnetic field vector will be in the positive zdirection. This is because all three vectors are mutually perpendicular.

Equation of electric field vector is given as:

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

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

And, magnetic field vector is given as:

$\overline{B} = B_0\ sin(kx - \omega t)\ \hat{k}\ \overline{B} = (4 \times 10^{-7})\ sin[1.05x - 3.14 \times 10^8 t]\ \hat{k}$

Q 8.9) Obtain the photonenergy in units of eV for different parts of the electromagnetic spectrum using the formula E = hv (for energy of a quantum of radiation: photon). How are the obtained different scales of photon energies related to the sources of electromagnetic radiation?

Answer 8.9:

Energy of a photon is given as:

E = hv = $\frac{hc}{\lambda}$

Where,

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

c = Speed of light = $3 \times 10^8\ m/s$

λ = Wavelength of radiation

$\therefore E = \frac{6.6 \times 10^{-34} \times 3 \times 10^8}{\lambda} = \frac{19.8 \times 10^{-26}}{\lambda}\ J$

= $\frac{19.8 \times 10^{-26}}{\lambda \times 1.6 \times 10^{-19}} = \frac{12.375 \times 10^{-7}}{\lambda}\ eV$

The given table lists the photon energies for different parts of an electromagnet spectrum for different λ.

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

The photon energies for the different parts of the spectrum of a source indicate the spacing of the relevant energy levels of the source

Q 8.10) (a) What is the wavelength of the electromagnetic wave in which the electric field oscillates sinusoidally at a frequency of 2×10^{10} Hz and amplitude 48 V m^{-1}. (b) Find the amplitude of the oscillating magnetic field and (c) Prove that the average energy density of the E field equals the average energy density of the B field. [c = $3 \times 10^8\ m\ s^{-1}$]

Answer 8.10:

Frequency of the electromagnetic wave, v = $2 \times 10^{10}\ Hz$

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

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

(a) Wavelength of a wave is given as:

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

= $\frac{3 \times 10^8}{2 \times 10^{10}} = 0.015\ m$

(b) Magnetic field strength is given as:

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

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

(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:

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

Where,

ϵ_0 = Permittivity of free space

μ_0 = Permeability of free space

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 on both sides, we get

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

=> $U_E = U_B$