Chapter.8
Electromagnetic Waves
Class – XII
Subject – Physics

8.1. Figure 8.6 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.

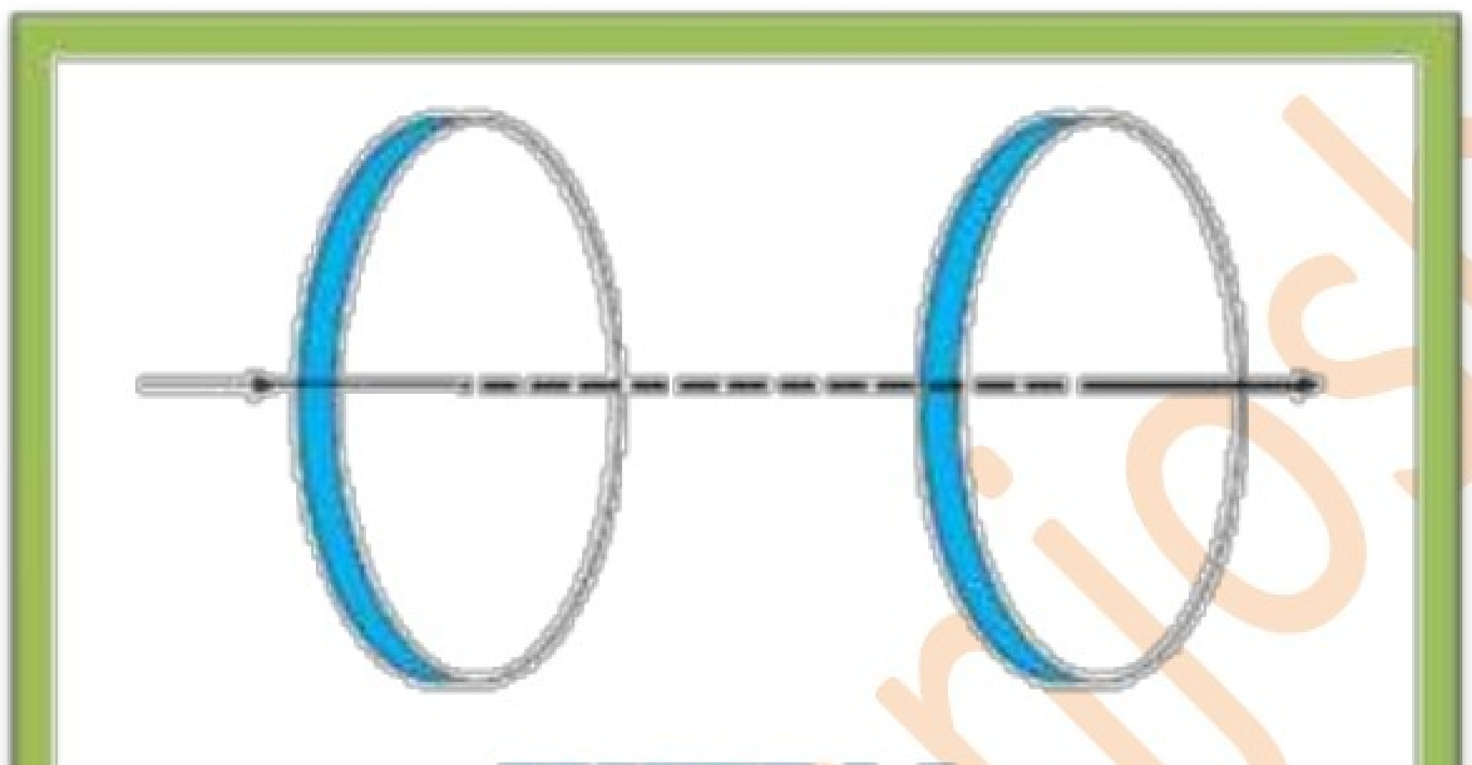

FIGURE 8.6

a) Calculate the capacitance and the rate of charge 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.

Sol.

Given:
r = 0.12 m
d = 0.05 m
I = 0.15 A

a) We know

$$C = \epsilon_o . \frac{A}{d}$$

Calculating area

A = 3.14 x 0.12 x 0.12

A = 0.045 sq. m

Substituting in above eqn

C = 80.1 pF

Now,

Rate of change of potential difference

dQ / dt = C.dV / dt

Or

dV / dt = I / C

Thus dV / dt = 0.15 / 80.1 p

Or dV / dt = 1.87 x 10^9 V / s

b) Displacement current is given by

$$i_d = \epsilon_o \frac{d\Phi_E}{dt} \quad \text{.................................(1)}$$

And Φ_E = E.A

So $d\Phi_E$ / dt = A.dE / dt

Now

E = Q / ϵ_o.A

Differentiating it w.r.t. time

dE / dt = i / ϵ_o.A

Substituting these simplified values in eq. (1)

i_d = ϵ_o.A.i / ϵ_o.A = i

Therefore

i_d = i = 0.15 A

c) It will be valid if both the conduction current and displacement current are taken into account.

8.2. **A parallel plate capacitor (Fig. 8.7) 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.**

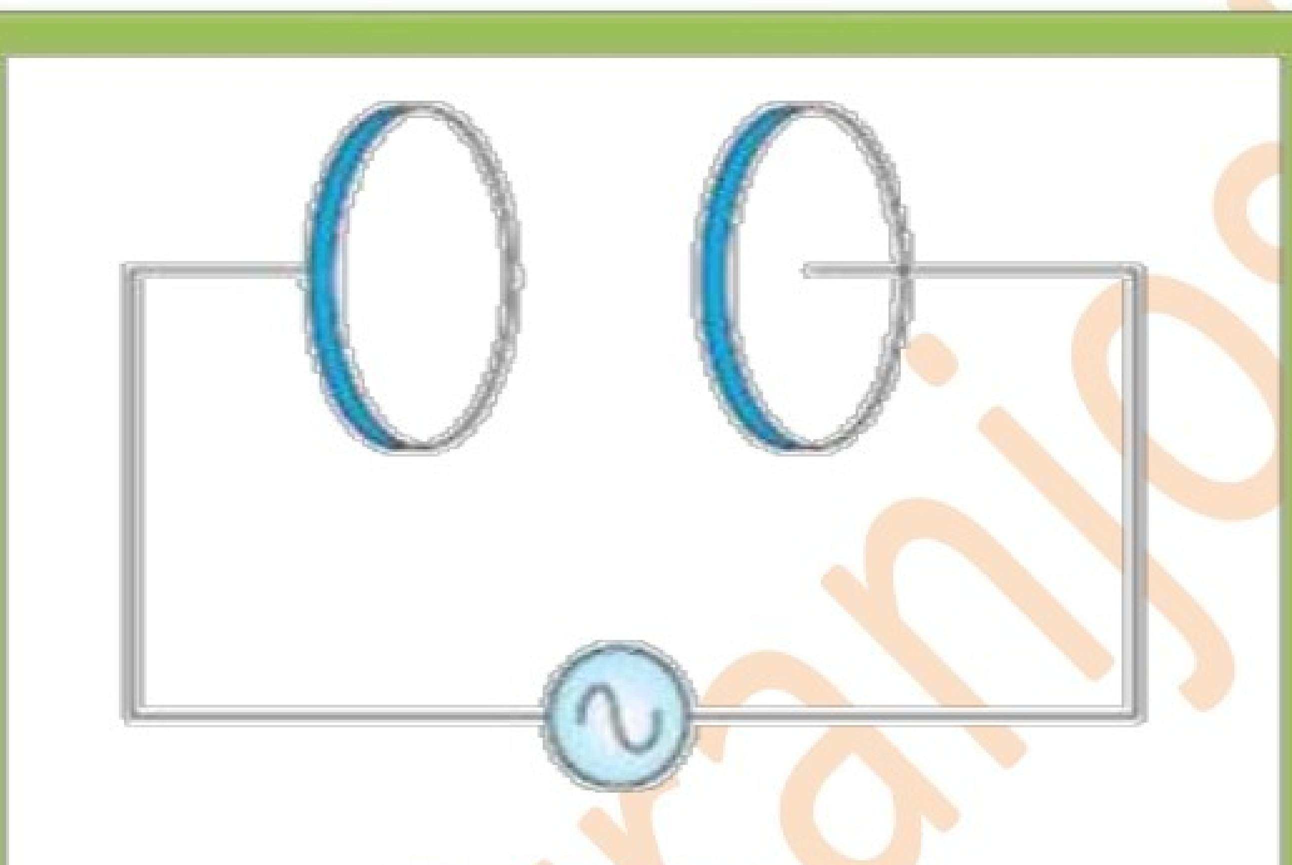

FIGURE 8.7

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.

Given:
R = 0.06 m
C = 100 pF
V = 230 V
w = 300 rad / s

a) Irms = V.wC

Substitution yields

Irms = 6.9 micro-amperes

b) Yes

c) For oscillating B and i

$$B_o = \frac{\mu_o}{2\pi} \cdot \frac{r}{R^2} \cdot i_o$$

i_o = 1.414 x Irms

Putting the required values

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

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

Sol.

Speed c. All electromagnetic waves travel with same speed.

8.4. 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?

Sol.

E and B will be mutually perpendicular and perpendicular to direction of propagation in x-y plane.

Wavelength = c / f

$= 3 \times 10^8 / 30 \times 10^6$

= 10 m

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

Sol.

$\lambda_1 = c / f_1$

$= 40\ m$

$\lambda_2 = c / f_2$

$= 25\ m$

Wavelength band = 40 m – 25 m

8.6. A charged particle oscillates about its mean equilibrium position with a frequency of 109 Hz. What is the frequency of the electromagnetic waves produced by the oscillator?

Sol. Same, i.e., 10^9 Hz.

8.7. The amplitude of the magnetic field part of a harmonic electromagnetic wave in vacuum is B0 = 510 nT. What is the amplitude of the electric field part of the wave?

Sol.

Given Bo = 510 nT

Using the relation

Eo / Bo = c

Eo = c.Bo

Eo = $(3\text{x}10^8).(510\text{x}10^{-9})$

Eo = 153 N / C

8.8. Suppose that the electric field amplitude of an electromagnetic wave is E0 = 120 N/C and that its frequency is ν = 50.0 MHz.
   a) Determine, B0,ω, k, and λ.
   b) Find expressions for E and B.

Sol.

Given:
$E_o = 120\ N/C$
$v = 50\ MHz$

a) $B_o = E_o / c$
   Or $B_o = 400\ nT$

   $\lambda = c / v$
   Or $\lambda = 6\ m$

   $k = 2\pi / \lambda$
   Or $k = 1.05\ rad/m$

   $w = c.k$
   Or $w = 3.14 \times 10^8\ rad/s$

b) $E = E_o \sin(kz - wt)$
   $E = 120 \sin [1.05x - (3.14 \times 10^8)t]$

   $B = B_o \sin(kx - wt)$
   $B = 400 \times 10^{-9} \sin [1.05x - (3.14 \times 10^8)t]\ \hat{k}$

8.9. The terminology of different parts of the electromagnetic spectrum is given in the text. Use the formula E = hν (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?

Sol.

We know

$E = h\nu = hc / \lambda$

Solving for different parts of electromagnetic spectrum

a) Long Radio Waves

$\lambda = 10^5$ m

$E = 1.24 \times 10^{-11}$ eV = 12.4 peV

b) AM Radio

$\lambda = 100$ m

$E = 1.24 \times 10^{-8}$ eV = 12.4 neV

c) Television and FM Radio

$\lambda = 10$ m

$E = 1.24 \times 10^{-7}$ eV = 0.124 μeV

d) Short Radio Waves

$\lambda = 10^{-1}$ m

$E = 1.24 \times 10^{-5}$ eV = 12.4 μeV

e) Microwaves

$\lambda = 10^{-2}$ m

$E = 1.24 \times 10^{-4}$ eV = 0.124 meV

f) Infrared

$\lambda = 10^{-4}$ m

$E = 1.24 \times 10^{-2}$ eV = 12.4 meV

g) Visible

$\lambda = 10^{-6}$ m

$E = 1.24$ eV

h) Ultraviolet

$\lambda = 10^{-7}$ m

E = 12.4 eV

i) X-rays

$\lambda = 10^{-10}$ m

E = 1.24 x 10^4 eV = 12.4 keV

j) Gamma Rays

$\lambda = 10^{-14}$ m

E = 1.24x10^8 eV = 124 MeV

Energy of a photon indicates the amount of energy it needs to be emitted.

8.10. In a plane electromagnetic wave, the electric field oscillates sinusoidally at a frequency of 2.0 × 1010 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 × 108 m s–1.]

Sol.

Given:

Frequency = 2 x 10^{10} Hz

Eo = 48 V / m

a) Wavelength is given by

$\lambda = c / f$

= 300000000 / 20000000000

= 0.015 m

b) Using the relation

Eo / Bo = c

Bo = Eo / c

Or

Bo = 48 / 300000000

= 1.6 x 10^{-7} T

c) Average energy of electric field

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

Average energy of magnetic field

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

Now E and B are related by the expression

E = c.B

Substituting the relevant values in the above relation

$$\sqrt{\frac{2U_E}{\varepsilon_o}} = \sqrt{\frac{1}{\mu_o \varepsilon_o}} \cdot \sqrt{2\mu_o U_B}$$

Squaring both sides and cancelling the common terms, we get

$U_E = U_B$

Hence shown!