Chapter-8

Electromagnetic Waves

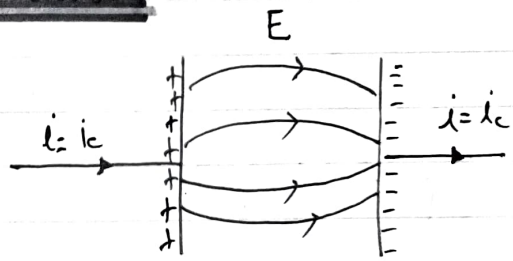
Maxwell's Concept of Displacement Current :-

When a changing electric current flows through the wire, charge on the plates of the capacitor changes with time. Thus a changing electric field is set up b/w the plates of the capacitor.

Maxwell showed that changing electric field intensity is equivalent to a current through the capacitor, and this current was named as displacement current.

Derivation for displacement current

Let $+Q$ and $-Q$ be the charge on the left and right plates of the capacitor. having charge density σ



Now electric field b/w the plates is given by

$$E = \frac{\sigma}{\varepsilon_0} = \frac{Q}{\varepsilon_0 A} \qquad \left\{ \sigma = \frac{Q}{A} \right.$$

$$EA = \frac{Q}{\varepsilon_0}$$

$$\left\{ \Phi_E = EA \right.$$

$$\Phi_E = \frac{Q}{\varepsilon_0}$$

$$\frac{d\Phi_E}{dt} = \frac{1}{\varepsilon_0}\frac{dQ}{dt}$$

$$\frac{d\Phi_E}{dt} = \frac{I_D}{\varepsilon_0} \Rightarrow \boxed{I_d = \varepsilon_0 \frac{d\Phi_E}{dt}}$$

Maxwell's Equations

i) $\oint E \cdot dA = \frac{Q}{\varepsilon_0}$ [Gauss's law for electricity]

ii) $\oint B \cdot dA = 0$ [Gauss's law for Magnetism]

iii) $\oint E \cdot dl = -\frac{d\Phi_B}{dt}$ (Faraday's law)

iv) $\oint B \cdot dl = \left(\mu_0 I_c + \mu_0 \varepsilon_0 \frac{d\Phi_E}{dt}\right)$ [Ampere-Maxwell law]

Electromagnetic Wave ⇒ Electromagnetic wave is a wave in which electric and magnetic fields are perpendicular to the direction of propagation of wave.

Properties of electromagnetic wave ⇒

(1) Electromagnetic wave do not require material medium for their propagation.

(2) Electromagnetic wave follows law of superposition.

(3) The electric field vector and magnetic field vector are interdated to each other.

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

(4) The speed of electromagnetic wave in vacuum is related to μ_0 and ε_0 by

$$C = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}$$

$$U = \frac{1}{2}\varepsilon_0 E^2 + \frac{1}{2}\frac{B^2}{\mu_0}$$

(5) Electromagnetic waves carry energy as they travel through space and this energy is shared equally by electric and magnetic field.

(7) Electromagnetic wave transport momentum as well and it is given by

$$P = \frac{U}{c} = \frac{\text{Total Energy}}{\text{Speed of light}}$$

(8) Energy density of electromagnetic wave in free space is given By

(i) Energy density due to ~~magnetic~~ Electric field $= \frac{1}{2}\varepsilon_0 E^2$

(ii) Energy density due to magnetic field $= \frac{1}{2}\frac{B^2}{\mu_0}$

Important Question Based Upon Displacement Current

Q→1 The charging current for a capacitor is 0.25A. What is displacement current across its plates? (Ans:- 0.25A)

Q→2 A capacitor has been charged by a DC source. What are the magnitude of conduction and displacement current, when it is fully charged?

Soln = Electric flux through the plates of capacitor

~~Q→3~~

$$\Phi_E = \frac{q}{\varepsilon_0}$$

$$I_D = \varepsilon_0 \frac{d\Phi_E}{dt}$$

$$I_D = \varepsilon_0 \frac{d(q/\varepsilon_0)}{dt}$$

$\boxed{I_D = 0}$ as q is constant when fully charged

$$I_C = \frac{C dV}{dt} = 0$$

$$I = I_D = I_C = 0$$