Physics Notes

BY

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Class:10+2

Unit: V

Topic: Electromagnetic Waves

<u>SYLLABUS</u>: UNIT-V

Electromagnetic waves and their characteristics (qualitative ideas only), Transverse of electromagnetic waves, Electromagnetic spectrum (radio waves, microwaves, infrared, visible, ultraviolet, x-rays, gamma rays) including elementary facts about their uses.

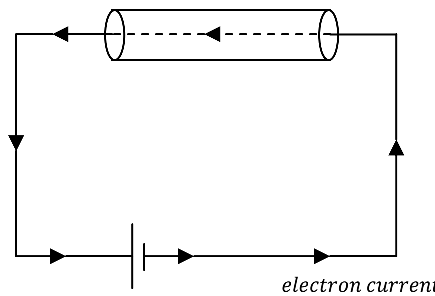
Q.1. Explain '*Conduction Current*' and '*Displacement Current*'?

Ans. **<u>Conduction Current</u>**:

In conduction current, electrons move and complete the loop.

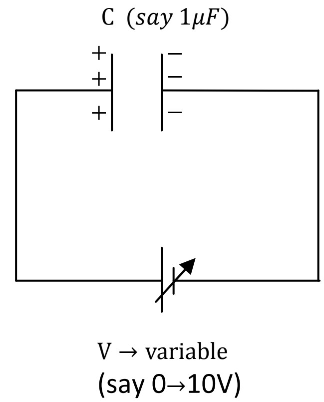
Current flowing in wire is an example of conduction current.

$$I_{cond} = \frac{dq}{dt}$$



<u>Displacement Current</u>:

When a variable voltage is applied across a capacitor, charge does not flow in the complete loop. Charges move in outer circuit from one place to another. No charge flows in between the two plates. Such a current which is due to displacement of charges is called ***Displacement Current***.

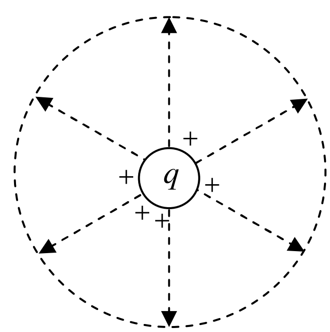


$$I_d = \frac{d(q)}{dt}$$

$$= \frac{d}{dt}(\epsilon_0 \phi_e)$$

$$= \epsilon_0 \frac{d}{dt} \phi_e$$

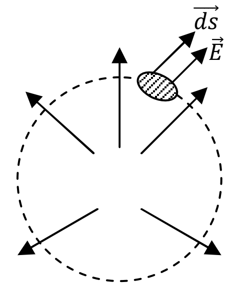
$$= \epsilon_0 \frac{d}{dt} \int E\, ds$$



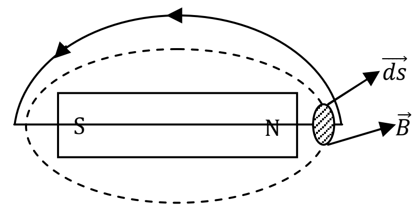
$$\phi_e = \frac{q}{\epsilon_0}$$

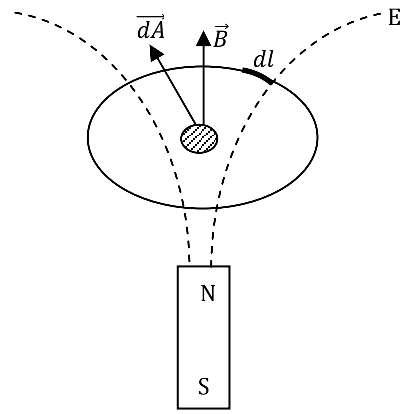
Q2. Write and Explain *Maxwell's* equations?

Ans.1. $\oint \vec{E}\,\overrightarrow{ds} = \frac{q}{\epsilon_0}$ (Gauss's law in electrostatics)



2. $\oint \vec{B}\,\overrightarrow{ds} = 0$ (Gauss's law in magnetostatics)



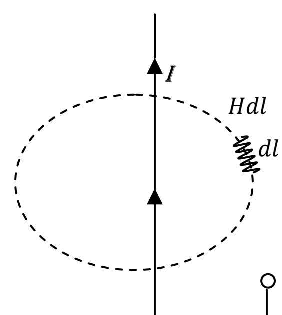


3. e $= \frac{-d\phi}{dt}$

$= \frac{-d}{dt} \int \vec{B} \,.\, \overrightarrow{dA}$

$\oint E\,dl = \frac{-d}{dt}\left[\int \vec{B} \,.\, \overrightarrow{dA}\right]$ (Faradays law of electromagnetic induction)

4. $\oint H\,dl = \mathrm{I}$ (Ampere circuit Law)



Ampere Maxwell Law

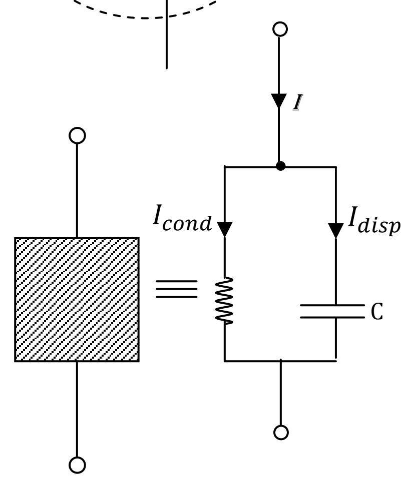
$\oint H\,dl = I_{cond} + I_{dis}$

$= I_{cond} + \frac{d(q)}{dt}$

$= I_{cond} + \epsilon_0 \frac{d}{dt} \phi_e$

$= I_{cond} + \epsilon_0 \frac{d\phi_e}{dt}$

$= I_{cond} + \epsilon_0 \frac{d}{dt} (\int E\,ds)$ (Ampere Maxwell Law)



5. Lorentz Force

$\vec{F} = q(\vec{E} + \vec{V} \times \vec{B})$

Q3. History of Electromagnetic waves? From concept to practical.

Ans. MAXWELL (1865)

Predicted existence of *em* waves with mathematical analysis.

HERTZ (1888)

Performed experiment to demonstrate *em* waves.

$$\lambda \rightarrow 6 \text{ metre}$$

J.C. BOSE (JAGDISH CHANDER BOSE) (1895)

5mm < λ < 25mm (lab level)

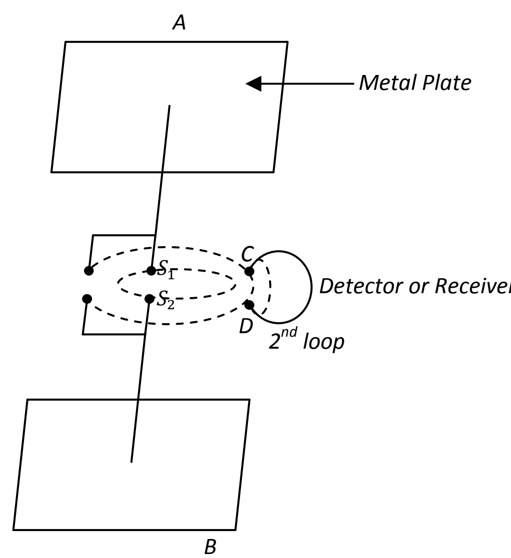
G.C. Marconi (1896)

Wireless communication across English Channel (50 km)

Q4. Explain construction, working of Hertz Experiments?

Ans. $\lambda = \frac{C}{f}$ [$C \rightarrow$ speed, $f \rightarrow$ frequency]

$$= \frac{3 \times 10^8}{5 \times 10^7} = 6\text{m}$$



A and *B* are two large square metal plates of copper or zinc. They are connected to metallic spheres s_1 and s_2. Potential difference is applied. Spark is produced between s_1 and s_2 and electromagnetic waves of high frequency are radiated. Two plates act as capacitor. The oscillating magnetic field linked with ring produces large induced *emf* which causes a spark to appear at the spheres *C* and *D*.

Dielectric strength of air

$$= 30 \frac{KV}{cm}$$

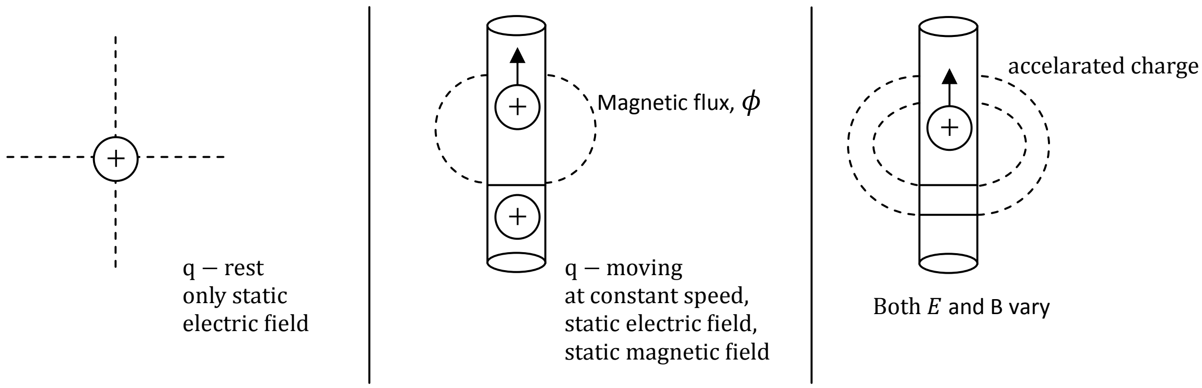
$$f = \frac{1}{2\pi\sqrt{LC}}$$

$$= 5 \times 10^7 HZ$$

Q5. Characteristics/Facts of *em* waves?

Ans.

1. Electromagnetic waves are produced by accelerated or oscillating charge

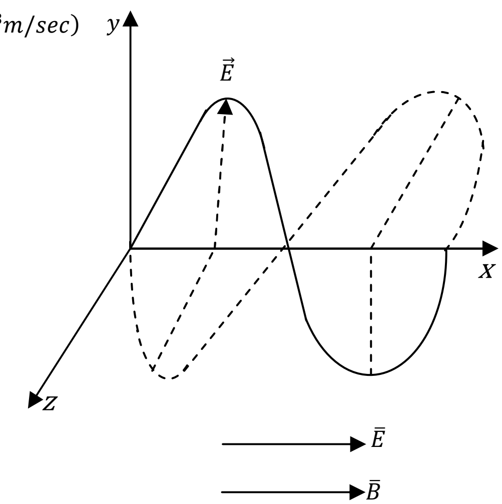


2. Electromagnetic waves can travel without medium

3. Speed in space, in vacuum, is $\frac{1}{\sqrt{\mu_0 \epsilon_0}}$ = 3 x 10^8

   Magnetic prop. Electric prop.

   Speed in any material, say water v = $\frac{1}{\sqrt{\mu_r \mu_0 \epsilon_r \epsilon_0}}$ < C $(3 \text{ x } 10^8 m/sec)$



4. E → X – Y plane

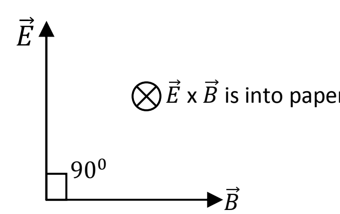
   B → X – Z plane

   E and B become zero, max, min simultaneously.

   $\bar{E}$ and $\bar{B}$ (phasors) are in phase.

   $\frac{\text{E}}{B}$ = C $(3 \text{ x } 10^8 m/\sec in\ vaccum)$

5. $\vec{E}$ and $\vec{B}$ (in SI Units) are perpendicular to each other. Direction of propagation of wave is $\left(\vec{E} \text{ x } \vec{B}\right)$ or $\left(\vec{E} \text{ x } \vec{H}\right)$ is *"Pointing vector"*.



6. speed, v $= \frac{1}{\sqrt{\mu_r \mu_0 \epsilon_r \epsilon_0}}$

$= \frac{1}{\sqrt{\mu_r \mu_0 \epsilon_r \epsilon_0}} < 3 \times 10^8$ (For medium other than vacuum)

7. Intensity $= \frac{Energy}{Area\ time}$

$= \frac{En}{Area\ time}\left(\frac{length}{length}\right)$

$= \frac{Energy}{volume}$ x velocity

= (Energy Density) x C

8. Energy, U $= mc^2$

U = (mc) . C

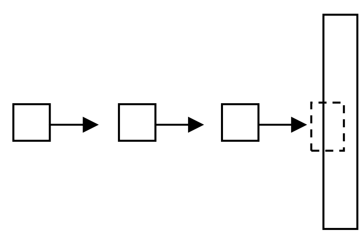
U = pc

$\frac{U}{C} = P$

<u>Case I</u>: 100% absorb (No reflection)

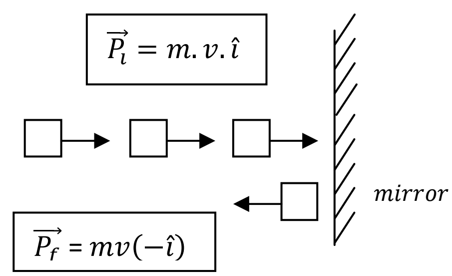
Δp $= \frac{U}{C}$ (Δp→ change in momentum)

$F_{absorbed} = \frac{\Delta P}{\Delta t} = \frac{U/C}{\Delta t} = n.\left(\frac{U}{C}\right)$



n → no. of photons/sec

<u>Case II</u>: 100% reflection



$|\overrightarrow{\Delta P}| = 2p$

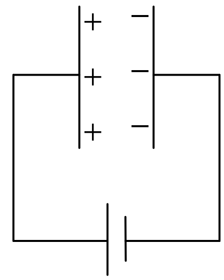
$\Delta P = 2\left(\frac{U}{C}\right)$

$\overrightarrow{P_f} = mv(-\hat{\imath})$

$F_{ref} = \frac{\Delta P}{\Delta t} = \frac{2\left(\frac{U}{C}\right)}{\Delta t} = n\ 2\left(\frac{U}{C}\right)$

Q6. Prove ratio of electric to magnetic energy in em wave is 50 : 50?

Ans. **Electrical Energy Density**:



1. Electrical Energy Density $= \frac{Electric\ Energy}{Volume}$

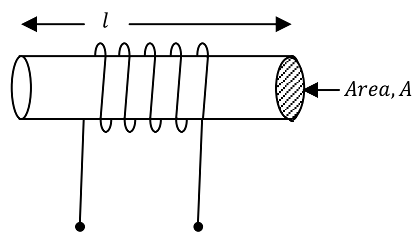
$$= \frac{\frac{1}{2}CV^2}{A.l}$$

$$= \frac{\frac{1}{2}\left(\epsilon_0 \frac{A}{l}\right)V^2}{A.l}$$

$$u_\epsilon = \frac{1}{2}\,\epsilon_0\,\frac{\left(\epsilon_0 \frac{A}{l}\right)V^2}{A.l}$$

$$\boxed{u_\epsilon = \frac{1}{2}\,\epsilon_0\,E^2}$$

2. **Magnetic Energy Density**:



$$H = \frac{N.I}{L}$$

Magnetic Energy Density, $u_m = \frac{\frac{1}{2}LI^2}{Volume}$

$$= \frac{\frac{1}{2}LI^2}{A.l}$$

$$= \frac{1}{2}\left(\frac{N^2}{R_e}\right)\frac{I^2}{A.l}$$

$$= \frac{1}{2}\left(\frac{N^2}{l}\right)\frac{I^2}{A.l}\,.\,\mu A$$

$$= \frac{1}{2}\,\mu_0\left(\frac{NI}{l}\right)^2$$

$$\boxed{u_m = \frac{1}{2}\,\mu_0\,H^2}$$

$$u_m = \frac{1}{2}\,\mu_0\,\frac{B^2}{{\mu_0}^2}$$

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

3. $\frac{u_E}{u_{avg}} = \frac{\frac{1}{2}\epsilon_0 E^2}{\frac{1}{2}\frac{B^2}{\mu_0}}$

$$= \mu_0\,\epsilon_0\left(\frac{E}{B}\right)^2$$

$$= \mu_0\,\epsilon_0\,C^2$$

$$= \mu_0\,\epsilon_0\left(\frac{1}{\sqrt{\mu_0\epsilon_0}}\right)^2$$

$$= \frac{\mu_0\,\epsilon_0}{\mu_0\,\epsilon_0}$$

$$= 1$$

Total Energy Density $= u_E + u_{mag}$

$$= \frac{1}{2}\,\epsilon_0\,E_{rms}^2 + \frac{1}{2}\frac{B_{rms}^2}{\mu_0}$$

$$= \frac{1}{2}\,\epsilon_0\,E_{rms}^2 + \frac{1}{2}\,\epsilon_0\,E_{rms}^2$$

$$= \epsilon_0\,E_{rms}^2$$

$$= \epsilon_0\left(\frac{E_{max}}{\sqrt{2}}\right)^2$$

$$= \frac{\epsilon_0\,E_{max}^2}{2}$$