

Chp-8: Electromagnetic waves

* Displacement current:

- Presence of 'B' over gap of capacitor plates proved presence of electric current due to varying electric field. This is displacement current.

$$\Phi_E = E \cdot A$$

$$= \frac{Q}{4\pi\epsilon_0 r^2} \times A = \frac{Q}{\epsilon_0 A} \times A = \frac{Q}{\epsilon_0}$$

Then,

$$\frac{d\Phi_E}{dt} = \frac{d}{dt} \left(\frac{Q}{\epsilon_0} \right) = \frac{i}{\epsilon_0}$$

$$\therefore i_d = \epsilon_0 \frac{d\Phi_E}{dt}$$

- Formulas of current:

$$\textcircled{1} i_{\text{displacement}} = \epsilon_0 \frac{d\Phi_E}{dt}$$

$$\textcircled{2} i_{\text{current}} = \frac{dQ}{dt}$$

$$\textcircled{3} i = \int_{\text{area}} \mathbf{J} \cdot d\mathbf{l}$$

$$\textcircled{4} \text{In conductors, } i = i_c + 0. \text{ In capacitor } i = 0 + i_d.$$

$$\therefore i_c = i_d$$

* Maxwell's equation:

- Gauss law in electrostatics:

$$\oint \vec{E} \cdot d\vec{s} = \frac{q}{\epsilon_0} \quad (q \text{ and } E \text{ co-exists})$$

- Gauss law in magnetism:

$$\oint \vec{B} \cdot d\vec{s} = 0$$

(Magnetic field is a continuous loop, N. and S cannot be separated)

- Faraday's law of EMI:

$$e = \frac{d\Phi_B}{dt} \Rightarrow \oint E \cdot d\vec{l} = \frac{dB}{dt} \cdot A$$

(Sources of electric field is varying magnetic field).

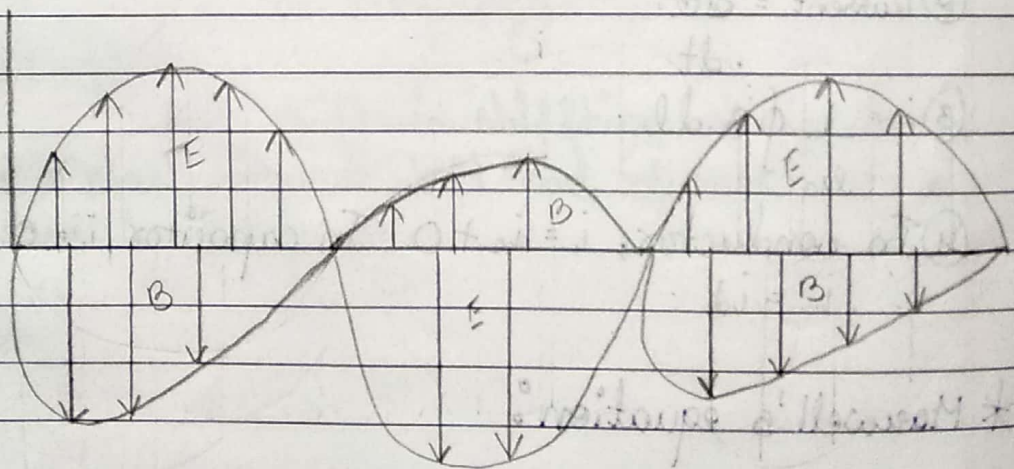
- $\oint B \cdot d\vec{l} = \mu_0 i_c + \mu_0 \cdot \epsilon_0 \cdot \frac{dE}{dt} \cdot A$

$$B \cdot \oint dl = \mu_0 i_c + \mu_0 \cdot \epsilon_0 \cdot \frac{dE}{dt} \cdot A$$

(This proves and relates that changing 'E' creates magnetic field).

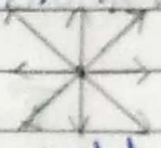
* Electromagnetic waves:

- Wave is a pattern created by disturbance (oscillation) by which energy is carried from one location to other.

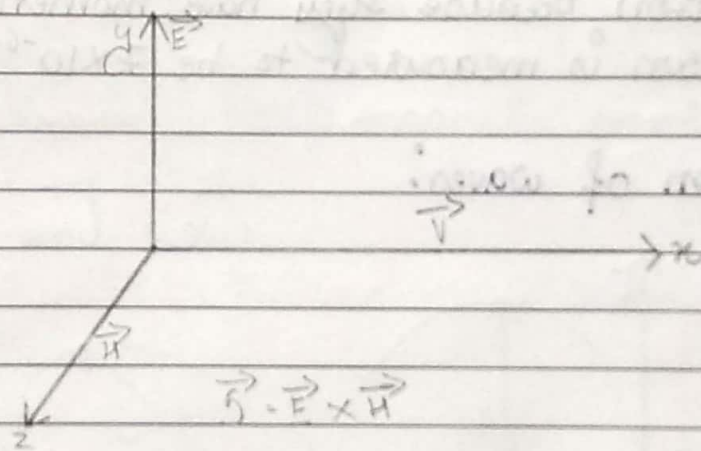


Note:

- ① A stationary charge creates a stationary field.
- ② A moving charge (current) creates magnetic field (stationary).
- ③ Source of electromagnetic waves is an accelerated charge. Oscillation charge is an example of accelerated charge.
- ④ Varying electric field and varying magnetic field constitute electromagnetic waves. These are autonomous (self-sustaining).



* Poynting vector:



- Energy \rightarrow scalar.
- Carrying energy in a particular direction.
- Poynting vector is which has unit watt m^{-2} and represent propagation of energy perpendicular to plain containing \vec{E} and \vec{H} , i.e. in direction of wave propagation.

* Generalisation of momentum:

$$\vec{P} = m \cdot \vec{v} \text{ and } U = mv^2$$

$$\Rightarrow U = mv = P \text{ and } P = \frac{U}{v}$$

Momentum is a quantity of translational invariance. Apply relation, $P = \frac{U}{v}$ in Electromagnetic waves.

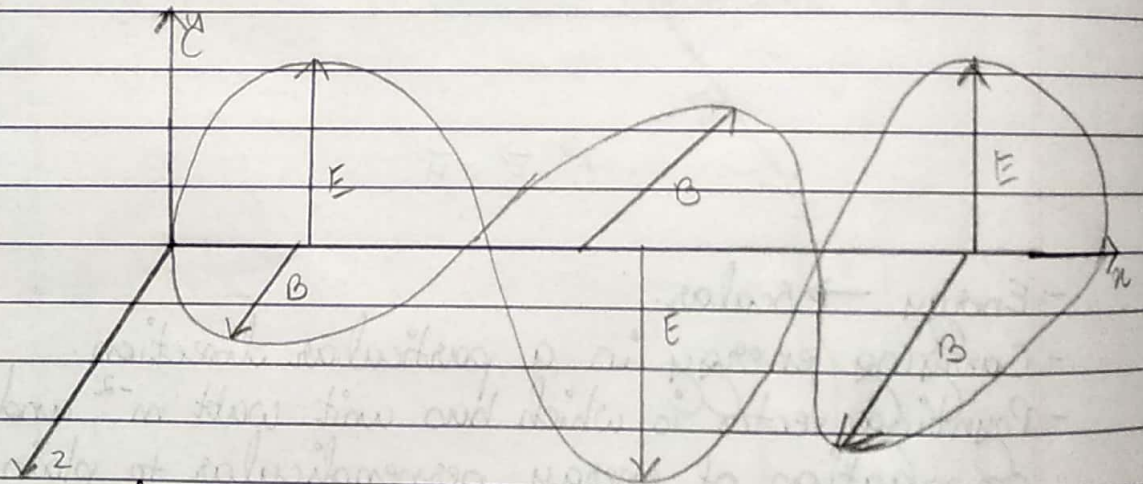
Energy $\propto \nu$. Where, ν - frequency.

Energy = $h\nu$. Where, h - Planck's constant.

$$P = \frac{h\nu}{c} = \frac{h\nu}{\nu \times \lambda} = \frac{h}{\lambda}$$

Electromagnetic waves can apply pressure on obstruction because they have momentum pressure due to sun is measured to be $7 \times 10^{-6} \text{ Nm}^{-2}$.

* Equation of waves:



$$\lambda = \frac{2\pi}{k} \text{ (Wave constant or propagation constant)}$$

ω = angular frequency = $2\pi\nu$.

$$E(x,t) = E_{\text{max}} \times \cos(kx - \omega t + \phi) \leftarrow \text{phase}$$

$$E(z, t) = B_{\text{max}} \times \cos(kx - \omega t + \phi)$$

Velocity of wave $\Rightarrow v = \frac{\omega}{k}$

* Energy in 'E' as well as 'B' :

$$U_E = \frac{1}{2} \epsilon_0 E^2, \quad U_B = \frac{1}{2} B^2$$

Note:

Energy is carried equally by electric and magnetic field.

$$U = U_E + U_B = \frac{1}{2} \epsilon_0 E^2 + \frac{1}{2} B^2$$

Speed of electromagnetic waves is decided by electric permittivity and magnetic permittivity.

$$c \propto \frac{1}{\mu_0} \text{ and } c \propto \frac{1}{\epsilon_0}$$

$$\therefore c = \frac{1}{\sqrt{\mu_0 \epsilon_0}} = 3 \times 10^8 \text{ ms}^{-1}$$

* Spectrum of electromagnetic waves:

Name	Frequency	Wavelength	Source	Detector	Use and cause
① Gamma	5×10^{20}	6×10^{-15}	Decay of nuclear fission, fusion and annihilation	Film, GM tube	Medical, Tracers, Cancer cure.
② X-rays	3×10^{19} 1×10^{16}	1×10^{-10}	Sudden retard of high energy electron	Film (X-ray)	Image detect in bones and metal.
③ UV	$8 - 10^4$	40×10^{-7}	Excitation of atoms and spark	Film	Sun-tan, kill bacteria.
④ Visible light	4×10^{14}	8×10^{-7}	Excitation of atoms and spark flame.	Eye, electronic device	Photo-graph
⑤ Infrared	1×10^{13}	3×10^{-5}	Excitation of atoms and molecules	Electronic detector, black thermo-meter	Remote control, Magic eye.