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Electromagnetic Waves

Displacement current :-

It is a current which produces in the region in which the electric field and hence the electric flux changes with time.

According to Ampere circuital law :-

$$\oint B \cdot dl = \mu_0 I$$

But according to maxwell, there is another current in the circuit which is called, displacement current (I_D).

$$\oint B \cdot dl = \mu_0 (I + I_D)$$

This rule is called Ampere's maxwell Rule

where, $I_D \rightarrow$ Displacement current

$I \rightarrow$ Conduction current.

Also, $\phi = \dfrac{q}{\varepsilon_0}$

Differentiating both side w.r. to time –

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

$$\frac{d\phi}{dt} = \frac{1}{\varepsilon_0} \frac{dq}{dt}$$

$$\because \frac{dq}{dt} = I_D$$

$$\frac{d\phi}{dt} = \frac{1}{\varepsilon_0} I_D$$

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

$$\because \boxed{I_D = \varepsilon_0 \frac{d\phi}{dt}}$$

Now, Ampere's Maxwell rule can be written as —

$$\oint \vec{B} \cdot d\vec{l} = \mu_0 \left(I + \varepsilon_0 \frac{d\phi}{dt} \right)$$

where, μ_0 = permeability
$= 4\pi * 10^{-7}$ V/Am

Maxwell's Equations

(i) $\oint_s E \cdot ds = \frac{q}{\varepsilon_0}$

This equation is Gauss's law in electrostatics.

(ii) $\oint_s E \cdot ds = 0$

This equation is Guass's law in magnetostatics.

(iii) $\oint_s E \cdot dI = -\frac{d}{dt} \oint_s B \cdot ds$

This equation is Faraday's Law of electromagnetic induction.

(iv) $\oint B \cdot dI = \mu_0 \left(I + \varepsilon_0 \frac{d\phi_E}{dt} \right)$

This equation is Ampere - Maxwell law.

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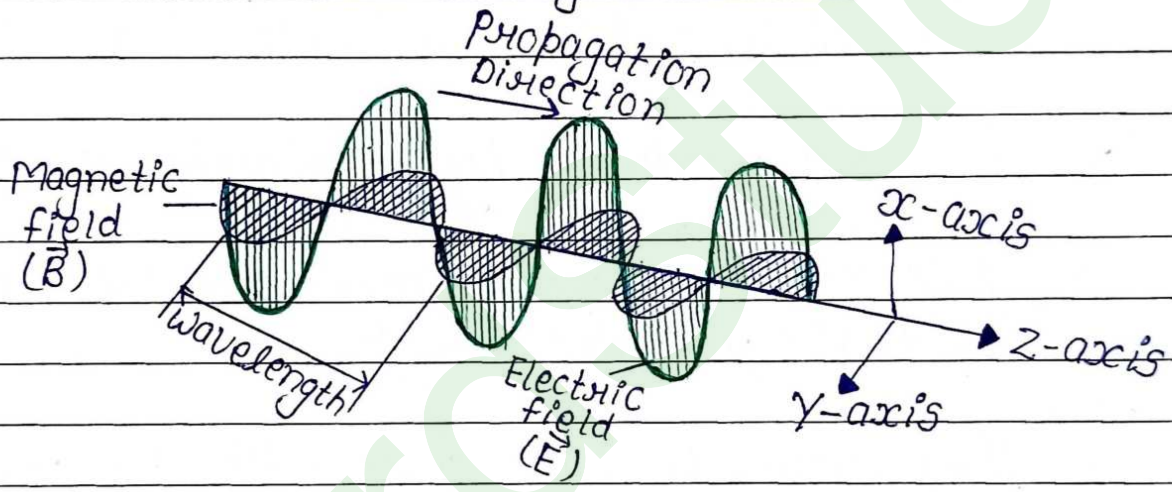
* Electromagnetic Waves :-

Electromagnetic waves are those waves in which electric and magnetic field vectors changes sinusoidally and are perpendicular to each other as well as at right angles to the direction of propagation of wave.

Graphical Representation :-

Electromagnetic wave



Equation of electromagnetic waves :-

$$E = E_x = E_0 \sin(kz - \omega t)$$
$$B = B_y = B_0 \sin(kz - \omega t)$$

Here, $K = \frac{2\pi}{\lambda}$ is called the wave number.

λ = wavelength
$\omega = 2\pi\nu$ is the angular frequency.
ν = frequency in Hertz.

The speed of electromagnetic waves in vaccum or free space is given by,

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

The speed of electromagnetic waves in medium :

$$V = \frac{C}{\sqrt{\mu_r \varepsilon_r}}$$

where,

$$\mu_0 = 4\pi \times 10^{-7} \ wb/Am$$
$$\varepsilon_0 = 8.85 \times 10^{-12} \frac{C^2}{Nm^2}$$

Properties of Electromagnetic waves :-

1) They are produced by accelerated or oscillating charge.
2) They do not require any material or medium for their propagation.
3) They travel in free space with the speed of light. i.e. 3×10^8 m/s.
4) The amplitude of electric field and magnetic field are related to each other by the formulae.

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

5) The cross - product of electric field and magnetic field tells us the direction of propagation of waves.
6) The direction of variation of electric field and magnetic field are always perpendicular to each other.

7) The speed of electromagnetic wave in medium is less than the speed of light in vaccum.

8) Both fields are in same phase.

9) EMW are know to exert 'radiation pressure'. This pressure is due to froce associated rate of ΔP.

Physical quantities of EM waves :-

(i) Speed —

In any other medium than air, the speed of an EM wave is given by,

$$v = \frac{1}{\sqrt{\mu \varepsilon}}$$

μ, ε, indicate the permeability and permittivity of the medium respectively.

(ii) Energy —

Energy density refers to the energy stared per unit volume in the wave. The energy density of the electric field is given by,

$$u_E - \frac{1}{2}\varepsilon_0 E^2$$

Similarly, the energy density of the magnetic field is given by

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

The total energy density is given by

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

The average energy density is given by

$$u_{av} = \frac{1}{4}\varepsilon_0 E_0^2 + \frac{1}{4\mu_0} B_0^2 = \frac{1}{2}\varepsilon_0 E_0^2 = \frac{B_0^2}{2\mu_0}$$

E_0 - peak value of electric field.
B_0 - peak value of magnetic field.

(iii) Intensity -

The quantity of energy crossing per unit area per unit time through a surface, in a direction perpendicular to the surface is called intensity.

$$I = u_{av} \times c = \frac{1}{2}\varepsilon_0 c E_0^2$$

$$I = \frac{\text{Energy}}{\text{Area} \times \text{Time}} \quad ; \text{ But power } (P) = \frac{\text{Energy}}{\text{Time}}$$

$$I = \frac{P}{4\pi r^2}$$

(iv) Momentum —

The momentum of an EM wave, when it is incident on a completely absoring surface is given by

$$P = \frac{\text{Energy}}{\text{speed}} = \frac{u}{c}$$

while incident on a totally reflecting surface, the momentum.

$$P = \frac{2u}{c}$$

(v) Magnetic and electric field —

Let E_0 indicate the maximum value of electric field and B_0 indicate the maximum magnetic field. Then,

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

where c is the speed of EM waves.

* Electromagnetic Spectrum :-

The white range of frequency / wavelength of the electromagnetic waves arranged in an order is known as Electromagnetic spectrum.

It consist of following waves :-

→ Radio waves
→ Micro waves
→ Infrared rays
→ visible light
→ Ultraviolet rays
→ X - rays
→ γ - rays (Gamma rays).

Wave type	Wavelength in m.	Frequency in Hz.
Radio wave	0.3 to 6×10^2	10^9 to 5×10^5
Micro wave	10^{-3} to 0.3	3×10^{11} to 1×10^9
Infrared wave	8×10^{-7} to 1×10^{-3}	4×10^{14} to 3×10^{11}
Visible light	4×10^{-7} to 8×10^{-7}	8×10^{14} to 4×10^{14}
Ultra violet	6×10^{-9} to 4×10^{-7}	5×10^{16} to 8×10^{14}
X-rays	1×10^{-13} to 3×10^{-8}	3×10^{21} X 1×10^{16}
Gamma rays.	0.6×10^{-14} to 1×10^{-10}	5×10^{22} to 3×10^{18}

Uses of Electromagnet waves :-

Radio waves :-

- Used in Amplitude Modulation (AM).
- Used in Frequency Modulation (FM).
- Used in cell phones.
- Used in telivision broadcasting.

Micro waves :-

- Used for cooking purpose in microwaves oven.
- Used in RADAR System for aircraft navigation.

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D) To measure speed of vehicle or speed of Cricket ball.

Source – Klystron / magnetron wave.

Infrared wave :–

→ Use in physiotherapy to treat mascular strain.
→ Use in solar water heater and cookers.
→ Use in weather forecasting and TV remote.
→ Thermal imaging sensor.

→ Infrared rays are readily absorbed by (water) molecules present in most of the substances and increase thermal motion.

→ Used to send signal in fog as this wave scatters less due to its longer wavelength.

Source – Vibration of atom and molecules.

Visible light :–

→ To see the beautiful world.
→ In movie screen, in cinema halls.
→ In laser (Light amplification by stimulated emission of radiation).

Ultraviolet Rays :–

→ To destroy bacteria in surgical instrument.

→ in burglar alarm.
→ in water purifiers.
→ eye surgery

X - Rays :-

→ To detect fractured bones.
→ To cure skin disease.
→ To detect explosive in body of smuglers.
→ In dectection of cracks of bridge.

Gamma Rays :-

→ In treatment of cancer (radiography).
→ To produce nuclear reaction.

* Microwave Oven :-

It is a device used in kitchen for heating and cooking the food.

→ The basic principle of working of oven is to create microwave radiations of suitable frequency in the working space of oven where the food is to be cooked.

→ The radiation may match the resonant frequency of rotation of water molecule which is about 2.45 GHz. In this situation, the energy from the wave is transferred efficiently to the kinetic energy of the molecule.

→ The microwave of this frequency is of energy equivalent to heating up water when microwave of this frequency fall on the food item containing water like fruit, vegetable etc. placed in oven, the water molecule absorb this radiation. There energy increases and the molecule share their energies with neighbouring food molecule. Due to this, the entire food get heated.

→ In microwave oven, we should use the porcelain vessels and not metal container for cooking the food item. It is required to avoid danger of getting electric shock and also melting of metal.

→ Energy transported by EM waves per unit area per sec. is called POYNTING vector ($\vec{S}$).

$$\boxed{\vec{S} = \vec{E} \times \frac{\vec{B}}{\mu_0}}$$