Electromagnetic Waves

Electromagnetic waves are a combination of electric and magnetic fields that oscillate perpendicular to each other and propagate through space. They do not require a medium to travel through, which distinguishes them from mechanical waves like sound waves. The **electromagnetic spectrum** encompasses a wide range of electromagnetic waves with varying frequencies and wavelengths. It includes radio waves, microwaves, infrared, visible light, ultraviolet, X-rays, and gamma rays, in order of increasing energy and frequency.

Formulae:

Displacement Current: Displacement current occur when there is change in electric flux w.r.t time.

Numerically $I_C = I_D$

$$I_D = \varepsilon_o \frac{d\phi}{dt} = \varepsilon_o \frac{d(EA)}{dt}$$

And, the generalisation made by Maxwell is- $I = I_e + I_D = I_c + \varepsilon_o \frac{d\phi}{dt}$

Modified Ampere's circuital Law or Ampere- Maxwell Law: $\oint B.dl = \mu_o I_c + \mu_o \varepsilon_o \frac{d\phi}{dt}$

Magnetic Field Between Plates of Capacitor:

- Since, the electric field between plates is: $\vec{E} = \frac{Q/A}{\varepsilon_o}\hat{x}$ where Q is the charge on a plate and A is the area of the plate, and $\hat{x}$ is directed from one plate to the other.
- Thus, the magnetic field from a changing electric field is: $\oint \vec{B}.d\vec{l} = \mu_o I_{enc} + \mu_o \varepsilon_o \frac{d\phi_E}{dt}$

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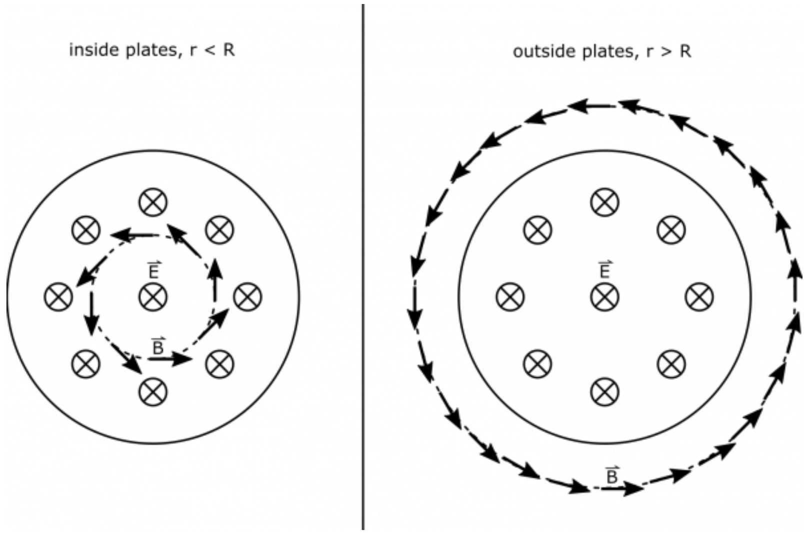
- Let's choose circular plates,



- Magnetic field between plates: $B(r)=\begin{cases}\dfrac{\mu_o I_r}{2\pi R^2} & r<R \\ \dfrac{\mu_o I}{2\pi r} & r>R\end{cases}$

Poynting Vector: The Poynting vector represents the direction of the energy flux density of the electromagnetic field. The Poynting vector expression is expressed as: $\vec{s}=\frac{1}{\mu_o}(\vec{E}\times\vec{B})$ and

$$S=\frac{1}{\mu_o}EB\sin\theta$$

Maxwell's Equations:

1. $\oint E.dA=\frac{Q}{\varepsilon_o}$ (Gauss's Law for electricity)
2. $\oint B.dA=0$ (Gauss's Law for magnetism)
3. $\oint E.dl=-\frac{d\phi}{dt}$ (Faraday's Law)
4. $\oint B.dl=\mu_o I_c+\mu_o\varepsilon_o\frac{d\phi}{dt}$ (Ampere-Maxwell Law)

Nature of electromagnetic waves:

- **Mathematical Expression of EM waves:** If electric field E_x propagate is along x-axis and magnetic field B_y is along y-axis where wave propagates in z-axis then these all are mutually perpendicular to each other. Hence,

$$E_x=E_o\sin(kz-\omega t)$$
$$B_y=B_o\sin(kz-\omega t)$$

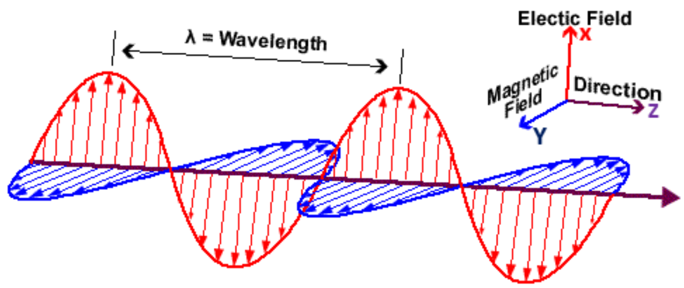
Where, k is related to the wave length λ of the wave then: $k = \frac{2\pi}{\lambda}$

ω=angular frequency

The speed of propagation= $\frac{\omega}{k}$

- To calculate the speed of wave: $\omega = ck,\ c = \frac{1}{\sqrt{\mu_o \varepsilon_o}}$ (in vacuum)
- Relationship of magnitude of electric field and magnetic field: $B_o = \frac{E_o}{c}$
- Speed of wave in medium: $c = \frac{1}{\sqrt{\mu\ \varepsilon}}$.

  Hence, by putting the value of permittivity and magnetic permeability we can find the speed of light which is also an electromagnetic wave which equals to $3 \times 10^8 m/s$



- Radiation pressure: Electromagnetic waves (like other waves) carry energy and momentum. Because electromagnetic waves carry momentum, they also generate pressure, this is called as radiation pressure. Which can express as:

$$p = \frac{U}{c}$$

If the total energy transferred to the surface in time t is U, this can be shown as: The size of the total impulse transmitted to this surface e.g., complete absorption.

Properties of Electromagnetic Waves:

- Electromagnetic waves can propagate through a vacuum without the need for a medium. This is a distinguishing feature, as mechanical waves (such as sound waves) require a medium for propagation.
- Electromagnetic waves can be polarized, meaning the oscillations of the electric and magnetic fields occur in a specific orientation. Polarization can be linear, circular, or elliptical.
- Electromagnetic waves are transverse waves, meaning that the oscillations of the electric and magnetic fields are perpendicular to the direction of wave propagation.
- Electromagnetic waves span a broad spectrum of frequencies and wavelengths. This spectrum includes radio waves, microwaves, infrared radiation, visible light, ultraviolet radiation, X-rays, and gamma rays. Each region of the spectrum has distinct properties and applications.
- Electromagnetic waves can interact with matter in various ways, including reflection, refraction, diffraction, absorption, and transmission.
- Different materials have different interactions with specific regions of the electromagnetic spectrum.

Electromagnetic Waves

- Electromagnetic waves exhibit both wave-like and particle-like properties. This duality is described by the wave-particle duality concept in quantum mechanics.
- The electromagnetic wave is a second order differential equation.
- The amplitude of an electromagnetic wave represents the maximum displacement from the equilibrium position.
- In the context of electromagnetic waves, amplitude is related to the intensity or brightness of the wave.

Electromagnetic Spectrum: