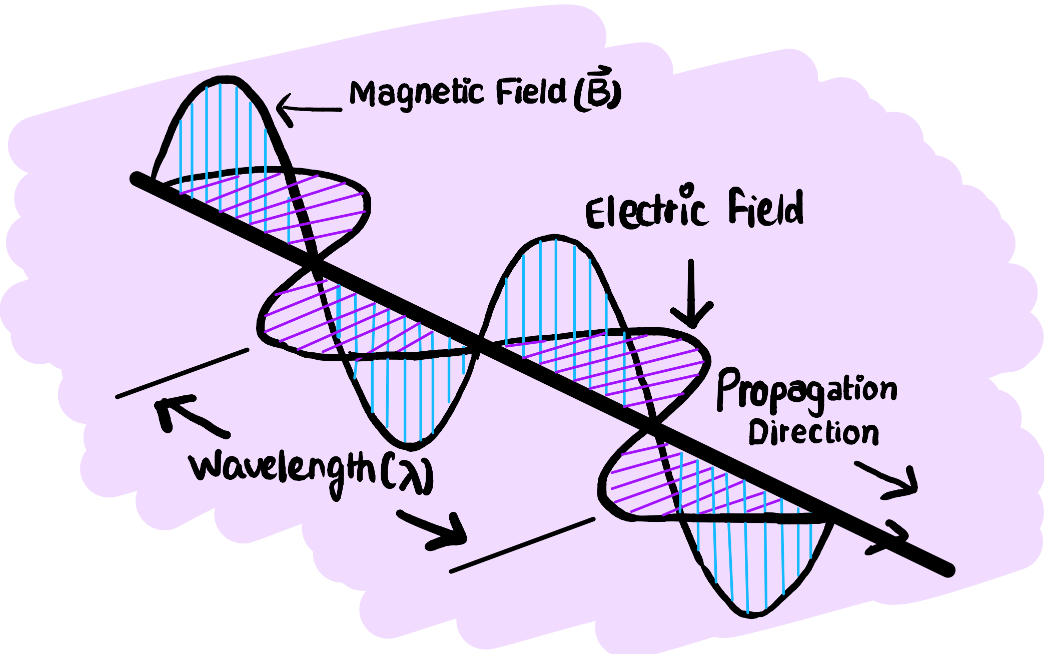
E.M Waves



CLASS 12 | New Notes | PHYSICS

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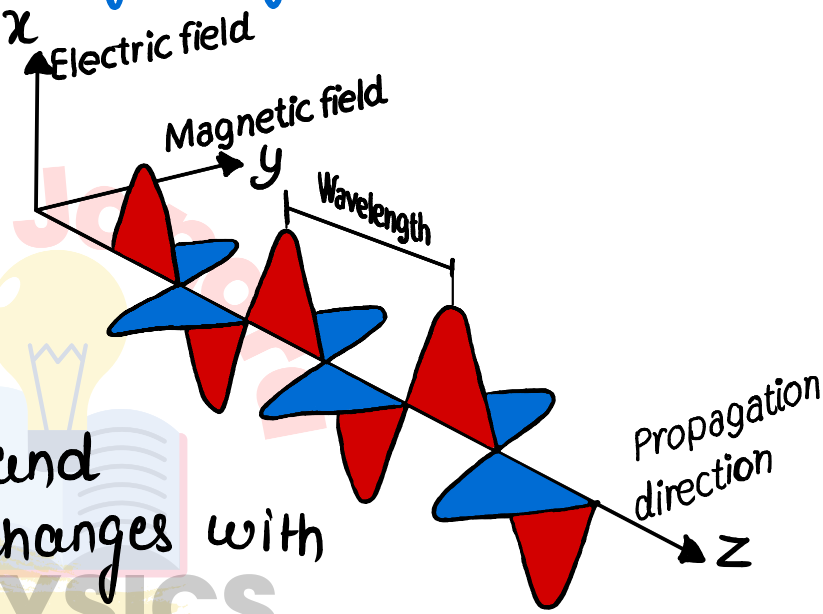
• Electromagnetic Waves

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

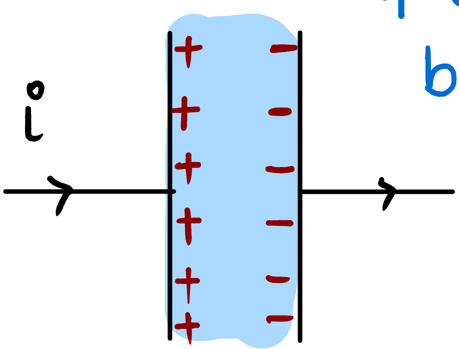


• Displacement Current

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

Displacement Current $\boxed{I_D = \varepsilon_0 \frac{d\phi_E}{dt}}$ ϕ_E = Electric flux

Derivation



if E is the electric field in the region between the plates of the Capacitor then

$$E = \frac{\sigma}{\varepsilon_0} = \frac{Q/A}{\varepsilon_0} = \frac{Q}{A\varepsilon_0}$$

$\sigma = \frac{Q}{A}$ surface charge density on the capacitor plate whose area is A.

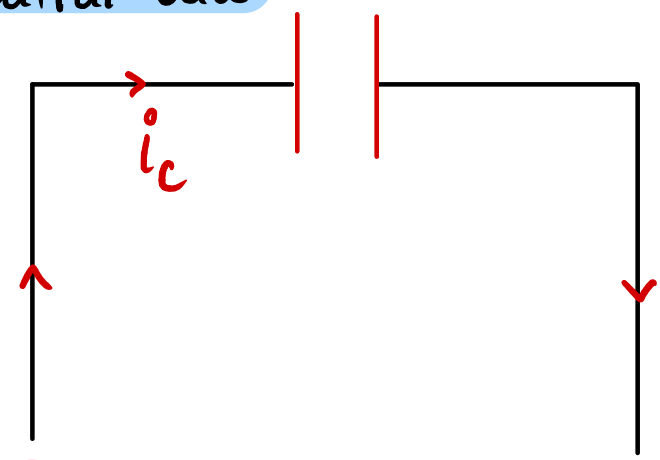
$\phi = EA$

so $Q = \varepsilon_0 EA$ or $\boxed{Q = \varepsilon_0 \phi}$

Thus $i_d = \frac{dQ}{dt}$ $\Rightarrow$ $\boxed{i_d = \varepsilon_0 \frac{d\phi}{dt}}$ i_d = displacement current.

Modification of Ampere's Circuital law

$$\oint \vec{B} \cdot d\vec{l} = \mu_0 (i_c + i_d)$$



i_d = displacement Current.

$$i_d = \varepsilon_0 \frac{d\phi_E}{dt}$$

MAXWELL'S EQUATIONS

1. $\oint \mathbf{E} \cdot d\mathbf{A} = Q / \varepsilon_0$ (Gauss's Law for electricity)
2. $\oint \mathbf{B} \cdot d\mathbf{A} = 0$ (Gauss's Law for magnetism)
3. $\oint \mathbf{E} \cdot d\mathbf{l} = \frac{-d\Phi_B}{dt}$ (Faraday's Law)
4. $\oint \mathbf{B} \cdot d\mathbf{l} = \mu_0 i_c + \mu_0 \varepsilon_0 \frac{d\Phi_E}{dt}$ (Ampere – Maxwell Law)

Source of Electromagnetic wave

An electric charge at rest has an electric field in the region around it but no magnetic field. when a charge moves, it produces both electric and magnetic fields.

If the charge moves with a constant velocity, the magnetic field will not change with time. It cannot produce electromagnetic wave.

NOTE :→ Maxwell found that, the acceleated or oscillating charge radiate electromagnetic waves

- These charge produce an oscillating electric field in space, which produces an oscillating magnetic field, which in turn is a source of oscillating electric field and so on.

The oscillating electric and magnetic fields regenerate each other as a continuous wave which propagates through space.

NOTE :→ The frequency of em wave is equal to the frequency of oscillation of charge.

$$\boxed{\nu = \frac{1}{2\pi\sqrt{LC}}}$$

The equation of plane progressive electromagnetic wave can be written as

$E_x = E_0 \sin(kz - \omega t)$ — E_x along x-axis

$B_y = B_0 \sin(kz - \omega t)$ — B_y along y-axis

Both varies sinusoidally with z, at given time.

(z is the direction of propagation)

where $K = \frac{2\pi}{\lambda}$ $\quad \lambda$ = wavelength of wave

ω = angular frequency $\quad K$ = wave vector

$\omega = ck \Rightarrow c = \frac{\omega}{K}$ (speed of propagation of the wave)

Properties of E·M Waves

- EM waves are transverse in nature.
- These waves propagate through space with speed of light, i.e 3×10^8 m/s. given by $C = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}$.

μ_0 is permeability of free space and ε_0 is permittivity of free space.

- Speed of em wave in a medium is $v = \frac{1}{\sqrt{\mu\varepsilon}}$

[ε and μ are the permittivity and magnetic permeability of a material medium.

- $C = \frac{E_0}{B_0}$ — E_0 and B_0 are maximum values of electric and magnetic field vectors.
- The rate of flow of energy in an electromagnetic wave is described by the vector $\vec{S}$ called the poynting vector.

$$\vec{S} = \frac{1}{\mu_0}(\vec{E}\times\vec{B})$$

  SI unit of S is watt/m^2 or joules/second.

- The energy in electromagnetic waves is divided equally between electric field and magnetic field vectors.
- The energy density (energy per unit volume) in an electric field E in vacuum is $\frac{1}{2}\varepsilon_0 E^2$ and that in magnetic field $\vec{B}$ is $\frac{B^2}{2\mu_0}$.
- The electric vector is responsible for the optical effects of an electromagnetic wave.
- Intensity of EM waves: Energy crossing per unit area per unit time perpendicular to the directions of Propagation of electromagnetic waves.

Intensity $\Rightarrow \boxed{I \Rightarrow \frac{E}{A \times t}}$ or $\boxed{I = \frac{1}{2}\varepsilon_0 E_0^2 c}$

• linear momentum of EM wave is $p = \frac{U}{c}$

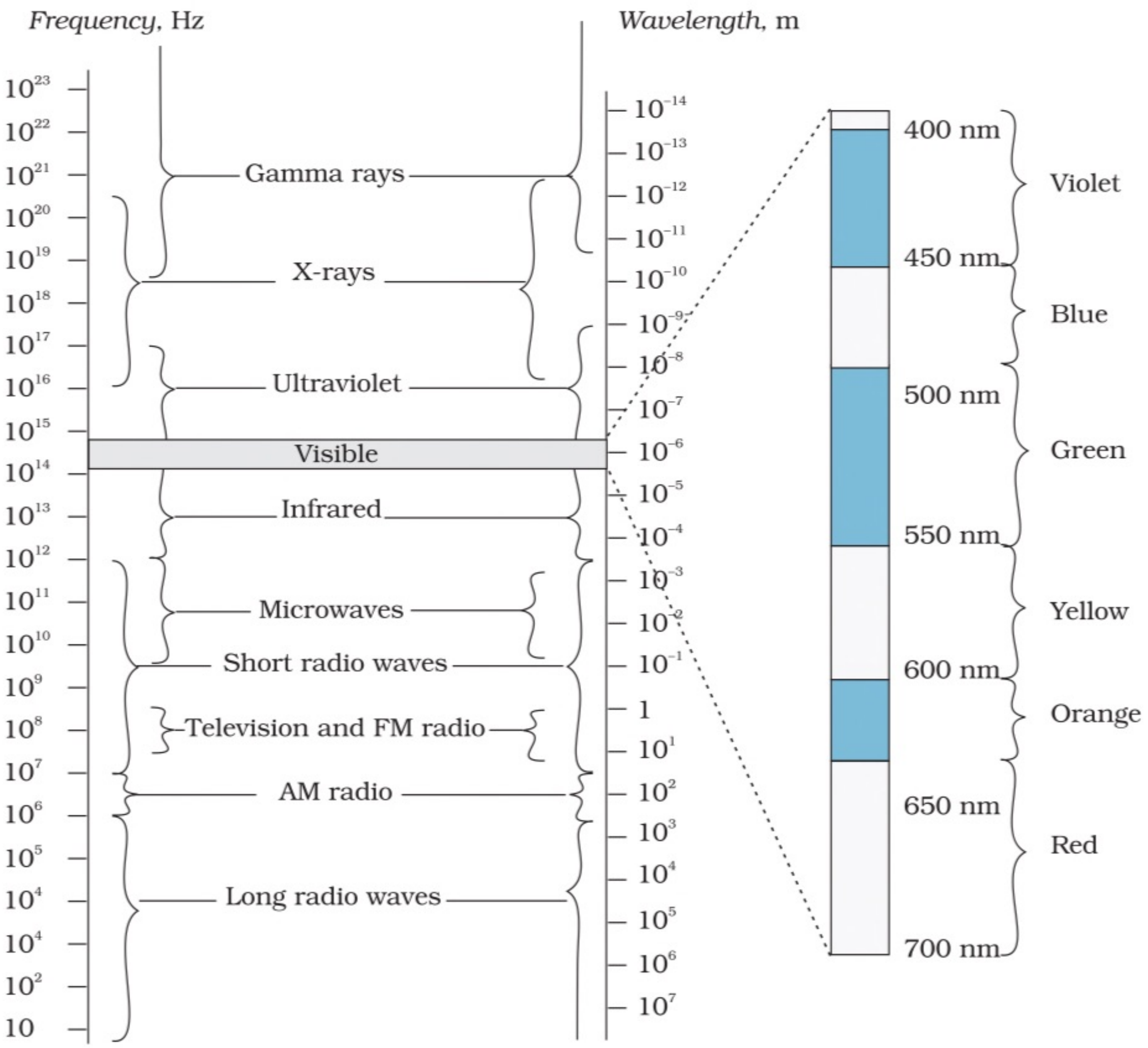
if a wave incident on a completely absorbing surface, then $\boxed{P = \frac{U}{c}}$

if a wave incident on a totally reflecting surface, then $\boxed{P = \frac{2U}{c}}$

• The existence of electromagnetic waves was confirmed by Hertz experimentally in 1888.

Electromagnetic Spectrum

The orderly arrangement of EM waves in increasing or decreasing order of wavelength λ and frequency ν is called electromagnetic spectrum.



The electromagnetic spectrum, with common names for various part of it. The various regions do not have sharply defined boundaries.

TABLE 8.1 DIFFERENT TYPES OF ELECTROMAGNETIC WAVES

Type	Wavelength range	Production	Detection
Radio	> 0.1 m	Rapid acceleration and decelerations of electrons in aerials	Receiver's aerials
Microwave	0.1m to 1 mm	Klystron valve or magnetron valve	Point contact diodes
Infra-red	1mm to 700 nm	Vibration of atoms and molecules	Thermopiles Bolometer, Infrared photographic film
Light	700 nm to 400 nm	Electrons in atoms emit light when they move from one energy level to a lower energy level	The eye Photocells Photographic film
Ultraviolet	400 nm to 1nm	Inner shell electrons in atoms moving from one energy level to a lower level	Photocells Photographic film
X-rays	1nm to 10^{-3} nm	X-ray tubes or inner shell electrons	Photographic film Geiger tubes Ionisation chamber
Gamma rays	$<10^{-3}$ nm	Radioactive decay of the nucleus	-do-

Gamma Rays

Wavelength range : 10^{-14} m to 10^{-12} m

Production : By disintegration of atomic Nuclei

Properties : Chemical reaction on photographic plates, fluorescence, ionisation, diffraction, highly-penetrating and chargeless

Uses : Provide information about structure of atomic nuclei, for the treatment of cancer disease.

X-Rays

Wavelength range : 10^{-12} m to 10^{-9} m

Production : By Bombardment of High-energetic electrons on heavy Target.

Properties : All properties of Gamma Rays but less penetrating and more ionising.

Uses : Reveal structures of inner atomic electron shells and Crystals, helps in medical diagnosis.

UV Radiation

Wavelength range : 10^{-8} m to 4×10^{-7} m

Production : By sun, electric discharge of gases.

Properties : All properties of Gamma rays but less penetrating, produce photoelectric effect

Uses : In detection of invisible writing, forged documents, finger print and to preserve food stuffs, make drinking water free from bacterias.

Visible light

Wavelength range : 4×10^{-7} m to 7.8×10^{-7} m

Production : Radiated by excited atoms in gases and incandescent bodies.

Properties : Reflection, refraction, interference, diffraction, polarisation, photoelectric effect, photographic action and sensation of sight.

Uses : In all optical devices eg microscopes, telescopes, camera etc. It is used to study molecular structure and arrangement of electrons in external shells of atoms.

Infrared Radiation

Wavelength range : 7.8×10^{-7} m to 10^{-3} m

Production : From hot bodies

Properties : Heating effect, reflection, refraction, diffraction, penetration through fog.

Uses : In green houses to keep the plants warm, in infrared photography, for operating electronic devices by remote.

Microwaves

Wavelength range : 10^{-3} m to 10^{-1} m

Production : By oscillating currents in special vacuum tubes.

Properties : Reflection, polarisation.
The waves of range from 1mm to 3cm are also called microwaves.

Uses : In radar, long distance wireless communication via satellites and in microwave ovens.

Radio Waves :

Wavelength range : 10^{-1} m to 10^{4} m

Production : Weak radiation from A.C circuits.

Properties : Reflected by layers of atmosphere.

Uses : In radio and television transmission.