DCAM classes
Dynamic Classes for Academic Mastery

Electromagnetic Waves

1.1 Displacement Current

The current which comes into existence in the region in which the electric field and the electric flux is changing with time is known as displacement current. It is expressed by the formulae,

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

where, ϕ_E is the electric flux.

Need for Displacement Current

Ampere's circuital law for conduction current during charging of a capacitor was found inconsistent. Therefore, Maxwell modified Ampere's circuital law by introducing the concept of displacement current.

1.2 Maxwell's Equations of Electromagnetic Waves

Maxwell's equations are the basic laws of electricity and magnetism.

These equations give complete discription of all electromagnetic interactions. On the basis of his equations, Maxwell predicted the existence of electromagnetic waves.

There are four Maxwell's equations which are below

(i) Gauss' law in electrostatics, $\oint \mathbf{E} \cdot d\mathbf{S} = q/\varepsilon_0$

(ii) Gauss' law in magnetostatics, $\oint \mathbf{B} \cdot d\mathbf{S} = 0$

(iii) Faraday's law of electromagnetic induction,
$$\oint \mathbf{E} \cdot d\mathbf{l} = -\, d\phi_B/dt$$

(iv) Ampere-Maxwell's circuital law,
$$\oint \mathbf{B} \cdot d\mathbf{l} = \mu_0 (I_C + I_D)$$

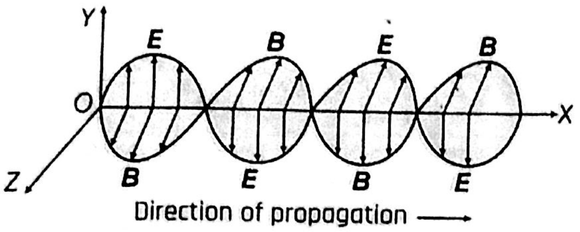
where, I_C is conduction current and I_D is displacement current.

1.3 Electromagnetic Waves

An electromagnetic wave is a wave radiated by an accelerated or oscillatory charge in which varying magnetic field is the source of electric field and varying electric field is the source of magnetic field. Thus, two fields become source of each other and the wave propagates sinusoidally in a direction perpendicular to both the fields.

Transverse Nature of Electromagnetic Waves

Electromagnetic waves are transverse in nature, i.e. electric and magnetic fields are perpendicular to each other and to the direction of wave propagation.



E (electric field) and **B** (magnetic field) in electromagnetic waves are in same phase.

Speed of electromagnetic wave

$$c = E_0/B_0 = 1/\sqrt{\mu_0\varepsilon_0} = 3\times10^8\ \text{ms}^{-1}$$

$$\left[\begin{aligned}\text{where, } \mu_0 &= 4\pi\times10^{-7}\text{Ns}^2\text{C}^{-2}\\ \varepsilon_0 &= 8.85\times10^{-12}\text{C}^2\text{N}^{-1}\text{m}^{-2}\end{aligned}\right]$$

where, μ_0 and ε_0 are the absolute permeability and absolute permittivity of free space, respectively.

Important Characteristics of Electromagnetic Waves

There are some important characteristics of electromagnetic waves

(*i*) The energy in electromagnetic wave is divided on average equally between electric and magnetic fields.

(*ii*) Energy associated with an electromagnetic wave is $U = \frac{1}{2}\varepsilon_0 E^2 + \frac{B^2}{2\mu_0}$.

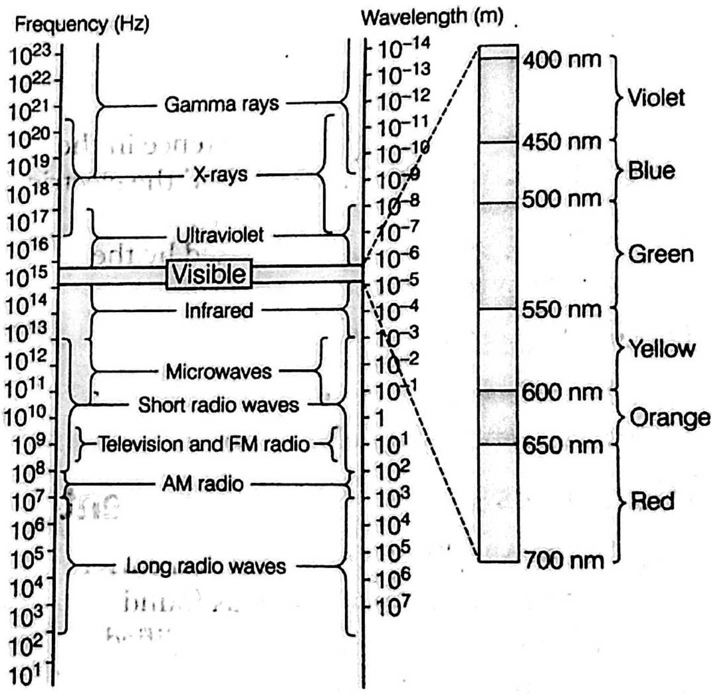
(*iii*) Electromagnetic waves also carry momentum and energy. Linear momentum delivered to the surface by an EM wave is $p = U/c$. where, U = total energy transmitted by electromagnetic waves and c = speed of electromagnetic wave. Since, it has momentum an EM wave also exerts pressure called radiation pressure.

(*iv*) Electromagnetic waves are not deflected by electric and magnetic fields.

(*v*) Electromagnetic waves obey the principle of superposition. They show the properties of reflection, refraction, interference, diffraction and polarization.

1.4 Electromagnetic Spectrum

The systematic sequential distribution of electromagnetic waves in ascending or descending order of frequency or wavelength is known as electromagnetic spectrum. The wavelength range varies from 10^{-12} m to 10^4 m, i.e. from γ-rays to radio waves.



The electromagnetic spectrum with common names for various part of it

Different types of electromagnetic waves

Type	Wavelength range	Frequency range (Hz)	Production	Detection
Radio wave	> 0.1 m	10^4 to 10^9	Rapid acceleration and deceleration of electrons in aerials.	Receiver's aerials
Microwave	0.1 m to 1 mm	10^9 to 10^{11}	Klystron valve or magnetron valve.	Point contact diodes
Infrared wave	1 mm to 700 nm	3×10^{11} to 4×10^{14}	Vibration of atoms and molecules.	Thermopile, Bolometer, infrared photographic film
Light	700 nm to 400 nm	4×10^{14} to 8×10^{14}	Electrons in atoms emit light when they move from one energy level to a lower energy level.	The eye, photocells, photographic film
Ultraviolet rays	400 nm to 1 nm	8×10^{14} to 8×10^{16}	Inner shell electrons in atoms moving from one energy level to a lower level.	Photocells, photographic film
X-rays	1 nm to 10^{-3} nm	1×10^{16} to 3×10^{21}	X-ray tubes or inner shell electrons.	Photographic film Geiger tubes, ionisation chamber
γ-rays	$<10^{-3}$ nm	5×10^{18} to 5×10^{22}	Radioactive decay of the nucleus.	Photographic film, ionisation chamber

Uses of Electromagnetic Waves

There are many uses of electromagnetic waves

Radio waves

(*i*) In radio and TV communication.

(*ii*) In astronomical field.

Microwaves

(*i*) In RADAR communication.

(*ii*) In analysis of molecular and atomic structure.

(*iii*) For cooking purpose.

(*iv*) In long distance communication systems *via* geo-stationary satellites.

Infrared waves

(*i*) In knowing molecular structure.

(*ii*) In remote control of TV, VCR, etc.

(*iii*) In treatment of muscular complaints.

(*iv*) In green house to maintain temperature suitable for plants.

Visible rays

(*i*) To see things, avoid bumping from them and escape danger.

(*ii*) To find other living things with which to consort so as to prolong the species.

Ultraviolet rays

(*i*) Used in burglar alarm.

(*ii*) To kill germs in minerals (in food preservation).

(*iii*) To study molecular structure.

X-rays

(*i*) In medical diagnosis and to cure malignant growths and untracable skin diseases as they pass through the muscles not through the bones.

(*ii*) In detecting faults, cracks, etc., in metal products.

Gamma-rays

(*i*) For food preservation by killing pathogenic microorganisms.

(*ii*) In radiotherapy for treatment of tumour and cancer.