ELECTROMAGNETIC WAVES

DISPLACEMENT CURRENT

(i) The displacement current is defined as

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

Where ϕ_E is the electric flux linked between the plates of the capacitor at any instant. Therefore Ampere-Maxwell circuital law may be expressed as

$$\oint \vec{B}.\vec{dl} = \mu_0 \left(I_C + \varepsilon_0 \frac{d\phi_E}{dt} \right)$$

(ii) The conduction current and the displacement current are always equal, i.e., $I_C = I_D$

(iii) Like conduction current, the displacement current is also the source of magnetic field.

PRODUCTION OF ELECTROMAGNETIC WAVES

(i) According to Maxwell, an accelerated charge sets up a magnetic field in its neighborhood. The magnetic field, in turn, produces an electric field in that region. Both these fields vary with time and act as sources for each other.

PROPERTIES OF ELECTROMAGNETIC WAVES

(i) The electric and magnetic fields satisfy the following wave equations, which can be obtained from Maxwell's third and fourth equations.

$$\frac{\partial^2 E}{\partial x^2} = \mu_0 \varepsilon_0 \frac{\partial^2 E}{\partial t^2}$$

(ii) Electromagnetic waves travel through vacuum with the speed of light c, where

$$c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}} = 3 \times 10^8 \text{ m/s}$$

(iii) The electric and magnetic fields of an electromagnetic wave are perpendicular to each other and also perpendicular to the direction of wave propagation. Hence, these are transverse waves.

(iv) The instantaneous magnitude of $\vec{E}$ and $\vec{B}$ in an electromagnetic wave are related by the expression

$$\frac{E}{B} = c$$

(v) Electromagnetic waves carry energy. The rate of flow of energy crossing a unit area is described by the Poynting vector $\vec{S}$

Where,

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

(vi) Electromagnetic waves carry momentum and hence can exert pressure (P) on surfaces, which is called radiation vector $\vec{S}$, incident on a perfectly absorbing surface

$$P = \frac{S}{c}$$

and if incident on a perfectly reflecting surface $P = \frac{2S}{c}$

(vii) The electric and magnetic fields of a sinusoidal plane electromagnetic wave propagating in the positive x-direction can also be written as

$$E = E_m \sin(kx - \omega t)$$

$$B = B_m \sin(kx - \omega t)$$

Where w is the angular frequency of the wave and k is wave number which are given by

$$w = 2 w f \quad \text{and } k = \frac{2\pi}{\lambda}$$

(viii) The intensity of a sinusoidal plane electro-magnetic wave is defined as the average value of Poynting vector taken over one cycle.

$$S_{av} = \frac{E_m B_m}{2\mu_0} = \frac{E_m^2}{2\mu_0 c} = \frac{c}{2\mu_0} = B_m^2$$

ELECTROMAGNETIC SPECTRUM

(i) The orderly distribution of electromagnetic waves (on the basis of wavelength or frequency) in the form of distinct groups having widely differing properties is called the electromagnetic spectrum.

The following table gives a complete and detailed picture of electromagnetic spectrum

(ii) Various parts of electromagnetic spectrum

S. No.	Radiation	Discover	How produced	Wavelength range	Frequency range	Energy range	Properties	Application
1.	γ&Rays	Henry Becquerrel and Madam Curie	Due to decay of radioactive nuclei	10^{-14} m to 10^{-10}m.	3×10^{22} Hz to 3×10^{18} Hz	10^{7}eV – 10^{4}eV	(a) High penetrating power (b) Uncha-rged (c) Low ionising power	(a) Gives information on nuclear structure (b)Medical treatment etc.
2.	X-Rays	Roentgen	Due to collisions of high energy electrons with heavy targets	6×10^{-10} m to 10^{-9} m	5×10^{19} Hz to 3×10^{17} Hz	2.4×10^{5}eV to 1.2×10^{3}eV	(a) Low penetrating power (b)other properties similar to γ&rays except wavelength	(a)Medical diagnosis and treatment (b) Study of crystal structure (c) Indus-trial radio-graphy
3.	Ultraviolet Rays	Ritter	By ionised gases, sun are lamp spark etc.	6×10^{-10} m to 3.8×10^{-7} m	3×10^{17} Hz to 5×10^{19} Hz	$2{\times}10^{3}$eV to 3eV	(a)All pro-perties (b)Photo-electric effect	(a) To detect adul-teration, (b) Sterili-zation of water due to its des-tructive act-ion on bac-teriaa
4.	Visible light (a)Violet (b)Blue (c) Green	Newton	Outer orbit electron transitions in atoms, gas disch-arge tube, incandes-cent	3.8×10^{-7} m to 7.8×10^{-7} m $3.9{\times}10^{-7}$ m to 4.55×10^{-7}m $4.55{\times}10^{-7}$ m to 4.92×10^{-7}m	8×10^{14} Hz to 4×10^{14} Hz 7.69×10^{14} Hz to $6.59{\times}10^{14}$Hz 6.59×10^{14} Hz to $6.10{\times}10^{14}$Hz 6.10×10^{14} Hz to $5.20{\times}10^{14}$Hz	3.2 eV to 1.6eV	(a) Sens-itive to hu-man eye	(a) To see objects (b) To study molecular structurea

	(d) Yellow (e)Orange (f) Red			4.92×10^{-7} m to 5.77×10^{-7}m 5.77×10^{-7} m to 5.97×10^{-7}m 5.97×10^{-7} m to 6.22×10^{-7}m 6.22×10^{-7} m to 7.80×10^{-7}m	5.20×10^{14} Hz to 5.03×10^{14}Hz 5.03×10^{14} Hz to 4.82×10^{14}Hz 4.82×10^{14} Hz to 3.84×10^{14}Hz			
5.	Infra-Red waves	William Herschell	(a) Rearr-angement of outer orbitals electrons in atoms and mole-cules (b)Change of molecu-larvibrati-onal and rotational energies. (c) By bodies at high temp-erature	7.8×10^{-7} m to 10^{-3}m	4×10^{14} Hz to 3×10^{11}Hz	1.6 eV to 1.6^{-3}eV	(a) Thermal effect (b) All prop ertiessimilar of those of light exceptλ	(a) Used in industry, me dicine and astronomya (b) Used for fog or have photographya
6.	Microwave s	Hertz	special electronic devices such as klystron tube	10^{-7} m to 0.3m	3×10^{11} Hz to 10^{9}Hz	10^{-3}eV to 10^{-5}eV	(a) Phenomena of reflection, refraction and diffraction	(a)Radar and telecom - munication (b) Analysis of fine details of molecular structurea
7. (A)	Radio waves Subparts of Radio spectrumS uper High (a) SHF Ultra High (b) (UHF)	Marconi	Oscillating circuits	0.3m to few kms. 0.1m to 0.1m	10^{9} Hz to few Hz 3×10^{10} Hz to 3×10^{9}Hz	10^{-3}ev to ≈ 0	(a) Exhibit waves like properies more than particle like properties	(a) Radio communication (b) Radar, Radio and sate llitecommunication (Microwaves) Radar and television broad cast short distance co mmunication,

	Very High (c) (VHF)			0.1m to 1m 1m to 10m	3×10^{9} Hz to 3×10^{8}Hz 3×10^{8} Hz to 3×10^{7}Hz			Television communication
(B)	High frequency Medium frequency Low Frequency Very low frequency			10m to 100m 100m to 1000m 1000m to 10000m 10000m to 30000m	3×10^{7} Hz to 3×10^{6}Hz 3×10^{6} Hz to 3×10^{5}Hz 3×10^{5} Hz to 3×10^{4}Hz 3×10^{4} Hz to 3×10^{4}Hz			Medium distance communication Marine and navigation use, long range communication. Long distance communication.