

CHAPTER--8 -ELECTROMAGNETIC WAVES

For a region where there are no charges and conduction current, Faraday's and Ampere's laws take the symmetrical form:

$$\oint \vec{E} \cdot d\vec{l} = - \frac{d\Phi_B}{dt}$$

$$\oint \vec{B} \cdot d\vec{l} = \mu_0 \epsilon_0 \frac{d\Phi_E}{dt}$$

Time – varying electric field produces space – varying magnetic field and time – varying magnetic field produces space – varying electric field
Electric and magnetic fields are sources to each other.

Maxwell found an inconsistency in the Ampere's law and suggested the existence of an additional current, called displacement current, to remove this inconsistency. This displacement current is due to time-varying electric field and is given by

$$i_d = \epsilon_0 \frac{d\Phi_E}{dt}$$

and acts as a source of magnetic field in exactly the same way as conduction current.

Using Gauss's law, it is

Now if the charge Q on the capacitor plates changes with time, there is a current $i = (dQ/dt)$,

$$\frac{d\Phi_E}{dt} = \frac{d}{dt} \left(\frac{Q}{\epsilon_0} \right) = \frac{1}{\epsilon_0} \frac{dQ}{dt}$$

This implies that for consistency,

$$\Phi_E = |\vec{E}| A = \frac{1}{\epsilon_0} \frac{Q}{A} A = \frac{Q}{\epsilon_0}$$

$$\epsilon_0 \left(\frac{d\Phi_E}{dt} \right) = i$$

The current carried by conductors due to flow of charges is called *conduction current*. The current, given by Eq. (1) is a new term, and is due to changing electric field (or electric *displacement*, an old term still used sometimes). It is, therefore, called *displacement current* or Maxwell's displacement current.

the total current i is the sum of the conduction current denoted by i_c , and the displacement current denoted by $i_d (= \epsilon_0 (d\Phi_E/dt))$. So we have

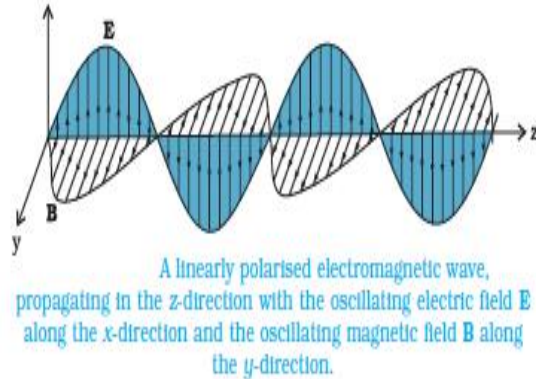
$$i = i_c + i_d = i_c + \epsilon_0 \frac{d\Phi_E}{dt}$$

In explicit terms, this means that outside the capacitor plates, we have only conduction current $i_c = i$, and no displacement current, i.e., $i_d = 0$. On the other hand, inside the capacitor, there is no conduction current, i.e., $i_c = 0$, and there is only displacement current, so that $i_d = i$.

MAXWELL'S EQUATIONS

1. $\oint \mathbf{E} \cdot d\mathbf{A} = Q / \epsilon_0$ (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. $\oint \mathbf{B} \cdot d\mathbf{l} = \mu_0 I_c + \mu_0 \epsilon_0 \frac{d\phi_E}{dt}$ (Ampere - Maxwell Law)

Electromagnetic wave is a wave in which electric and magnetic fields are perpendicular to each other and also perpendicular to the direction of propagation of wave.



In Fig. we show a typical example of a plane electromagnetic wave propagating along the z direction (the fields are shown as a function of the z coordinate, at a given time t). The electric field E_x is along the x-axis, and varies sinusoidally with z, at a given time. The magnetic field B_y is along the y-axis, and again varies sinusoidally with z. The electric and magnetic fields E_x and B_y are perpendicular to each other, and to the direction z of propagation. We can write E_x and B_y as follows:

$$E_x = E_0 \sin(kz - \omega t)$$

$$B_y = B_0 \sin(kz - \omega t)$$

Here k is related to the wave length λ of the wave by the usual equation

$$k = \frac{2\pi}{\lambda}$$

$$\begin{aligned} E &= E_x(t) = E_0 \sin(kz - \omega t) \\ &= E_0 \sin\left[2\pi\left(\frac{z}{\lambda} - \nu t\right)\right] = E_0 \sin\left[2\pi\left(\frac{z}{\lambda} - \frac{t}{T}\right)\right] \\ B &= B_y(t) = B_0 \sin(kz - \omega t) \\ &= B_0 \sin\left[2\pi\left(\frac{z}{\lambda} - \nu t\right)\right] = B_0 \sin\left[2\pi\left(\frac{z}{\lambda} - \frac{t}{T}\right)\right] \end{aligned}$$

$$\omega = ck, \text{ where, } c = 1/\sqrt{\mu_0 \epsilon_0} ; \nu (= \omega/2\pi) \text{ and wavelength, } \lambda (= 2\pi/k) ; B_0 = (E_0/c) \quad p = \frac{U}{c}$$

P=MOMENTUM U= The total energy

The speed of light, or of electromagnetic waves in a material medium is given by $v = 1/\sqrt{\mu \epsilon}$

2) Properties of Electromagnetic Waves:

1. Variations in both electric and magnetic fields occur simultaneously. Therefore, they attain their maxima and minima at the same place and at the same time.

2. The direction of electric and magnetic fields are mutually perpendicular to each other and as well as to the direction of propagation of wave.
3. The electric field vector E and magnetic field vector B are related by
4. $c = E_0 / B_0$ where E_0 and B_0 are the amplitudes of the respective fields and c is speed of light.
5. The velocity of electromagnetic waves in free space, $c = 1 / \sqrt{\mu_0 \epsilon_0}$
6. The velocity of electromagnetic waves in a material medium $= 1 / \sqrt{\mu \epsilon}$ where μ and ϵ are absolute permeability and absolute permittivity of the material medium
7. Electromagnetic waves obey the principle of superposition.
8. Electromagnetic waves carry energy as they propagate through space. This energy is divided equally between electric and magnetic fields
9. Electromagnetic waves can transfer energy as well as momentum to objects placed on their paths.
10. For discussion of optical effects of EM wave, more significance is given to Electric Field, E . Therefore, electric field is called 'light vector'.
11. Electromagnetic waves do not require material medium to travel.
12. An oscillating charge which has non-zero acceleration can produce electromagnetic waves.

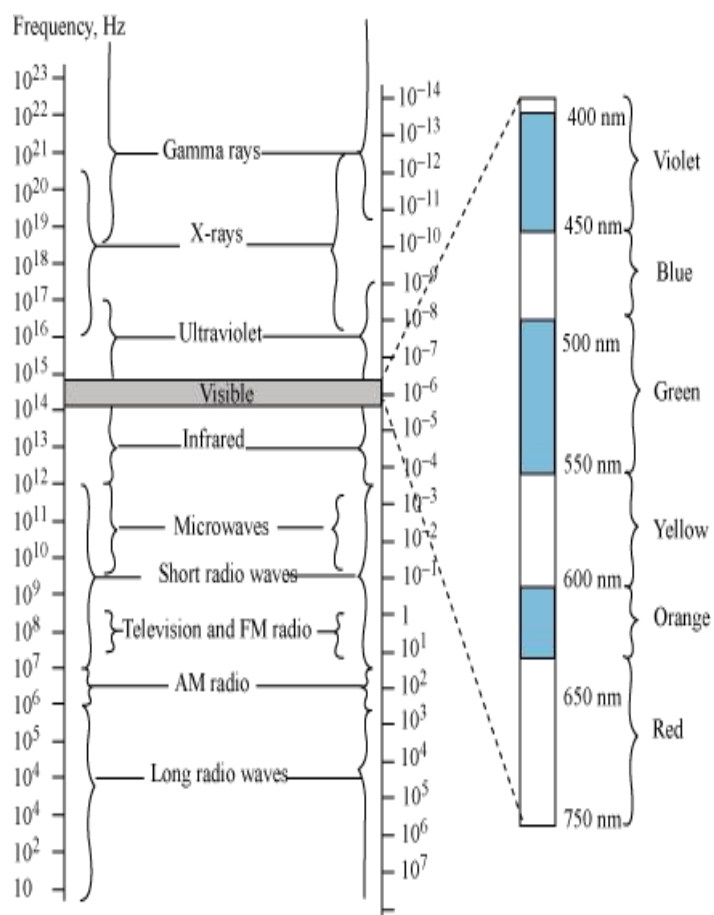
Electromagnetic Spectrum:

S. No.	EM Wave	Range of λ	Range of ν	Source	Use
1	Radio Wave	A few km to 0.3 m	A few Hz to 10^9 Hz	Oscillating electronic circuits	Radio and TV broadcasting
2	Microwave	0.3 m to 10^{-3} m	10^9 Hz to 3×10^{11} Hz	Oscillating electronic circuits	Radar, analysis of fine details of atomic and molecular structures & Microwave oven
3	Infra Red wave	10^{-3} m to 7.8×10^{-7} m	3×10^{11} Hz to 4×10^{14} Hz	Molecules and hot bodies	Industry, medicine, astronomy, night vision device, green house, revealing secret writings on ancient walls, etc.

4	Light or Visible Spectrum	$7.8 \times 10^{-7} \text{ m}$ to $3.8 \times 10^{-7} \text{ m}$	$4 \times 10^{14} \text{ Hz}$ to $8 \times 10^{14} \text{ Hz}$	Atoms and molecules when electrons are excited	Optics and Optical Instruments, Vision, photography, etc.
5	Ultra Violet Rays	$3.8 \times 10^{-7} \text{ m}$ to $6 \times 10^{-10} \text{ m}$	$8 \times 10^{14} \text{ Hz}$ to $3 \times 10^{17} \text{ Hz}$	Atoms and molecules in electrical discharges and Sun	Medical application, sterilization, killing bacteria and germs in food stuff, detection of invisible writing, forged documents, finger print, etc.
6	X - Rays	10^{-9} m to $6 \times 10^{-12} \text{ m}$	$3 \times 10^{17} \text{ Hz}$ to $5 \times 10^{19} \text{ Hz}$	Inner or more tightly bound electrons in atoms	X-ray photography, treatment of cancer, skin disease & tumor, locating cracks and flaws in finished metallic objects, detection of smuggled goods in bags of a person, study of crystal structure, etc.
7	γ -Rays	They overlap the upper limit to of the X-Ray. 10^{-10} m to 10^{-14} m	$3 \times 10^{18} \text{ Hz}$ to $3 \times 10^{22} \text{ Hz}$	Radioactive substances	Information about structure of nuclei, astronomical research, etc.

Hint to memorize the electromagnetic spectrum in decreasing order of its frequency and increasing order of wavelength.

Gandhiji's X-rays Used Vigorously In Medical Research



RESOURCES:

NCERT TEXT BOOK- CLASS XII, TUTOR VISTA

PPT- MR.C. MANI, RETD DEPUTY COMMISSIONER, KVS RO, CHENNAI