CLASS-XII SUB-PHYSICS

NAME OF CHAPTER- ELECTROMAGNETIC WAVES

MAXWELL'S DISPLACEMENT CURRENT

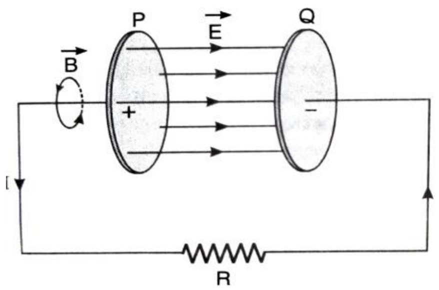
According to Ampere's circutal law, the line integral of magnetic field around a closed path is equal to μ_0 times the total current threading the closed path.

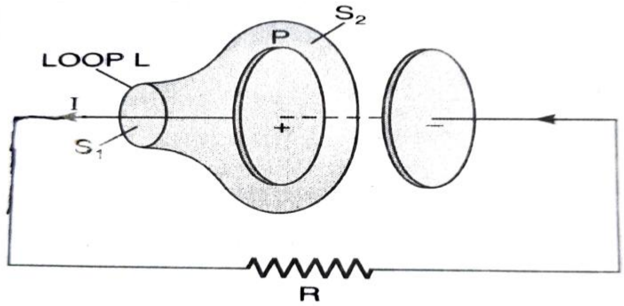
Mathematically $\oint \boldsymbol{B}.\boldsymbol{dl} = \mu_0 I$

When this law was applied to an electric circuit containing a capacitor as one of the circuit element, the law appeared to be inconsistent or incomplete. In order to overcome this inconsistency, Maxwell introduced the concept of displacement current.

Consider a charged parallel plate capacitor is made to discharge through a resistor as shown in fig. Consider two surfaces S_1 and S_2 bounded by the same loop L as shown in fig.

Let us apply Ampere's circuital law to the surfaces S_1 and S_2.





For surface S_1

$\oint \boldsymbol{B}.\boldsymbol{dl} = \mu_0 I$ (S_1 encloses current I)

For surface S_2

$\oint \boldsymbol{B}.\boldsymbol{dl} = \mu_0(0)$ (S_2 encloses no current)

$=0$

LHS of both of the above equations are the same but RHS of the two equations are unequal. Hence it follows that Ampere's circutal law is not logically consistent. Maxwell pointed out that the inconsistency in Ampere's circuital law is due to the wrong assumptions that no current flows across the space between the two plates of the capacitor. Maxwell assumed the flow of current across the gap between the plates of the capacitor. He named it as displacement current and it is produced due to the time varying electric field between the plates of the capacitor.

Ampere-Maxwell's circuital law

$$\oint \boldsymbol{B}.\boldsymbol{dl} = \mu_0(I_C + I_D)$$

I_C- Conduction current

I_D- Displacement current

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

Therefore $\oint \boldsymbol{B}.\boldsymbol{dl} = \mu_0(I_C + \varepsilon_0 \frac{d\Phi}{dt})$

To prove $I_C = I_D$

Let q be the instantaneous value of the charge and E, the electric field between the plates of the capacitor at that time. If A is area of the plates of the capacitor, then

$$E=q/(\varepsilon_0 A)$$

The electric field between the plates of the capacitor is

$$\Phi=EA$$
$$= (q/\varepsilon_0 A) A$$
$$=q/ \varepsilon_0$$

Displacement current, $I_D = \varepsilon_0 \frac{d\Phi}{dt} = \varepsilon_0 \frac{d(\frac{q}{\varepsilon_0})}{dt} = \frac{dq}{dt} = I_C$

Let us now check the consistency of modified Ampere's circuital law

For surface S_1

$$\oint \boldsymbol{B}.\boldsymbol{dl} = \mu_0(I_C + I_D)$$
$$= \mu_0(I_C + 0)$$
$$= \mu_0 I_C$$

For surface S_2

$$\oint \boldsymbol{B}.\boldsymbol{dl} = \mu_0(I_C + I_D)$$
$$= \mu_0(0 + I_D)$$
$$= \mu_0 I_D$$

Since $I_C = I_D$, it follows that for both the surfaces the value of $\oint \boldsymbol{B}.\boldsymbol{dl}$ is the same. Therefore, inconsistency in Ampere's circuital law is overcome by introducing the concept of displacement current.

MAXWELL'S EQUATIONS

1. $\oint \mathbf{E} \cdot d\mathbf{A} = Q/\varepsilon_0$ (Gauss's Law for electricity)

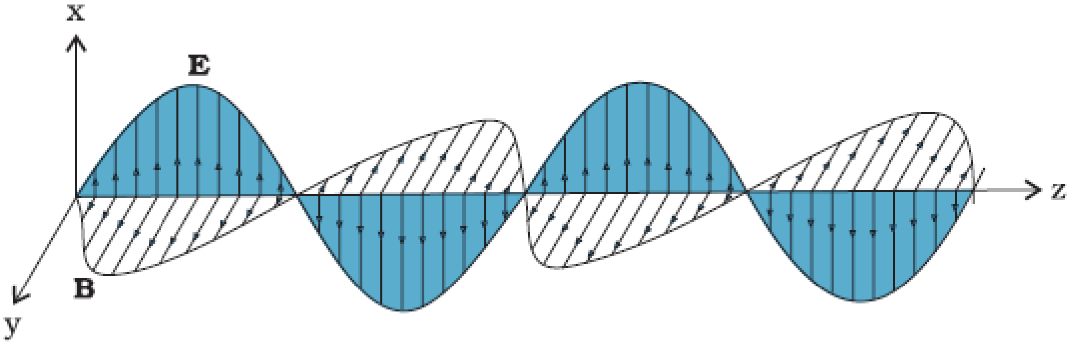
2. $\oint \mathbf{B} \cdot d\mathbf{A} = 0$ (Gauss's Law for magnetism)

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)

ELECTROMAGNETIC WAVES

In 1865, Maxwell predicted the existence of electromagnetic waves on the basis of these equations. According to him, an accelerated charge produces a sinusoidal time varying magnetic field, which in turn produces a sinusoidal time varying electric field. The two fields so produced are mutually perpendicular and sources of each other. These two fields constitute electromagnetic waves, which propagate in space in a direction perpendicular to the directions of both the fields.



Here the direction of propagation of the electromagnetic wave is along +Z-direction.
At any time the electric and magnetic fields are represented as

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

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

Where ω is the angular frequency and k is the magnitude of the propagation vector.

$\omega = 2\pi\nu$ & $k = 2\pi/\lambda$ ν is the frequency and λ is the wavelength of the em wave.

E_0- amplitude of electric field vector.

Bo- amplitude of magneic field vector.

Speed of the em wave is same as speed of light in vacuum (c).

$$c = E/B$$

$$\text{or } c = E_0/B_0$$

Properties of Electromagnetic Waves

- Electromagnetic waves are transverse in nature.
- Electromagnetic waves are produced by accelerated charges.
- Electromagnetic waves do not require any material medium for their propagation.
- In free space electromagnetic waves travel with a velocity,

  $c = 1/\sqrt{\mu\,\varepsilon}$ μ_0-absolute permeability of free space

  $= 3\times10^{8}\ ms^{-1}$ ε_0- absolute permittivity of free space

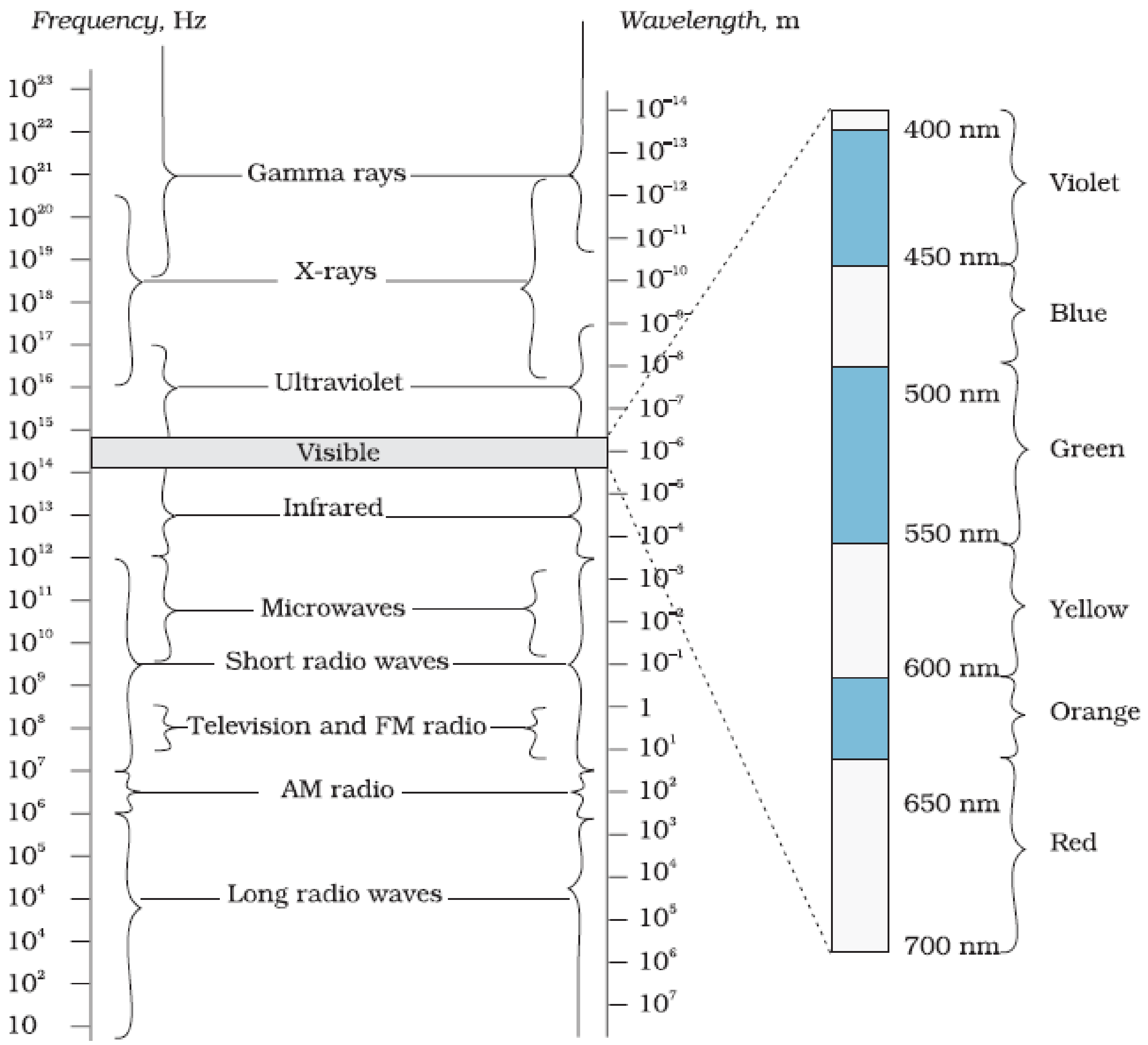
  In a material medium, velocity of electromagnetic waves is given by

  $V = 1/\sqrt{\mu\,\varepsilon}$
- The energy of the electromagnetic wave is equally divided between electric and magnrtic field vectors.
- The momentum transported by electromagnetic wave is given by p=U/C

  Where U is energy transported by electromagnetic waves in a given time and c is speed of electromagnetic wave in free space.

Electromagnetic spectrum

The orderly distribution electromagnetic radiations according to their wavelength or frequency is called electromagnetic spectrum.



(Classification of em waves according to frequency and wavelength is shown above fig.)

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-

1. **Radio waves**
   - ➢ Radio waves are produced by accelerated motion of charges in conducting wires.
   - ➢ Frequency range from 500kHz to about 1000MHz.

   Uses
   - ✓ Used in radio and television communication systems
2. **Microwaves**
   - ➢ Microwaves are produced by special vacuum tubes called klytrons, magnetrons and Gunn diodes.
   - ➢ Frequency range from $3x10^8$Hz to $3x10^{11}$Hz.

   Uses
   - ✓ Used in RADAR systems
   - ✓ Used in microwave ovens
3. **Infrared waves**
   - ➢ Infrared waves are produced by hot bodies and molecules.
   - ➢ Frequency range from $3x10^{11}$Hz to $4x10^{14}$Hz.

   Uses
   - ✓ Used in remote switches of TV
   - ✓ Used in solar water heaters and solar cookers
   - ✓ Used to take photographs during fog,smoke etc.
4. **Visible light**
   - ➢ Visible light is produced when electron in an atom move from one energy level to a lower energy level.
   - ➢ It is the part of the electromagnetic spectrum that is detected by human eye.
   - ➢ Frequency range from $4x10^{14}$Hz to $7x10^{14}$Hz.

   Uses
   - ✓ Helps to see the colourful world around us.
5. **UV rays**
   - ➢ UV radiation is produced by special lamps and very hot bodies.
   - ➢ Frequency range from $8x10^{14}$Hz to $8x10^{16}$Hz

   Uses
   - ✓ Used in water purifier.

- ✓ Used to sterilise surgical instruments.

6. **X-rays**
   - ➢ X rays can be produced by bombarding a metal target by high energy electrons.
   - ➢ Frequency range from 10^{16}Hz to $3x10^{19}$Hz.

   Uses
   - ✓ Used to detect fracture in bones.
   - ✓ Used by detective departments for detection of explosives.
   - ✓ Used to detect cracks and flaws in metals.

7. **Gamma rays**
   - ➢ Gamma radiations are produced during radioactive decay of the nucleus.
   - ➢ They lie in the upper frequency range of the electromagnetic spectrum.
   - ➢ Frequency range from $3x10^{19}$Hz to $5x10^{20}$Hz.

   Uses
   - ✓ Used for treatment of cancer.
   - ✓ Used to produce nuclear reactions.
   - ✓ Used in food industry to preserve the foodstuffs for a prolonged time by killing microorganisms.

MODEL QUESTION PAPERS

1. The art of the electromagnetic spectrum having wavelength 10^{-2}m is
   a) UV rays b) X rays c) Microwaves d) Visible light
2. Which of the following radiations has the least wavelength ?
   a) X rays b) Gamma rays c) Infrared rays d) UV rays
3. Transverse nature of em wave is evident by:
   a) Polarisation b) Interference c) Reflection d) Diffraction
4. The art of electromagnetic spectrum used for treatment of cancer is
   a) Microwave b) Infrared rays c) Gamma rays d) X rays
5. Which of the following statements is a wrong one? Electromagnetic waves
   a) are produced by accelerated charges.
   b) are transverse in nature.
   c) travel with the same speed irrespective of the nature of the medium.
   d) Travel with velocity of light in vacuum.
6. What physical quantity is the same for X-rays of wavelength 10^{-10} m, red light of wavelength 6800 Å and radio waves of wavelength 500m?
7. A plane electromagnetic wave travels in vacuum along *z*-direction. What can you say about the directions of its electric and magnetic field vectors? If the frequency of the wave is 30 MHz, what is its wavelength?
8. Arrange the following electromagnetic spectrum in increasing order of their wavelengths.
   X rays, Gamma rays, Microwaves , Infrared rays, UV rays
9. Microwaves are used in RADAR. Why?
10. What is the value of displacement current when a capacitor is fully charged.

Answers

1. c) Microwaves 2. b) Gamma rays 3. a) Polarisation 4. c) Gamma rays
5. c) travel with the same speed irrespective of the nature of the medium.
6. speed
7. Electric field along X direction, magnetic field along Y direction. Wavelength=10 m
8. Gamma rays, X rays, UV rays, Infrared rays, microwave
9. Due to short wavelength microwaves travel in a straight path without bending.
10. Zero.

...........x.............x..............x..........