

# RAY OPTICS

## 1. THEORIES OF LIGHT

### POINTS TO REMEMBER

1. **Newton's corpuscular theory** : Every source of light emit tiny particles called corpuscles in all directions. Different colours are due to the different sizes of these particles. Velocity of light in denser medium is greater than that in the rarer medium. This theory could not explain partial reflection and refraction.
2. **Huygens' wave theory**: Light consist of waves traveling through a hypothetical medium "ether". Different colours are due to the different wavelengths. Velocity of light in the rarer medium is greater than that in the denser medium It can explain rectilinear propagation of light, reflection, refraction, interference and diffraction. But it cannot explain polarization, black body radiation, photoelectric effect and Compton effect.
3. **Maxwell's electromagnetic wave theory**: Light waves are transverse, electromagnetic waves. Electromagnetic waves are produced by accelerated charges. Electromagnetic waves consists of sinusoidal time varying electric and magnetic fields acting at right angles to each other as well as right angles to direction of propagation of the wave. For a wave propagating along  $x$  direction

$$E = E_0 \sin \omega \left( t - \frac{x}{c} \right) \quad \text{and} \quad B = B_0 \sin \omega \left( t - \frac{x}{c} \right)$$

$E$  = electric field      and       $B$  = magnetic field

$$\text{Velocity light } v = \frac{1}{\sqrt{\mu_0 \epsilon_0}} .$$

Where  $\mu_0$  = permeability of free space      and       $\epsilon_0$  = permittivity of free space.

4. **Electromagnetic spectrum**: The different types of electromagnetic waves in the ascending order of wavelengths are i)  $\gamma$ -rays ii) X-rays iii) U-V rays iv) visible light v) I – R rays vi) Microwaves and vii) Radio waves.
5. **Wave front**: It is the locus of all the points which are being disturbed at the same instant of time and are in the same phase of vibration.
6. **Wave normal**: It is the normal to the wave front at any point. It gives the direction of propagation of light.
7. **Huygens principle** : Every point on the given wave front acts like a source of secondary wavelets that move in the forward direction at the same speed as that of the wave. The new position of the wave front at any instant is a line drawn as tangent to the edges of the wavelets at that instant.

### LONG ANSWER QUESTIONS

1. **Discuss various theories of light and comment on them.**

A. **Theories of Light**

1. **Newton's Corpuscular Theory**

According to the Newton's theory,

- a) Every source of light (sun, stars etc) emits tiny particles called corpuscles in all directions.
- b) Different colours are due to the different sizes of these particles.
- c) These travel in straight lines with great speed.
- d) The mechanical action of the corpuscles on the retina causes the sensation of sight.
- e) As the temperature increases, velocity of the corpuscles increases.

- f) Reflection of light is due to the force of repulsion of the particles of the denser medium on the corpuscles.
- g) Refraction of light is due to the force of attraction of the particles of the denser medium such as glass or water on the corpuscles
- h) Velocity of light in denser medium is greater than that in the rarer medium.

**Failures**

- a) Velocity of light in the rarer medium is greater than that in the denser medium which was proved by Foucault's experiment
- b) Velocity of light is independent of the temperature of the source.
- c) This theory could not explain partial reflection and refraction.
- d) When the source emits corpuscles, in due course of time the mass of the source of light should decrease which is not true.
- e) This theory failed to explain interference, diffraction and polarization.

**2. Huygen's Wave Theory**

- a) According to Huygens, every source of light emits light waves in all directions.
- b) These wave are longitudinal mechanical waves traveling in a very dilute and highly elastic homogenous medium called ether.
- c) Different colours are due to the different wavelengths.
- d) Velocity of light in the rarer medium is greater than that in the denser medium which was supported by Foucault's experiment.
- e) This theory could explain reflection, refraction, diffraction and interference.
- f) The propagation of light was explained by the concept of wave front.

**Failures**

- a) This theory failed to explain the existence of the ether medium experimentally.
- b) This theory failed to explain polarization, black body radiation, photoelectric effect etc.

**3. Electromagnetic theory**

According to Maxwell's electromagnetic theory

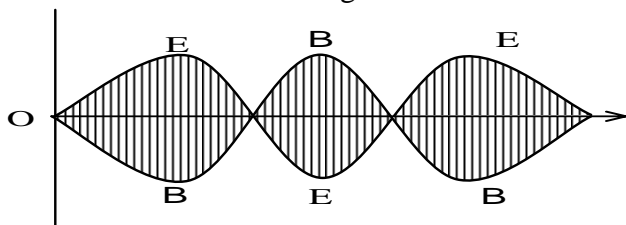
- a) Light waves are transverse, electromagnetic waves.
- b) Electromagnetic waves are produced by accelerated charges.
- c) Electromagnetic waves consists of sinusoidal time varying electric and magnetic fields acting at right angles to each other as well as right angles to direction of propagation of the wave. For a wave propagating along  $x$  direction

$$E = E_0 \sin \omega \left( t - \frac{x}{c} \right)$$

$$B = B_0 \sin \omega \left( t - \frac{x}{c} \right)$$

E = electric field

B = magnetic field



- d) The velocity of electromagnetic waves in space is given by

$$C = \frac{1}{\sqrt{\mu_0 \epsilon_0}}$$

Where  $\mu_0$  = permeability of free space

$$\mu_0 = 4\pi \times 10^{-7} \text{H/m}$$

$\epsilon_0$  = permittivity of free space

$$= 8.854 \times 10^{-12} \text{C}^2/\text{Nm}^2$$

e) In any medium of absolute permeability  $\mu$  and absolute permittivity  $\epsilon$ .

$$C = \frac{1}{\sqrt{\mu \epsilon}}$$

f) Electromagnetic waves obey the principle of superposition

g) If the electric and magnetic field magnitudes are  $E_0$  and  $B_0$ .  $C = \frac{E_0}{B_0}$

h) Experimentally it was proved that most of the optical properties depend on the electric vector called light vector.

i) Intensity of electromagnetic wave is the product of average electric or magnetic energy density and the velocity of light.

### Failure

This theory failed to explain the photoelectric effect.

### 4. Quantum theory :

According to Max Planck

a) Light travels in the form of discrete energy packets called quanta

b) Energy of each quantum is given by  $E = h\nu = \frac{hc}{\lambda}$

c) Quantum of light is also called photon.

d) The energy of a quantum is directly proportional to the frequency of radiation in vacuum.

e) This could explain photoelectric and Compton effect.

Failures : This theory could not explain interference, diffraction and polarization.

### SHORT ANSWER QUESTIONS

1. Describe Newton's corpuscular theory of light ? State its limitations.

A. According to the Newton's theory,

1. Every source of light (sun, stars etc) emit tiny particles called corpuscles in all directions.
2. Different colours are due to the different sizes of these particles.
3. These travel in straight lines with great speed.
4. The mechanical action of the corpuscles on the retina causes the sensation of sight.
5. As the temperature increases, velocity of the corpuscles increases.
6. Reflection of light is due to the force of repulsion of the particles of the denser medium on the corpuscles.
7. Refraction of light is due to the force of attraction of the particles of the denser medium such as glass or water on the corpuscles
8. Velocity of light in denser medium is greater than that in the rarer medium.

### Failures

1. Velocity of light in the rarer medium is greater than that in the denser medium which was proved by Foucault's experiment
2. Velocity of light is independent of the temperature of the source.
3. This theory could not explain partial reflection and refraction.
4. When the source emits corpuscles, in due course of time the mass of the source of light should decrease which is not true.
5. This theory failed to explain interference, diffraction and polarization.

**2. What is Huygen's wave theory of light? Given its limitations.**

- A. According to Huygens, every source of light emits light waves in all directions.
1. These wave are longitudinal mechanical waves traveling in a very dilute and highly elastic homogenous medium called ether.
  2. Different colours are due to the different wavelengths.
  3. Velocity of light in the rarer medium is greater than that in the denser medium which was supported by Foucault's experiment.
  4. This theory could explain reflection, refraction, diffraction and interference.
  5. The propagation of light was explained by the concept of wave front.

**Failures**

1. This theory failed to explain the existence of the ether medium experimentally.
2. This theory failed to explain polarization, black body radiation, photoelectric effect etc.
3. State the characteristics of electromagnetic waves.

- A. 1. Sinusoidal time varying electric and magnetic fields that are perpendicular to each other and also perpendicular to the direction of propagation of the wave constitute an electromagnetic wave i.e., electromagnetic waves are transverse in nature.
2. Electromagnetic waves do not require any material medium for their propagation.
  3. The relation between the maximum values of the electric and magnetic field is  $E_0 = cB_0$  where c is the velocity of light in vacuum
  4. The average electric energy density is equal to the average magnetic energy density.
  5. The intensity (I) of an electromagnetic wave is equal to the product of average electric or magnetic energy density and velocity of light.
  6. Electromagnetic waves travel through a medium with the velocity of light in that medium

**3. Explain Maxwell's electromagnetic wave theory of light.**

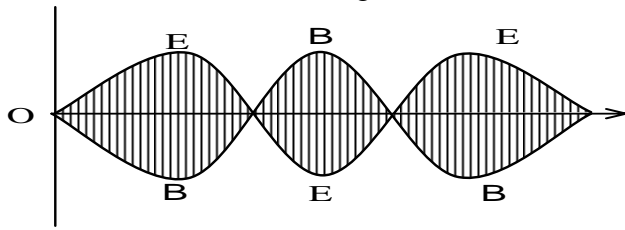
- A. According to Maxwell's electromagnetic theory
1. Light waves are transverse, electromagnetic waves.
  2. Electromagnetic waves are produced by accelerated charges.
  3. Electromagnetic waves consists of sinusoidal time varying electric and magnetic fields acting at right angles to each other as well as right angles to direction of propagation of the wave. For a wave propagating along x direction

a.  $E = E_0 \sin \omega \left( t - \frac{x}{c} \right)$

b.  $B = B_0 \sin \omega \left( t - \frac{x}{c} \right)$

1. E = electric field

2. B = magnetic field



4. The velocity of electromagnetic waves in space is given by

$$i. \quad C = \frac{1}{\sqrt{\mu_0 \epsilon_0}}$$

b. Where  $\mu_0$  = permeability of free space

$$5. \quad \mu_0 = 4\pi \times 10^{-7} \text{H/m}$$

i.  $\epsilon_0$  = permittivity of free space

$$ii. \quad = 8.854 \times 10^{-12} \text{C}^2/\text{Nm}^2$$

6. In any medium of absolute permeability  $\mu$  and absolute permittivity  $\epsilon$ .

$$C = \frac{1}{\sqrt{\mu \epsilon}}$$

7. Electromagnetic waves obey the principle of superposition

8. If the electric and magnetic field magnitudes are  $E_0$  and  $B_0$ .  $C = \frac{E_0}{B_0}$

9. Experimentally it was proved that most of the optical properties depend on the electric vector called light vector.

10. Intensity of electromagnetic wave is the product of average electric or magnetic energy density and the velocity of light.

### Failure

This theory failed to explain the photoelectric effect.

### 4. Describe the electromagnetic spectrum.

A. The wavelength of electromagnetic waves ranges between  $10^{-15}$  m and 30 km

### Radio Waves

- These are produced by charged accelerating particles in AC circuit consisting of inductor and capacitor.
- These were discovered by Marconi. The frequency range is few hertz to  $5 \times 10^9$  Hz.
- These are used in radio and TV communication.

### Micro waves

- Electric circuits having oscillating currents produce microwaves.
- These are used in radar system and other communication systems.
- Microwave ovens are used for cooking.
- The frequency range is about  $5 \times 10^9 - 10^{12}$  Hz.
- These were studied by Hertz.

### Infrared Rays

- These are emitted by atoms and molecules of hot bodies.

- These are used in physical therapy, sun incandescent lamps and infrared lamps are the sources.
- The frequency range is about  $10^{12} - 4 \times 10^{14}$  Hz.
- These were discovered by Herschel.

### Visible Light

- If emitted by atoms under suitable conditions.
- The frequency range is  $4 \times 10^{14} - 8 \times 10^{14}$  Hz.
- These were discovered by Newton.

### Ultraviolet rays

- These are also emitted by atoms.
- These are a part of solar spectrum. Human body generates vitamin D when the skin is exposed to sunlight.
- Frequency range is about  $8 \times 10^{14} - 10^{16}$  Hz.
- These were discovered by Ritter.

### X-Rays

- These are generated when fast moving electrons are stopped by a target.
- These are used in medical diagnosis.
- These are harmful to living cells in large amounts.
- Frequency range is  $10^{16} - 3 \times 10^{19}$  Hz.
- These were studied by Roentzen.

### Gamma Rays

- These are emitted by nuclei.
- Their wavelength is shortest ( $10^{-14}$  m –  $10^{-10}$  m).
- Gamma rays are harmful to living cells.

## 5. Define : Wave front and wave normal.

State the nature of the wave fronts in the following

1. The source is a point source of light
2. A narrow slit is illuminated by a source of light.

A. **Wave front** : Wave front is defined as the locus of all the points which are being disturbed at the same instant of time and are in the same phase of vibration.

**Wave normal** : The wave normal at any point of the wave front in the direction of propagation of light is the ray of light.

Nature of the wave front :

i) Spherical ii) cylindrical wave front

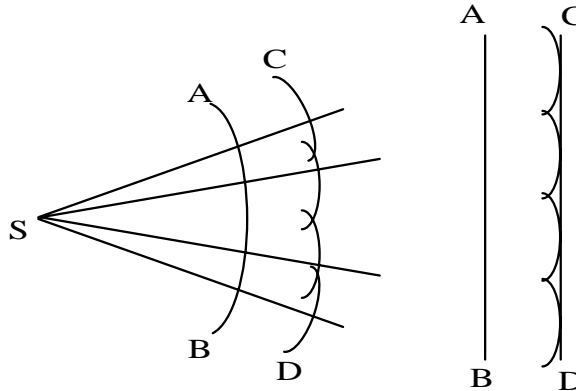
## 6. State and explain Huygen's Principle.

A. According to Huygens

- a) Every point on the given wave front acts like a source of secondary wavelets that move in the forward direction at the same speed as that of the wave.
- b) The new position of the wave front at any instant is a line drawn as tangent to the edges of the wavelets at that instant.

### Explanation

Consider a wave front AB moving away from a point source of light S. Every point on AB acts like a secondary source of light. From different points on AB circular arcs are drawn with radius  $ct$  where  $t$  is the time after which the new position of the wave front is required. The common tangent drawn to these arcs (CD) is the new position of the wave front.



The wave front (energy) propagates only in the forward direction.

### **VERY SHORT ANSWER QUESTIONS:**

1. Name the various theories of light. Mention the parameter on which the colour of the light depends according to wave theory.
  - A. The various theories of light are 1) Corpuscular theory of Newton 2) Huygen's wave theory 3) Maxwell's electromagnetic theory 4) Planck's quantum theory. According to Huygen's wave theory, colour of light depends on wavelength  $\lambda$ .
2. How are electromagnetic waves generated? Name the different type of electromagnetic waves.
  - A. Accelerated charges produce electromagnetic waves. An accelerated charge produces sinusoidal time varying electric field which is associated with sinusoidal time varying magnetic field which is mutually perpendicular to each other. Various types of electromagnetic waves are 1) radio waves 2) micro waves 3) infrared rays 4) visible light 5) ultra violet rays 6) X-rays and 7)  $\gamma$ -rays
3. State the relation between i) the maximum values of electric and magnetic field vectors, ii) the average electric energy density and average magnetic energy density of an electromagnetic wave.
  - A. i) Relation between maximum values of electric and magnetic field vectors is  $E_0 = cB_0$  where  $c$  is velocity of light in vacuum.
  - ii) Average electric energy density and average magnetic energy density of an electromagnetic wave are equal.
4. What is an electromagnetic spectrum? State the frequency range of microwaves and give their uses.
  - A. The arrangement of electromagnetic waves according to different categories is called electromagnetic spectrum.

### **Micro waves**

1. The frequency range is about  $5 \times 10^9 - 10^{12}$ Hz.
2. These are used in radar system and other communication systems.
3. Microwave ovens are used for cooking.
5. When a plane wave front of light is incident on the separating surface between two media, the reflected wave front is of same width like the incident wave front whereas the refracted wave front is of different width. Explain?
  - A. In the case of reflection, both the incident and reflected wave fronts will have the same speed whereas in the case of refraction; the refracted wave front is of

different width because wavelength and speed of light differs in the second medium.

**ASSESS YOURSELF**

1. Can an electromagnetic wave be deflected by electric and magnetic fields?  
A. Electromagnetic wave can't be deflected by electric and magnetic fields.
2. Do all the electromagnetic waves travel with the same velocity?  
A. Yes. Electromagnetic waves travel with the velocity of light.