Chapter

NATURE AND PROPAGATION OF LIGHT

INTRODUCTION: *Wave optics is the branch of science that deals with the production, emission and propagation of light, its nature, and the study of the phenomenon of reflection, refraction, interference, diffraction and polarization. Wave optics is based on wave theory of light put forward by Huygen. According to wave theory, light is a form of energy which travels through a medium in the form of transverse wave.*

NATURE AND SOURCES OF LIGHT: *Light is an electromagnetic wave. When light is transmitted from one material to another, the frequency of the light is unchanged but the wavelength and wave speed can change. Nature of light has been subject of controversy. Since, the early times, scientists have made discussion on the true nature of light and have postulated various theories.*

NEWTON'S COUPUSCULAR THEORY: *Newton was the first to give corpuscular theory of light. According to which, light consists of tiny particles called corpuscles which are emitted by the sources of light. This theory could explain rectilinear propagation of light and reflection of light. Newton's corpuscular theory failed as it could not explain why light travels faster in a rarer medium than in a denser medium. This theory also could not explain interference, diffraction and polarization of light.*

HUYGEN'S WAVE THEORY: *Huygen, in 1690 proposed a new theory about nature of light. According to this theory, light propagates from the source in the form of wave in all direction. Huygen assumed that, for the propagation of light, medium is necessary and all space is filled with medium called ether. So, light wave is longitudinal wave. Huygen's wave theory could explain reflection, refraction, interference and diffraction of light but, it failed to explain the phenomenon of polarization of light.*

ELECTROMAGNETIC THEORY: *Maxwell proved theoretically that light gets propagated in the form of electromagnetic waves. Electromagnetic waves are transverse waves consisting of electric and magnetic fields mutually perpendicular. The velocity of electromagnetic wave is equal to the velocity of light. Electromagnetic theory failed to explain the phenomena of photoelectric effect.*

QUANTUM THEORY: *Max planck suggested Quantum theory of light, according to which light consists of packets of energy called photons or quanta. The energy of photon is given by,*

$$E = hf$$

Where, h is planck's constant and f is the frequency of photon.
This theory explained the photoelectric effect but it could not account for the phenomena of interference, diffraction and polarization.

DUAL NATURE OF LIGHT: *DeBroglie suggested dual theory of light. According to this theory, light behaves both particle nature and wave nature. Photoelectric effect is explained by quantum theory but this theory could not explain interference, diffraction and polarization. These phenomena can be explained using wave theory. All phenomena and effects of light were explained on the basis o f this dual theory.*

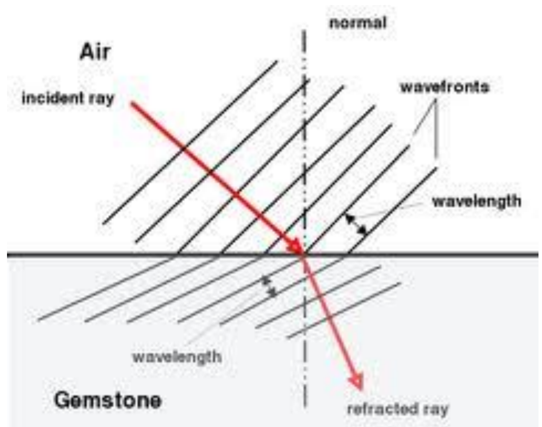
Electromagnetic waves

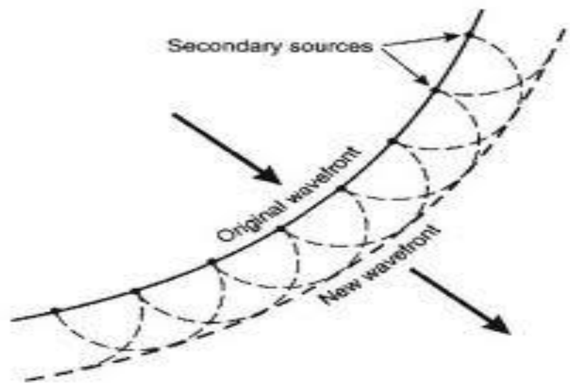
(i)	Radio wave	-	(greater than 10^{-1}m)
(ii)	Microwave	-	(10^{-1}m – 10^{-3}m)
(iii)	Infrared	-	(10^{-3}m – 7 x 10^{-7}m)
(iv)	Visible ray	-	(7 x 10^{-7}m – 4 x 10^{-7}m)
(v)	Ultraviolet ray	-	(4 x 10^{-7}m – 10^{-8}m)
(vi)	X – ray	-	(10^{-8}m – 10^{-11}m)
(vii)	γ – ray	-	(less than 10^{-11}m)

Wave theory of light

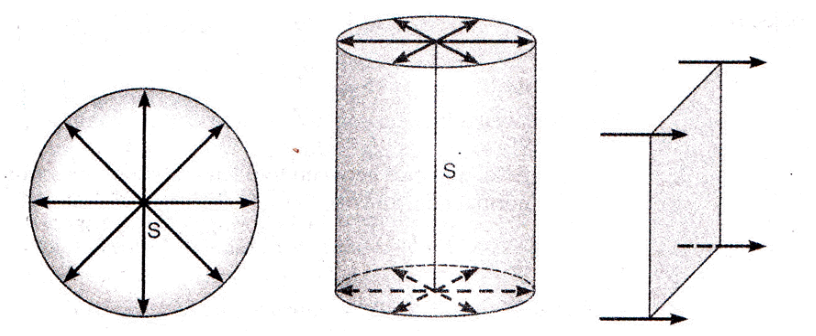
- Wave optics describes the connection between wave and rays of light.
- The wave theory of light was explained on the basis of Huygen's principle.
- According to this theory, light travels through a hypothetical ether medium present everywhere.
- This theory is able to explain phenomenon of reflection, refraction, interference and diffraction. But this theory couldnot explain the theory of polarization.

WAVEFRONT: According to wave theory of light, a source of light sends out disturbance in all directions and if the medium is homogeneous, the disturbance reaches all those particles of the medium in same phase, which are located at same distance from the source of light. All such particles at equal distance from the source of light are thus vibrating in same phase. ***The locus of the particles of the medium vibrating in the same phase is called wavefront.*** *For example, if a stone is dropped in a calm pool of water, waves spread out in circular rings from the point of impact. All points on such a circle are oscillating in same phase. Such a circle is known as a wave front. The direction of propagation of a wave at a point is perpendicular to the wavefront. The wavefronts of wave originating from a point source are spherical.*





Types of wavefront



[a] Spherical Wavefront: If we have a point source of light then the locus of all the points which are vibrating in same phase lies on a sphere and the wave front formed is called spherical wavefront as shown in figure.

[b]Cylindrical Wavefront: When the source of light is linear in shape then the locus of all the point which are equidistant from the linear source lies on a cylinder and the wavefront formed is called cylindrical wavefront as shown in figure.

[c] Plane Wavefront: if is small part of spherical or cylindrical wavefront when the source of light lies at large distance from the wavefront as shown in figure.

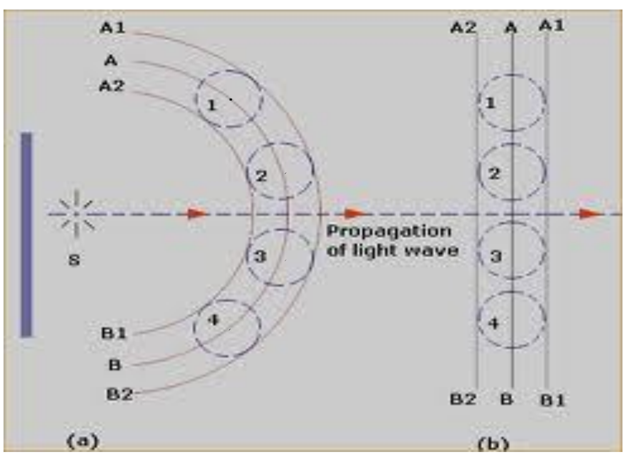
WAVELETS: *Every point on the wavefront acts a source of a disturbance, these disturbances from the points are called wavelets.*

HUYGEN'S PRINCIPLE:

(i) ***Each point on the primary wavefront acts as a new source of disturbance.The disturbances from these points are called secondary wavelets.These wavelets spread out in all direction in the medium with the velocity of light.***

(ii) ***The new wavefront is then obtained by constructing a tangential plane to all the secondary wavelets.The new position of wavefront at any instant is given be the forward envelope of the secondary wavelets at that instant.***

Consider a primary wavefront AB of the source 'S' at any instant 't'. To find the position of a secondary wavefront after time t, take points 1, 2, 3 ….. on the wavefront AB. The distance travelled by light in time t is 'ct', where c is velocity of light in air. Taking each point as centre, draw spheres of radius 'ct'. These surfaces represent the position of secondary wavelets at time 't'. The tangent to the secondary wavelets is called secondary wavefront.



LAWS OF REFLECTION ON THE BASIS OF WAVE THEORY

The laws of reflections are:

1. The angle of incidence is equal to the angle of reflection. i.e. i = r.
2. The incident ray, the reflected ray and the normal to the reflecting surface all lie in the same plane.

Consider a plane wavefront AB incident on the reflecting surface XY at an angle of incidence i and the rays 1,2 and 3 are perpendicular to the wavefront AB as shown in figure. The point A of the wavefront reaches the surface at first. After time t, B reaches at A' and at the same time A reaches at B'. according to Huygens's principle, the secondary wavelets from A and B spread out in the form of sphere of radius AB' = BA' = ct, where c is the velocity of light. Draw a tangent to the sphere from A'. Then A'B' represents reflected wavefront.

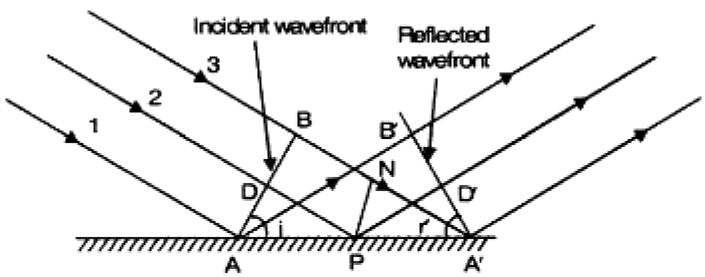


Fig: Reflection at plane surface

Draw A'N' normal to the reflecting surface. Now, $\angle B'A'A$ is the angle of reflection.

In Δ ABA' and Δ AB'A'

(i)	AA' = AA'	(Common side)
(ii)	$\angle AB'A'$ = <ABA'	(Both right angles)
(iii)	AB' = BA'	(Distance travelled in same time)

Therefore, two triangles ABA' and AB'A' are congruent.

Hence, <BAA' = <B'A'A

Or, <i = <r

i.e. the angle of incidence is equal to the angle of reflection. This proves first law of reflection.

Also, from the figure, it is clear that the incident ray, reflected ray and the normal at the point of incidence all lie in the same plane (i.e. plane of paper). This proves second law of reflection.

LAWS OF REFRACTION ON THE BASIS OF WAVE THEORY:

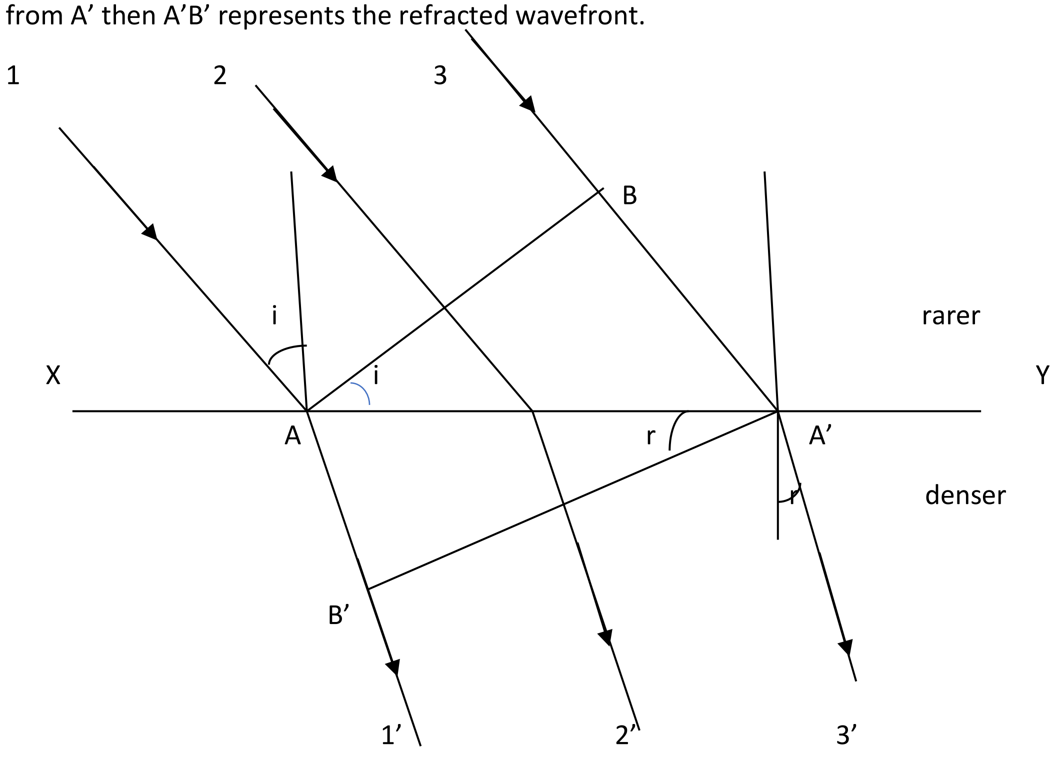
When light passes from rarer medium to denser medium with velocity c and v respectively then the laws of refraction are:

(i) The ratio of the sine of angle of incidence to the sine of the angle of refraction is constant for only two given media.

i.e. $\frac{\sin i}{\sin r}$ = c/v = μ, where μ is the constant called the refractive index of the medium with respect to air.

(ii) The incident ray, the refracted ray and the normal at the point of incident on the refracting surface all lie on the same place.

Consider a plane wavefront AB incident on the refracting surface XY at an angle of incidence i and the rays 1,2 and 3 are perpendicular to the wavefront AB as shown in figure. Let, c and v be the velocities of light in the rarer medium and the denser medium respectively. According to huygen's principle, every point the wavefront AB is a source of secondary wavelets. If t is the time taken by the secondary wavelet to travel from B to A' then BA' = ct. during this time, the secondary wavelet originating at A travels a distance AB' = vt in the denser medium. Similarly, the wavelet from point C reaches at point E in the same time t. if we draw a sphere of radius AB' = vt and a tangent to the sphere from A' then A'B' represents the refracted wavefront.



In right angle $\Delta ABA'$, sin i = $\frac{A'B}{AA'}$ = $\frac{ct}{AA'}$………………(i)

Similarly, in rt angle $\Delta AB'A'$, sin r = $\frac{AB'}{AA''}$ = $\frac{vt}{AA'}$………………(ii)

Dividing equation (i) by (ii), we get, $\frac{\sin i}{\sin r}$ = c/v

Where c/v = μ is the refractive index of the denser medium with respect to rarer medium.

$$\frac{\sin i}{\sin r} = c/v = \mu$$

This proves the first law of refraction (Snell's law)

Also, the incident ray, refracted ray and the normal to the refracting surface at the point of incidence all lie in the same place (i.e. plane of paper). This proves second law of refraction.

Short questions

1. Differentiate between a plane wave front and a spherical wave front.
2. Which parameters of light does not change on refraction?
3. What is Huygens's principle?
4. When monochromatic light incidents on a surface, the reflected and refracted wave will have same frequency. Why?
5. State Huygen's principle. Does it apply to sound waves in air?
6. What is wave front?
7. Can Snell's law be verified form wave theory? Explain with figure only.
8. Distinguish between wave fronts and wavelets.
9. A normally incident wave front does not deviate, when it travels from one medium to another. Explain.
10. If light travels from one medium to another, its velocity changes? Is it due to change in frequency or wavelength? Explain
11. Differentiate between a plane wave front and a spherical wave front.

Long questions

1. State and explain Huygen's principle. Use the principle to verify the laws of refraction of light on the basis of wave theory.
2. What is a wavefront? Using Huygen's principle, prove that for a parallel beam of light incident on a reflecting surface, the angle of incidence is equal to angle of reflection.
3. State and explain Huygen's principle. Use the principle to verify the laws of refraction of light on the basis of wave theory.