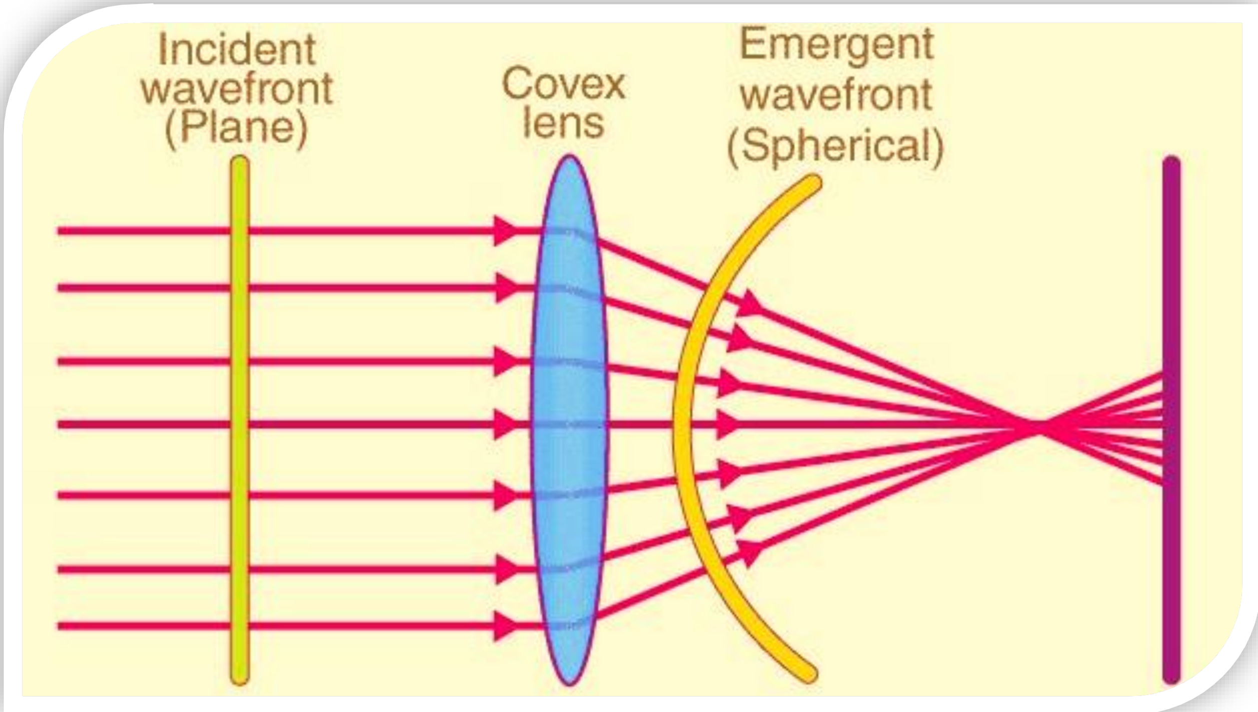
WAVE OPTICS


Incident wavefront (Plane)
Covex lens
Emergent wavefront (Spherical)

Wave Optics

Interference

Huygen's Principle and Interference

Physical Optics is a branch of optics that deals with the nature of light. Several theories have been proposed to explain the nature of light. There is no single theory that can completely explain all the observed phenomena with regard to light.

Newton's Corpuscular Theory

According to this theory, light is a stream of tiny particles, called corpuscles, that carry energy and move along straight lines (in a homogeneous medium). Using this theory, the rectilinear propagation of light, the laws of reflection; and to some extent, refraction and total internal reflection can be explained. This theory is not in use because

a. it predicted that light travels faster in a denser medium. Foucalt's rotating mirror experiment (speed of light in different media was determined) disproves this.

b. it cannot explain satisfactorily the phenomenon of simultaneous reflection and refraction, at a refracting surface.

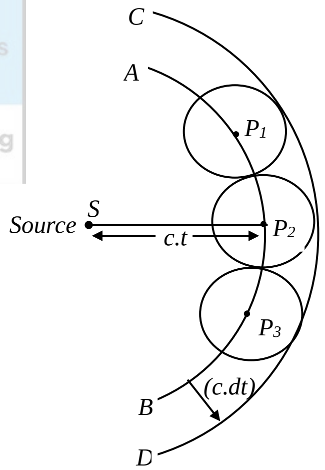
c. it cannot explain the phenomena of interference, diffraction and polarization.

Huygens' Wave Theory

According to this theory, every source of light is a source of waves spreading outwards in all directions. Fresnel modified this theory to explain rectilinear propagation, reflection, refraction, total internal reflection, dispersion, interference, diffraction and polarisation. However, this theory fails to explain the instantaneous emission of photoelectrons in photoelectric effect.

Features of Huygen's Wave theory

1. **Wave Optics** is based on wave theory of light put forward by Huygens. According to wave theory, light is a form of energy which travels through a medium in the form of transverse waves.



2. **A wavefront** is defined as the locus of all particles of a medium, which are vibrating in same phase. When a source of light is a point source, the wavefront is spherical. When a source is linear, the wave front is cylindrical. At very large distances from the source, a portion of spherical or cylindrical wavefront appears to be plane. A wave front travels parallel to itself and perpendicular to the rays.

3. **Huygen's principle** of geometrical construction of a wavefront at any instant says:

(i) Every point on a given wavefront (called primary wavefront) acts as a fresh source of new disturbance, called secondary wavelets.

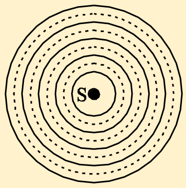
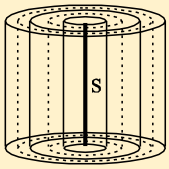
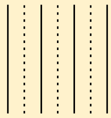
(ii) The secondary wavelets travel in all directions with the speed of light in the medium.

(iii) A surface touching these secondary wavelets tangentially in the forward direction at any instant gives the new (secondary) wavefront at that instant.

Using Huygen's principle, we can prove the laws of reflection, refraction and associated phenomena.

A point source generates a spherical wavefront and a line source generates a cylindrical wavefront. The wavefront due to a source at infinity is considered a plane wavefront.

Huygen's theory assumes that light waves are elastic mechanical longitudinal waves in a medium called ether.

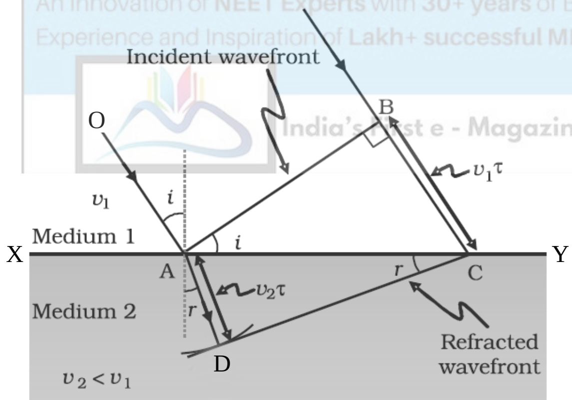
Source	Wavefront	Schematic representation
Point	Spherical	
Linear	Cylindrical	
Source at large distance	Planar	

Reflection of a plane wave by a plane surface and proof of laws of reflection using Huygens' Principle

Let XY represent the surface separating medium 1 and medium 2 as shown in the figure. Let v_1 and v_2 be the speeds of light in medium 1 and medium 2 respectively. Let a plane wavefront AB propagating in the direction OA incident on the interface at an angle 'i' as shown in the figure. If 't' is the time taken by the wavefront to travel the distance BC, then,

$$BC = v_1 t$$

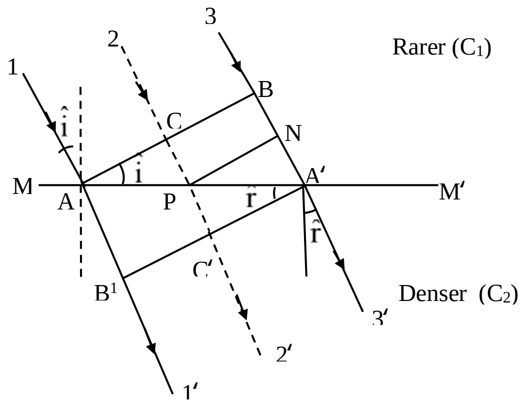
In order to determine the shape of refracted wavefront, we construct a sphere of radius v_2t from point A inside the second medium. Draw the tangent CD to this sphere from C. Then represents the refracted wavefront. Further, AD = v_2t



Refraction on the basis of Huygens theory

MM' is a surface separating two media rarer and denser figure. C_1 is the velocity light in rarer medium and C_2 in the denser.

AB is the incident plane wave front A′B′ is the refracted wavefront such that BA′ = C_1t and AB′ = C_2t



Draw PN ⊥ BA^1 so that CP = BN

From ΔABA′ and ΔPNA′, $\frac{AA'}{PA'} = \frac{BA'}{NA'}$ and from Δ AA′B′ and Δ PC′A′

We have $\frac{AA^1}{PA^1} = \frac{AB^1}{PC^1}$ giving

$$\frac{BA'}{NA'} = \frac{C_1 \times t}{NA'} = \frac{AB'}{PC'} = \frac{C_2 \times t}{PC'}$$

Or $\frac{NA'}{C_1} = \frac{PC'}{C_2} \therefore \frac{CP}{C_1} + \frac{PC'}{C_2} = \frac{BN}{C_1} + \frac{NA'}{C_1} = \frac{BA'}{C_1}$

Hence B′C′A′ is the true refracted wavefront

Further $\sin i = \frac{BA'}{AA'} = \frac{C_1 t}{AA'}$ and $\sin r = \frac{AB'}{AA'} = \frac{C_2 t}{AA'}$ giving $\frac{\sin i}{\sin r} = \frac{C_1}{C_2} = {}_1n_2$ which is Snell's law.

Also, incident ray, refracted ray and the normal to the surface at point of incidence all lie in the same plane.

Hence laws of reflection and refraction are established on the basis of wave theory.

Phase difference and path difference

As the concepts of phase and path difference are often used in this chapter, these concepts are briefly discussed below.

Phase, optical path, amplitude and intensity

The argument of sine ratio or cosine ratio in the expressions for wave disturbance is given by

$y = a \sin(\omega t - kx)$ or

$y = a \cos(\omega t - kx)$

i.e., $\phi = (\omega t - kx)$ is called the phase of the wave. Suppose we write $\phi = k\left(\frac{\omega}{k}.t - x\right)$

or $\phi = \frac{2\pi}{\lambda}\left[t.\frac{\omega}{k} - x\right] = \frac{2\pi}{\lambda}(tv - x)$ then, $(tv - x) = \Delta$ is called the optical path traversed by the wave in a time t. So

the phase $\phi = \frac{2\pi}{\lambda}(\Delta)$ is a function of either t or x or both.

The intensity at any point along the path of a beam is proportional to square of the amplitude of light at that point.

i.e., $I \propto a^2$

Consider two light waves of amplitudes A_1 and A_2 and frequencies ν_1 and ν_2 respectively emitted from two different sources and propagated along positive x axis. They are mathematically represented by

$y_1 = a_1 \sin(\omega t - k_1 x_1)$ … (7)

$y_2 = a_2 \sin(\omega_2 t - k_2 x_2)$ … (8)

The phase difference $\Delta\phi$ between the two waves is given by

$\Delta\phi = \phi_1 - \phi_2 = (\omega_1 t - k_1 x_1) - (\omega_2 t - k_2 x_2) = (\omega_1 - \omega_2)t + (k_2 x_2 - k_1 x_1)$

$= (\omega_1 - \omega_2)t + 2\pi\left(\frac{x_2}{\lambda_2} - \frac{x_1}{\lambda_1}\right)$

If $\omega_1 = \omega_2$ then $\lambda_1 = \lambda_2 = \lambda$ and $\Delta\phi = \frac{2\pi}{\lambda}(x_2 - x_1) = \frac{2\pi}{\lambda}.\Delta x$

Δx is the optical path difference between the two waves in general.

As already discussed propagation of light energy is nothing but propagation of vibrating electric and magnetic vectors. Electric vector represented by $\vec{E}$ and magnetic vector represented by $\vec{H}$ vibrate in phase and remain always mutually perpendicular. The direction of propagation of these vectors i.e., energy propagation direction represented by $\vec{P}$ (the Pointing vector) $\propto (\vec{E} \times \vec{H})$ which is perpendicular to vibration directions of $\vec{E}$ as well as $\vec{H}$. $\vec{E}$ $\vec{H}$ and

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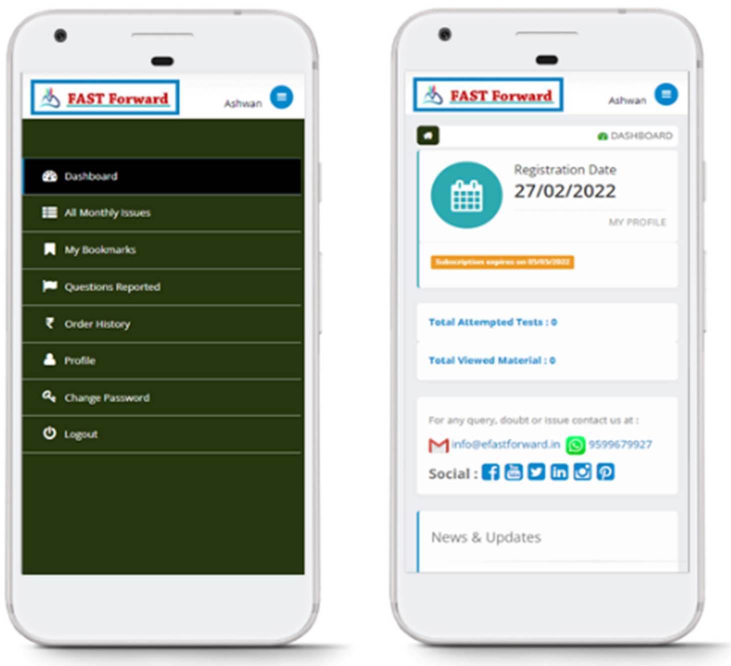

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