WAVE THEORY

Huygens Wave Theory of Light

- Light travels in the form of longitudinal waves which travel with uniform velocity in homogeneous medium
- Different colours are due to the different wavelengths.
- When light enters our eyes, we get sensation of light
- A material medium is necessary for propagation of longitudinal waves.

To explain propagation of light through vacuum, Huygens suggested the existence of an hypothetical medium called 'Luminiferous Ether' which is supposed to be present everywhere in space.

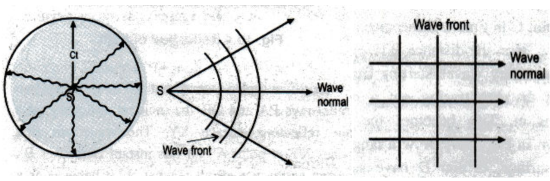
Success:

- Could explain laws of refection, refraction, interference, diffraction, etc.
- Speed of light in the denser medium is less than that in the an optically rarer medium.

Drawbacks:

- Could not explain rectilinear propagation of light
- Couldn't explain polarization of light,Compton effect,photoelectric effect
- Experiments concluded there is no ether drag when earth moves.

Wave Front and Wave Normal:

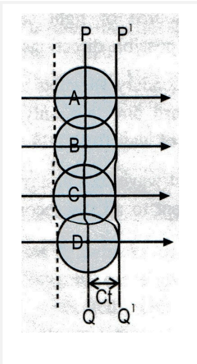


A locus of all the points of medium to which waves reach simultaneously so that all the points are in the same phase is called ***wavefront***.
A perpendicular drawn to the surface of a wavefront at any point of a wavefront in the direction of propagation of light, is called a ***wave normal***.

Huygens' Principle:

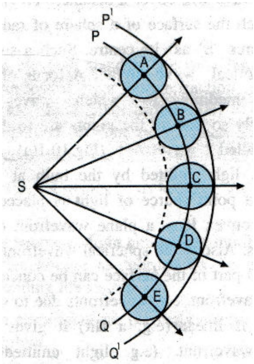
>> Every point on a wavefront behaves as if it is a secondary source of light sending secondary waves in all possible directions.
>> The new secondary wavelets are more effective in the forward direction only
>> The resultant wavefront at any position is given by the tangent to all the secondary wavelets at that instant.

Construction of plane wavefront:



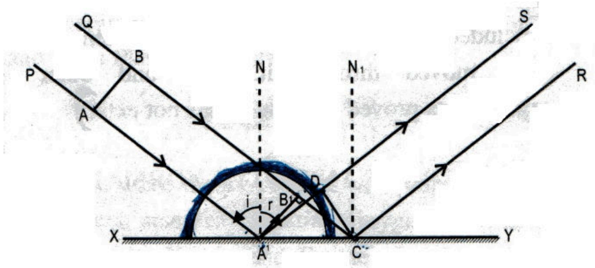
Let PQ be a plane wavefront perpendicular to the plane of the paper, due to the source (S), at any instant and at very large distance. The is the primary wavefront. Now consider points A,B,C,D on PQ. They act as secondary wavelets as per Huygens' principle. Each wave will describe a distance 'ct', where 'c' is the speed of light and 't' the time. With A,B,C,D as centres, spheres each of radius 'ct' will be traced. Each sphere represents a secondary wavefront. The common tangential surface (envelope) i.e. P'Q' drawn to these secondary wavefronts represents the new position for the wavefront after time 't'. The secondary waves moving in the backward direction do not exist and therefore they are shown with dotted lines.

Construction of Spherical Wavefront :



Let PQ be a cross-section of a spherical wavefront due to a point source (S) , at any instant. This is called as primary wavefront. Now consider points A, B, C, D, E on PQ. They act as secondary sources and send out secondary wavelets as per Huygens' principle. Each wave will describe a distance 'ct', where 'c' is the speed of light and 't' the time. With A,B,C,D,E as centres, spheres each of radius 'ct' will be traced. Each sphere represents a secondary wavefront. The common tangential surface (envelope) i.e. P'Q' drawn to these secondary wavefronts represents the new position for the wavefront after time 't'. The secondary waves moving in the backward direction do not exist.

Reflection at a Plane Surface :



Consider a plane wavefront AB bounded by two parallel rays PA and QB, incident obliquely on a plane reflecting surface XY. The wavefront first reaches at A'. At this instant B reaches B'. As soon as the wavefront reaches A' it behaves as a secondary source and begins to emit secondary waves in the same medium. Let the wavefront at B' move to C in time t. Is speed of light in medium is 'c' then the distance B'C=ct. During this time the secondary waves starting from A' will cover an equal distance tracing out a hemisphere of radius ct. Then draw a tangent CD. C and D have the same phase. Thus CD represents the reflected wavefront and is bounded by A'S and CR.

ΔA'B'C congruent ΔCDA'

Thus, /_B'A'C = /_DCA' ..... (i)

/_NA'B' = 90 – i therefore, /_ B'A'C = 90 – /_B'A'C = 90 – (90 – i) = i ..(ii)

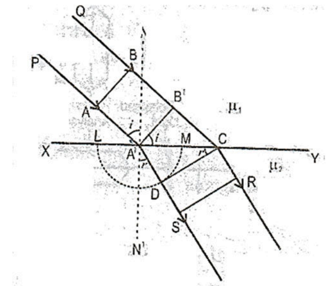
/_NA'D = r Thus, /_DA'C = 90 - /_NA'D = 90 – r

In ΔCDA', /_DCA' = 180 - /_CDA' - /_DA'C = 180 – 90 – (90 – r) = r .... (iii)

From (i) , (ii) and (iii) we can conclude i = r

Also the incident ray, reflected ray and normal lie in the same plane. Thus laws of reflection can be proved using Huygens' wave theory.

Refraction of a Plane Wavefront :



XY : Plane refracting surface
AB, A'B' : Incident plane wavefront
CD : Plane refracted wavefront
NN' : Normal

Consider a plane wavefront AB bounded by rays PA and QB, be incident obliquely on a plane surface XY separating two media, a raraer medium of refractive index μ_1 and a denser medium of refractive index μ_2. A'B' is the incident plane wavefront in the rarer medium. A' behaves as a secondary source of light and emits secondary waves in the denser medium. Meanwhile the point at B' in the rarer medium, advances further and reaches at C on XY in time t.

If c_1 is speed of light in first medium, then B'C = c_1t. During this time the secondary waves from A' will cover a distance of c_2t in the second medium giving rise to a spherical wavefront & tracing out a hemisphere of radius c_2t, where c_2 is the speed of light in second medium.

Draw tangent CD to this wavefront. Draw AD=c_2t, and produce it further. CD becomes the refracted wavefront bounded by rays DS and CR.

Draw NN' as the normal to XY at A. /_PA'N = i and /_DA'N' = r

By geometry, /_B'A'C = i and /_A'CD = r

From ΔB'A'C and A'CD

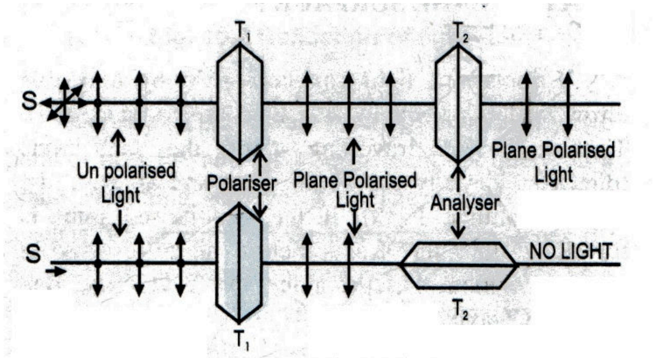
$\sin i = \frac{B'C}{A'C}$ and $\sin r = \frac{A'D}{A'C}$

Thus, $\frac{\sin i}{\sin r} = \frac{B'C}{A'D} = \frac{c_1t}{c_2t} = \frac{c_1}{c_2}$

But $\frac{\mu_2}{\mu_1} = \frac{c_1}{c_2} = \frac{\sin i}{\sin r}$

Thus Snell's law can be proved using Huygens' principle. Also it can be seen that the incident ray, refracted ray and the normal lie in the same plane.

POLARISATION



A beam of light from source 'S' is allowed to pass through tourmaline crystals. Consider two crystals T_1 and T_2 which are cut parallel to its crystallographic axis or optical axis, and kept with their axis parallel to each other. A light source 'S' is incident on crystal T_1 which acts as slit for light.

>> Now rotate both the crystals together with their axis parallel to each other in all positions, then it is found that there is no change in the intensity of light transmitted by T_2.

>> When crystal T_1 is kept fixed and T_2 is rotated then it is found that the intensity of light transmitted by T_2 decreases, finally becomes zero when their axis are perpendicular to each other.

>> If crystal T_2 is rotated further again then the intensity of light transmitted from T_2 increases and finally becomes maximum when they are parallel.

This experiment shows that light is not propagated as longitudinal waves, but is transverse in nature.

Secondly, T_1 only allows those vibrations to pass through it, which are parallel to its axis. Hence when they emerge out of the crystal they vibrate in only one direction. Thus light is said to be linearly polarized. This phenomenon is called ***Polarisation.***

T_1 is called the polarizer because it polarizes the unpolarised light passing through it. T_2 is called the analyser which helps analyse the state of polarization, when axis of T_2 is parallel to T_1 it allows the light to pass through and when axis of T_2 is perpendicular to that of T_1, it stops the light

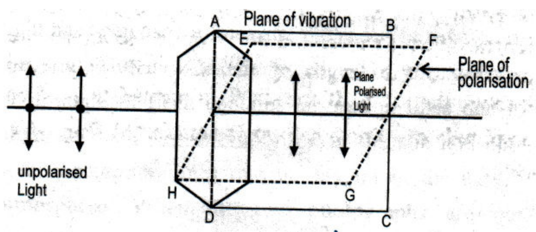
Example: tourmaline crystal, Nicol prism.

Definitions:

>> The phenomenon of restriction of the vibrations of light waves in a particular plane perpendicular to the direction of propagation of wave motion is called ***polarisation of light waves.***

>> The plane in which the vibrations of polarized light take place is called as ***plane of vibration***

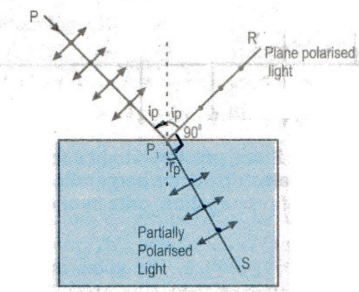
>> The plane perpendicular to the plane of vibration in which there are no vibrations of polarized light is called ***plane of polarisation***.



BREWSTER'S LAW :

Malus discovered the phenomenon of polarisation by reflection.

Sir David Brewster in 1892 discovered that when the light is incident on a transparent medium at a polarizing angle, the reflected light is completely plane polarized in the plane of incidence, and the reflected and refracted rays are separated by 90º.



i_p : polarizing angle, μ : refractive index of the medium

$i_p + 90^\circ + r_p = 180^\circ$. therefore $r_p = 90^\circ - i_p$

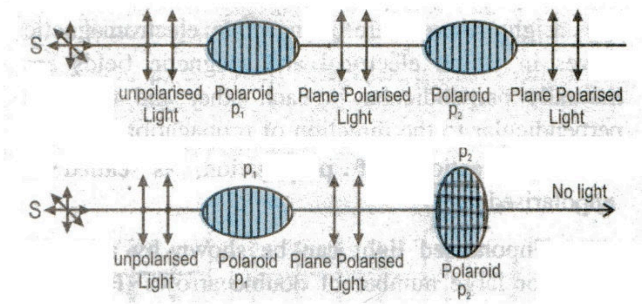
From snell's law, $\mu = \dfrac{\sin i_p}{\sin r_p} = \dfrac{\sin i_p}{\sin(90 - i_p)} = \dfrac{\sin i_p}{\cos i_p} = \tan i_p$

Brewster's Law: The tangent of the polarizing angle is equal to the refractive index of the refracting medium at which partial reflection takes place.

Polarizing angle depends on wavelength and is different for different colours. Brewster's law does not hold good for polished metallic surfaces.

POLAROIDS:

The property by which some doubly refracting crystals absorb the ordinary ray (O-ray) and extraordinary rays whose direction is parallel to the optical axis is called ***Dichroism***. E.g Tourmaline is a dichroic crystal. This phenomenon if selective absorption is used in construction of Polaroid's. In 1852, W.H.Herapath, discovered a synthetic material, iodosulphate of quinine, known as Herapathite. Though it shows strong dichroism, these crystals are not stable and are affected by slight strain. In 1934, E.H.Lamb developed a polarizer known as a Polaroid. He arranged herapathite crystals side by side in such a way that the optical axis of each of them were parallel to each other, so that they acted as a single crystal of large dimensions.



P1 and P2 are kept with axis parallel. Light incident on it, the emerging light from P1 is plane polarized. Now this is transmitted through P2 whose axis is parallel toP1. When P1 is fixed and P2 is rotated about its axis, the intensity gradually decreases. When the axis of P2 and P1 are crossed, the intensity will be zero.

Uses: Motor car headlights to remove glare, 3D movie cameras, Filter in photographic cameras, sunglasses, calculators, watches, LCD screens.

DOPPLER EFFECT IN LIGHT :

Doppler effect in light is symmetric i.e. it depends only on the relative velocity of the source and the observer, irrespective of which of the two is moving. From theory of relativity frequency of light is given as

$$\nu' = \nu\left(\frac{1 \pm \frac{V_r}{c}}{\sqrt{1 - \left(\frac{V_r}{c}\right)^2}}\right)$$

Where V_r is the radial component of the velocity of the source relative to the observer. When $V_r << c$, we have

$$\nu' = \nu\left(1 \pm \frac{V_r}{c}\right)$$

This leads us to $\dfrac{\Delta\nu}{\nu} = \dfrac{\Delta\lambda}{\lambda} = \dfrac{V_r}{c}$

Red Shift and Blue Shift: Due to Doppler effect, a wavelength in the middle of the visible spectrum will be shifted towards red (frequency decrease, wavelength increase) when source and observer move away from each other, and towards blue (frequency increase, wavelength decrease), if they approach each other. This helps us to study the motion of stars and galaxies.

Applications:

Measurement of radial velocity of galaxies and plasma temperature.

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