Chapter Ten

WAVE OPTICS

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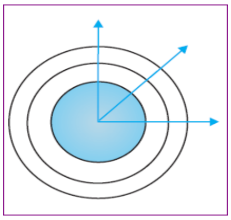
Wavefront

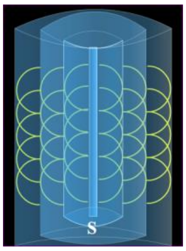
- A wavefront is locus of all points in a medium which are at the same phase of vibration.
- The speed with which the wavefront moves outwards from the source is called the speed of the wave.
- The energy of the wave travels in a direction perpendicular to the wavefront.

Types of wavefront

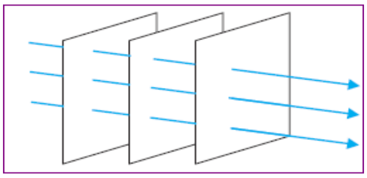
- **Spherical wavefront –** wavefront from a point source



- **Cylindrical wavefront**- wavefront from a linear source.

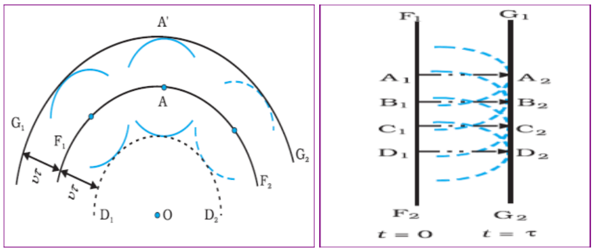


- **Plane wavefront : - w**avefront at large distances from a point source.



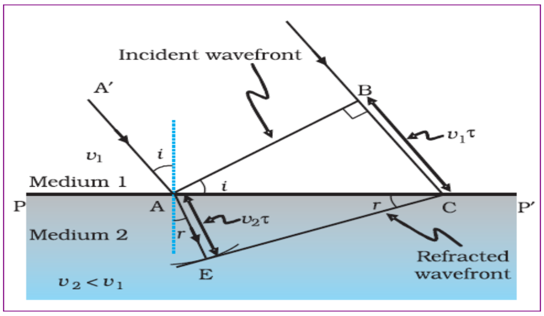
Huygen's Principle

- According to Huygens principle, *each point of the wavefront is the source of a secondary disturbance and the wavelets (secondary wavelets) emanating from these points spread out in all directions with the speed of the wave.*
- *By drawing a common tangent to all these spheres, we obtain the new position of the wavefront at a later time.*



- Huygens argued that the amplitude of the secondary wavelets is maximum in the forward direction and zero in the backward direction

Refraction of a plane wave



- Let τ be the time taken by the wavefront to travel the distance BC.
- Thus $BC = v_1 \tau$
- From the triangle ABC we get

$$\sin i = \frac{BC}{AC} = \frac{v_1 \tau}{AC}$$

- Also from triangle AEC

$$\sin r = \frac{AE}{AC} = \frac{v_2 \tau}{AC}$$

- Thus

$$\frac{\sin i}{\sin r} = \frac{v_1}{v_2}$$

- If *c represents the speed of light in* vacuum, then,

$$n_1 = \frac{c}{v_1} \qquad n_2 = \frac{c}{v_2}$$

- Therefore

$$n_1 \sin i = n_2 \sin r$$

- This is the ***Snell's law of refraction***.
- If λ_1 and λ_2 denote the wavelengths of light in medium 1 and medium 2, respectively, then

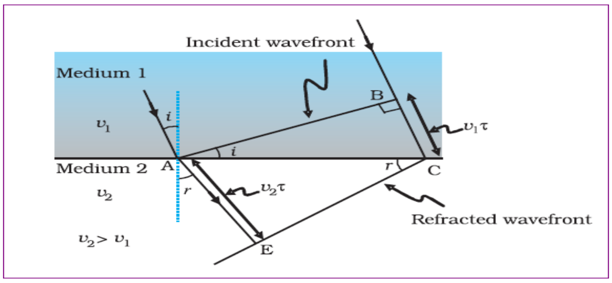
$$\frac{\lambda_1}{\lambda_2} = \frac{BC}{AE} = \frac{v_1}{v_2}$$

- That is

$$\frac{v_1}{\lambda_1} = \frac{v_2}{\lambda_2}$$

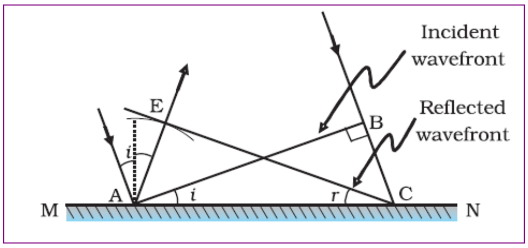
- This implies that **when a wave gets refracted into a denser medium, the wavelength and the speed of propagation decrease but the frequency ν (=v/λ) remains the same.**

Refraction at a rarer medium



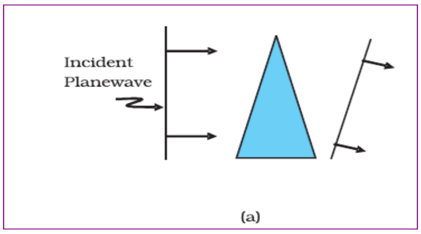
- The angle of refraction will be greater than angle of incidence.
- Thus, if $i = i_c$ *then sin r = 1 and r = 90°.*
- Therefore $$\sin i_c = \frac{n_2}{n_1}$$
- The angle i_c is known as the **critical angle** and for all angles of incidence greater than the critical angle the wave will undergo **total internal reflection.**

Reflection of a plane wave by a plane surface

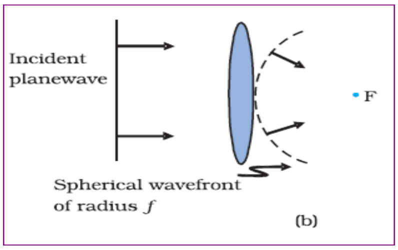


- If *v represents the speed of the wave in the medium and if τ* represents the time taken by the wavefront to advance from the point B to *C then* $BC = v\tau$
- Also $AE = BC = v\tau$
- The triangles EAC and BAC are congruent
- Therefore the angles *i* and *r would* be equal. This is the *law of reflection*.

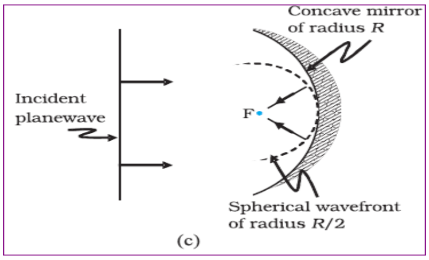
A plane wave passing through a thin prism.



A plane wave incident on a thin convex lens



A plane wave is incident on a concave mirror



The Doppler effect

- The apparent change in frequency of light seen by an observer ,whenever there is a relative motion between source and observer is called Doppler Effect.
- When **the source is moving towards the observer** with a velocity v, then the apparent frequency of light

$$\nu' = \nu\left(1 + \frac{v}{c}\right)$$

- Where ν- actual frequency, v – velocity
- Therefore the fractional change in frequency

$$\frac{\Delta\nu}{\nu} = \frac{v}{c}$$

- If the source is moving away from the observer, the apparent frequency

$$\nu' = \nu\left(1 - \frac{v}{c}\right)$$

- Hence the fractional change in frequency is

$$\frac{\Delta \nu}{\nu} = -\frac{v}{c}$$

Red shift

- When the source moves away from the observer, there is an apparent decrease in the frequency of light. This is called **red shift**.

Blue shift

- When the source moves towards the observer, there is an apparent increase in the frequency of observed light. This is called **blue shift**.

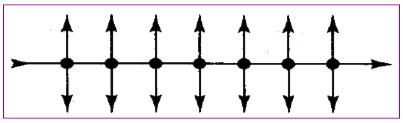
POLARISATION

- When ordinary light passes through certain crystals like tourmaline crystal, the vibrations of electric field vector are restricted. This phenomenon is called **polarization.**
- Polarization shows that **light is a transverse wave.**
- Sound waves cannot polarize**.**

Unpolarised light

- The ordinary light which contains the vibrations of electric field vector in every plane perpendicular to the direction of propagation is called unpolarised light.

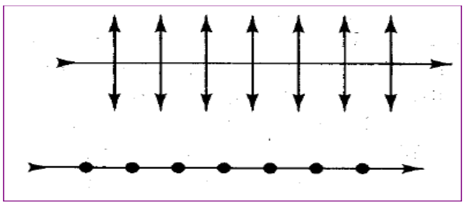
Representation of unpolarised light



Plane polarized light

- The polarized light in which the electric field vibrations of light are confined to a single plane are called plane polarised light.

Representation of plane polarised light



Plane of vibration

- It is the plane in which the vibrations of the polarized light take place.

Plane of polarization

- It is the plane perpendicular to the plane of vibration of the plane polarized light.

Polarizer

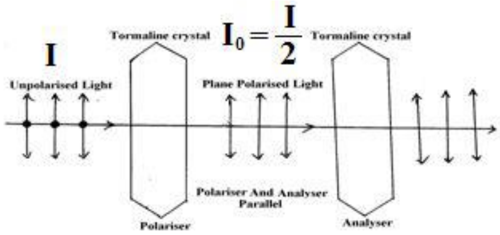
- The crystal which produces polarized light is called a polarizer.

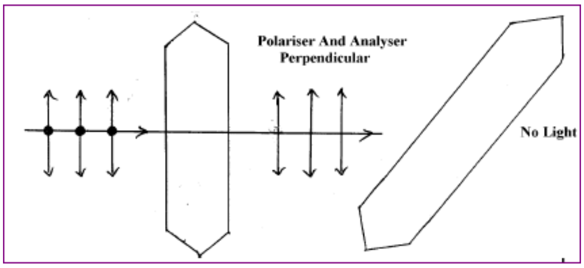
Analyzer

- The crystal which is used to check whether the light is polarized or not is called analyzer or detector.

An experiment to study polarization of light

- When unpolarized light passes through polarizer the light coming out of it is plane polarized.





- If the polarizer and analyser are parallel the intensity of light coming through the analyser will be maximum.
- If the analyser is rotated through 90^0 the intensity of light coming out of it becomes zero.

Polaroids

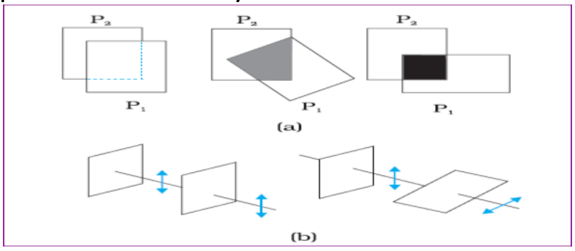
- Polaroid is an artificially made polarising material that produce intense beam of polarised light by selective absorption.
- Polaroids are in sunglasses, windowpanes, photographic cameras, 3D movie cameras etc.

Malus' law

- Malus's law states that when a beam of plane polarised light is incident on the analyser, then the intensity of the emergent light is directly proportional to square of the cosine of the angle between the polariser and analyser.

$$I = I_0 \cos^2\theta$$

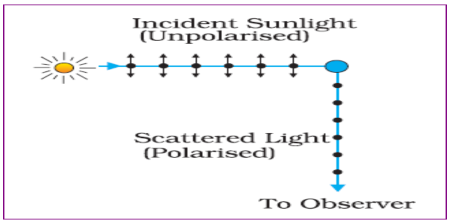
- Where θ is the angle between the axes of polarizer and analyzer.



Methods of polarization

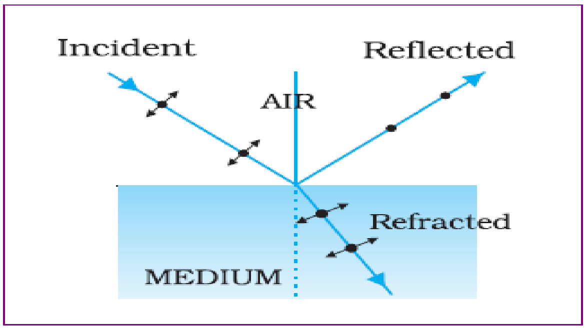
- **Polarization by scattering**
- **Polarisation by reflection**

Polarization by scattering



- When sunlight is incident on the gas molecules in the atmosphere, it gets scattered.
- The scattered light seen in a direction perpendicular to the direction of incidence is found to be plane polarised. This phenomenon is called polarisation by scattering.
- When this polarised light is viewed through a polaroid which is rotated, then the intensity changes with rotation.
- The scattering of light by molecules was intensively investigated by C.V. Raman and his collaborators .Raman was awarded the Nobel Prize for Physics in for this work.

Polarisation by reflection



- When ordinary light falls on a surface separating two transparent media, a part of the light is reflected and the other part is transmitted (refracted).
- When reflected wave is perpendicular to the refracted wave, the reflected wave is a totally polarised wave.

Brewster's angle (polarizing angle)

- The angle of incidence at which the reflected ray is totally polarized is called ***Brewster's angle*** *and is denoted by* i_B.

Brewster's law

- Brewster's law states that the tangent of the Brewster's angle is equal to the refractive index of the medium.

$$\tan i_B = \mu$$

Proof

- From Snell's law

$$\mu = \frac{\sin i_B}{\sin r} = \frac{\sin i_B}{\sin(\pi/2 - i_B)}$$

$$= \frac{\sin i_B}{\cos i_B} = \tan i_B$$

Distinguishing a polarized light and unpolarized light

- When we observe unpolarised light (ordinary light) through a Nicol prism (tourmaline crystal), the intensity of the light coming out of the prism does not change if the crystal is rotated.
- But when we observe polarized light through a Nicol prism, the intensity of the light coming out of the prism changes if the crystal is rotated.

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