HUMAN EYE AND COLORFUL WORLD

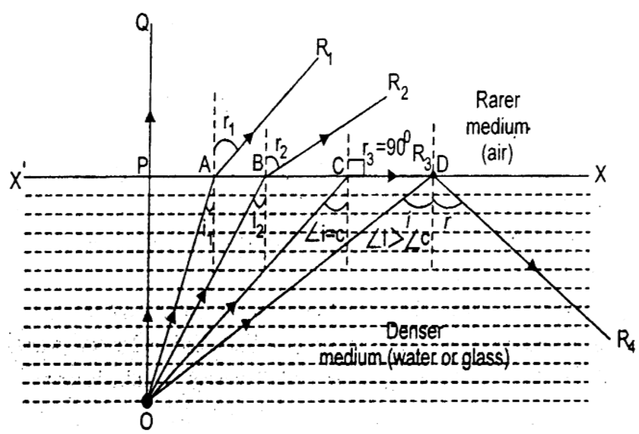
TOTAL INTERNAL REFLECTION

TOTAL INTERNAL REFLECTION

1 Definition

It is the phenomenon of reflection of light totally back into a denser medium as it travels from denser medium to meet the interface with rarer medium at an angle greater than critical angle 'C'.

As shown in fig. when a ray of light starting from point O in denser medium goes to a rarer medium, it bends away from the normal and angle of refraction $\angle r$ increases as angle of incidence $\angle i$ goes on increasing. Normal ray OP ($\angle$ i = 0, \ $\angle$r = 0) goes undeviated along PQ and for oblique rays at A, B $\angle r > \angle i$. At point C, $\angle i = \angle c$, critical angle for which refracted ray goes along CR_3, i.e. along XX' and r = 90º in rarer medium.



At point D, i> c, and ray, instead of suffering refraction, undergoes reflection totally back along DR_4, in denser medium. Hence beyond C, rays suffer "Total Internal Reflection.".

Necessary Conditions for total internal reflection to occur

(i) The rays of light must travel from denser to rarer medium.

(ii) The angle of incidence ∠i in the denser medium must be greater than the critical angle i_C, for the given pair of media.

2 Definition of Critical Angle (i_C)

It is that angle of incidence in the denser medium for which angle of refraction in the rarer medium is 90º.

3 Relation Between Critical Angle and Refractive Index

In above figure, for refraction at C, the light ray is travelling from denser medium to rarer medium.

∴ Refractive index of air w.r.t. denser medium :

$$^{med}\mu_{air} = \frac{\sin i_c}{\sin 90^0}$$

$$or \ ^{med}\mu_{air} = \frac{\sin i_c}{1}$$

$$^{air}\mu_{med} = \frac{1}{\sin i_c}$$

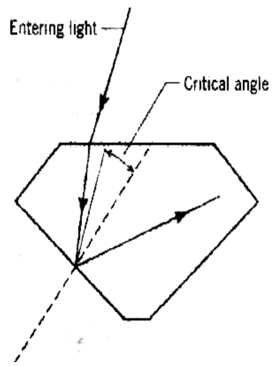
$$or \ i_c = \sin^{-1}\left(\frac{1}{\mu}\right)$$

APPLICATIONS OF TIR

1. Sparkling of diamond:

A diamond sparkles because, when it is held in a certain way, the intensity of the light coming from it is greatly enhanced. Fig. helps to explain that this enhancement is related to total internal reflection. Part of the drawing shows a ray of light striking a bottom face of the diamond at an angle of incidence exceeding the critical angle, the ray is totally reflected back into the diamond, eventually exiting the top surface to give the diamond its sparkle.

The critical angle is **24.4°**. The value is so small, therefore the index of refraction of diamond is large compared to that of air.

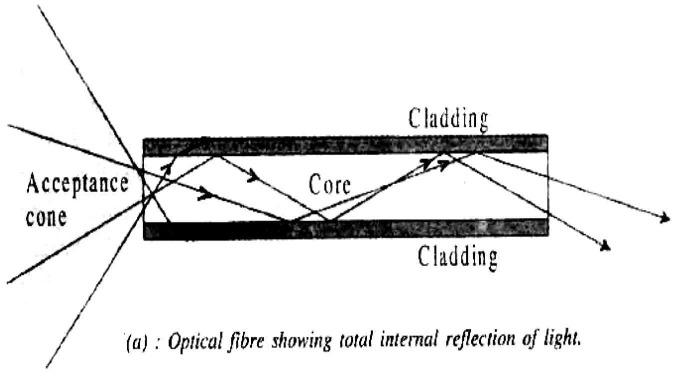


Now consider what happens to the same ray of light within the diamond when the diamond is placed in water. Because water has a larger index of refraction than air, the critical angle increases to 33.3°. Therefore, only this part of the light is reflected back into the diamond, and the remainder escapes into the water. Consequently, less light exits from the top of the diamond, causing it to lose much of its brilliance.

2. Optical fibre :

Take a thin solid wire (called strand) made up of glass or quartz, etc. Coat it from outside with some material whose m is less than that of glass or quartz, etc. Now, because it is thin, hence whichever ray of light enter it from one of its ends, will strike the inside surface at some angle which will definitely be greater than the critical angle. Hence, it will suffer total interned reflection again and again until it comes out from the other end. This is the principle on which optical fibres work. Hence in effect, light can travel axially within an optical fibre, although the axis of fibre may be flexible having bent or wavy profile.

A bundle of optical fibres is called a light pipe and is able to send image of an extended object from one end to another by picking up images of small-small parts of the object and sending them likewise to the other end.



(a) : Optical fibre showing total internal reflection of light.

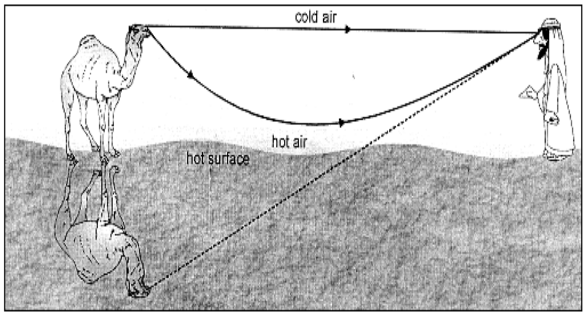
Use of Optical fibres :

(a) For medical examination inside the stomach, intestines etc., called endoscopy.

(b) The recent trend is to send even electrical signal through optical fibres, by converting them into electromagnetic radiations/light waves.

3. Mirage :

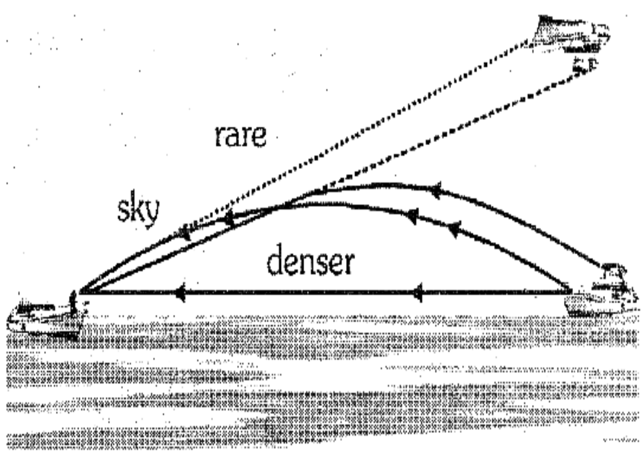
It is an optical illusion, in which inverted image of a distant object can be seen, as it reflected from a pond or a lake in hot regions due to continuous atmospheric refraction and total internal reflection. In deserts, because of intense heat, the layers of air, near the surface of the earth get heated so soon that the density adjustment does not take place, hence the densities and refractive indices of the layers immediately above the sand are lower than those of the layers higher up. The rays of light from a distant object, after passing through layers, which are gradually less refracting, bend more and more away from normal, till they fall on a layer at an angle, greater than the critical angle and it gets totally reflected. These reflected rays then travel up and undergo a series of refractions, but in a direction opposite to those in first case, they now pass through layers which are gradually more and more refracting, till they reach the eye of the observer, who sees an image of the object, as though reflected from the surface of a lake of water.



4. Looming :

It is an optical illusion in which inverted image of a distant object can be seen, as if reflected from a pond or lake or sometimes as if suspended in the atmosphere in cold regions due to continuous atmospheric refraction and total internal refection. Looming is observed in very cold regions caused by the total internal reflection of light coming from the ship or any other object.

In cold region, air above water is cold (denser) whereas above it, it is hot (rarer). So when light ray from the object travels from cold to warm air (denser to rarer) it undergoes continuous atmospheric refraction, and causes total internal reflections in downward directions due to which we see objects hanging up in sky.



Ex. A laser beam is directed at an angle q, to the normal of one side of a rectangular block to fused quartz. Part of the light striking the side of the block passes into the block and strikes an adjacent face. For what angle q will the laserbeam be totally reflected in the block?

Sol Snell's law gives for the refraction into the block (1.00) sin q = n_2 sin q_2.

If the beam is totally internally reflected at the adjacent face, the incident angle on that face must be at least.

$$\theta_c = \sin^{-1}\left(\frac{1.000}{1.458}\right) = 43.30^0$$

Since the block is rectangular, $q_2 + q_c = 90°$ so q_2 is less than 46.70° for the internal reflection of occur.

sin q = (1.458) sin 46.70° = 1.06.

The sine function cannot be greater than one, so the angle, q, which will produce the internal reflection must be less than or equal to 90°. That is, all incident angles will cause the light to be totally internally reflected at the adjacent face as long as the light strikes that faces.

Secondary Rainbow

The secondary rainbow is formed when the sunlight suffer two total internal reflection as well as dispersion from water droplets suspended in the atmosphere. The colour pattern is just reverse of that in the primary rainbow, i.e. violet colour on the outer edge and red colour on the inner edge of the rainbow. It is seen at an angle 52º-55º with the line joining the sun and the observer, when the sun is at the back of the observer. The primary rainbow is found to be more intense than the secondary rainbow.