Special Effects Due To Refraction

Objectives

After going through this module, the learners will be able to:

- Explain various natural phenomenon due to refraction of light.
- Learn a method to find the refractive index of a given medium using the concept of real depth and apparent depth.
- Know about the phenomenon of total internal reflection.
- Apply the phenomenon of total internal reflection to explain sparkling of diamonds and optical fibres.

Content Outline

- Unit Syllabus
- Module wise distribution of unit syllabus
- Words you must know
- Introduction
- Special effects due to refraction
- Relation between refractive index, Real depth and apparent depth
- To determine the refractive index of a liquid
- Total internal reflection
- Relation between refractive index and critical angle
- Total internal reflection in nature and its technological applications
- Summary

Unit Syllabus

UNIT 6: Optics

Chapter–9: Ray Optics and Optical Instruments

Ray optics Reflection of light; spherical mirrors; mirror formula; refraction of light; total internal reflection and its applications; optical; fibres; refraction at spherical surfaces; lenses; thin lens formula; lens maker's formula; magnification, power of a lens; combination of thin lenses in contact; refraction and dispersion of light through a prism.

Scattering of light – blue colour of sky and reddish appearance of the sun at sunrise and sunset

Optical instruments – microscopes and astronomical telescopes (refracting and reflecting) and their magnifying powers

Wave optics: wave front and Huygens' Principle; reflection and refraction of plane waves at a plane surface using wave fronts. Proof of laws of reflection and refraction of light using Huygens ' Principle. Interference; Young's double slit experiment and expression for fringe width, coherent sources and sustained interference of light; diffraction due to single slit; width of central maxima; resolving power of microscope and astronomical telescope, polarization; plane polarized light; Brewster's law; uses of plane polarized light and polaroids.

Module Wise Distribution Of Unit Syllabus 15 Modules

Module 1	● Introduction ● How we will study optics-plan ● Light facts ● Ray optics, beams ● Light falling on surfaces of any shape texture ● Peculiar observations
Module 2	● Reflection of light ● Laws of reflection ● Reflection of light by plane and spherical surfaces ● Spherical Mirrors aperture, radius of curvature, pole principal axis ● Focus, Focal length, focal plane ● Image – real and virtual ● Sign convention ● The mirror equation, magnification ● To find the value of image distance v for different values of object distance u and find the focal length of a concave mirror ● Application of mirror formula
Module 3	● Refraction of light

	- Optical density and mass density - Incident ray, refracted ray emergent ray - Angle of incidence, angle of refraction angle of emergence To study the effect on intensity of light emerging through different coloured transparent sheets using an LDR - Refractive index - Oblique incidence of light, Snell's law - Refraction through a parallel sided slab Lateral displacement, factors affecting lateral displacement - To observe refraction and lateral displacement of a beam of light incident obliquely on a glass slab - Formation of image in a glass slab
Module 4	- Special effects due to refraction - Real and apparent depth - To determine the refractive index of a liquid using travelling microscope - Total internal reflection - Optical fibres and other applications
Module 5	- Refraction through a prism - Deviation of light -angle of deviation - Angle of minimum deviation - Expression relating refractive index for material of the prism and angle of minimum deviation - To determine the angle of minimum deviation for a given prism by plotting a graph between angle of incidence and angle of deviation - Dispersion , spectrum
Module 6	- Refraction at spherical surfaces - Radius of curvature - Refraction by a lens - Foci, focal plane, focal length, optical center, principal axis - Formation of images real and virtual

	- Lens maker’s formula - Lens formula and magnification - Sign convention - Application of lens formula - Power of lens - Combination of thin lenses in contact

Module 7	- To study the nature and size of image formed by a
	  ○ convex lens
	  ○ concave mirror using a candle and a screen
	- To determine the focal length of convex lens by plotting graphs between u and v , between 1/u and 1/v
	- To determine the focal length of a convex mirror using a convex lens
	- To find the focal length of a concave lens using a convex lens
	- To find the refractive index of a liquid by using a convex lens and a plane mirror

Module 8	- Scattering of light – - Blue colour of sky - Reddish appearance of the sun at sunrise and sunset - Dust haze
Module 9	- Optical instruments - Human eye - Microscope - Astronomical telescopes reflecting and refracting - Magnification - Making your own telescope
Module 10	- Wave optics - Wave front - Huygens’ principle shapes of wave front - plane wave front - Refraction and reflection of plane wave front using Huygens’ principle

	● Verification of Laws of refraction and reflection of light using Huygen's principle
Module 11	● Superposition of waves ● Coherent and incoherent addition of waves
Module 12	● Interference of light ● Young's double slit experiment ● Expression for fringe width ● Graphical representation of intensity of fringes ● Effect on interference fringes in double slit experiment ● Black and white or coloured fringes
Module 13	● Diffraction ● Diffraction at a single slit ● Width of the central maxima ● Comparison of fringes in young's experiment and those in diffraction from a single slit
Module 14	● Diffraction in real life ● Seeing the single slit diffraction pattern ● Resolving power of optical instruments ● Validity of ray optics ● Fresnel distance
Module 15	● Polarisation ● To observe polarization of light using two polaroids ● Plane polarised light ● Polariser- analyser Malus law ● Brewster/s law ● Polarisation due to scattering ● Uses of plane polarised light and polaroids

Words You Must Know

Light: Light is a form of energy which gives the sensation of vision when it falls on the retina of the eye.

Ray of light: The straight line path along which light travels is called a ray of light. Light rays start from each point of a source and travel along a straight line until they strike an object or a surface separating two media.

Beam of light: A group of rays of light is called a beam of light.

Parallel beam of light: If all the rays of light in the group are parallel to each other, then the beam is said to be a parallel beam of light.

Converging beam of light: If the rays of light in the group come closer to each other i.e. converge to a point, then the beam is said to be a converging beam of light.

Diverging beam of light: If the rays of light in the group move away from each other i.e. diverge, then the beam is said to be a diverging beam of light.

Transparent medium: A medium through which light can pass freely over a large distance is called a transparent medium. Glass and still water are some examples of transparent objects.

Opaque medium: A medium through which light cannot pass is called an opaque medium. Wood and metals are some examples of opaque objects.
Real image: If the rays of light after reflection from a mirror actually meet at a point i. e. the reflected beam is a converging beam, then the image is said to be a real image.

Virtual image: If the rays of light after reflection from a mirror do not actually meet at a point but meet on producing backwards i.e. the reflected beam is a diverging beam, then the image is said to be a virtual image.

Reflection of light: The phenomenon of bouncing back of light after striking a reflecting surface is called reflection of light.

Laws of reflection of light:

- angle of incidence = angle of reflection

- The incident ray, the reflected ray and the normal at the point of incidence, all lie in the same plane.

Refractive index: n = speed of light in vacuum/ speed of light in the medium

Relative refractive index: Consider light going from medium 1 to medium 2

Then refractive index of medium 2 with respect to medium 1 is

$$n_{21} = (n_2 / n_1) = v_1 / v_2$$

Laws of refraction of light:

- The incident ray, the refracted ray and the normal at the point of incidence, all lie in the same plane.
- The ratio of sine of the angle of incidence i to the sine of the angle of refraction ***r**, for two media* is constant for a given wavelength of light and is equal to the refractive index of the second medium with respect to the first medium.

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

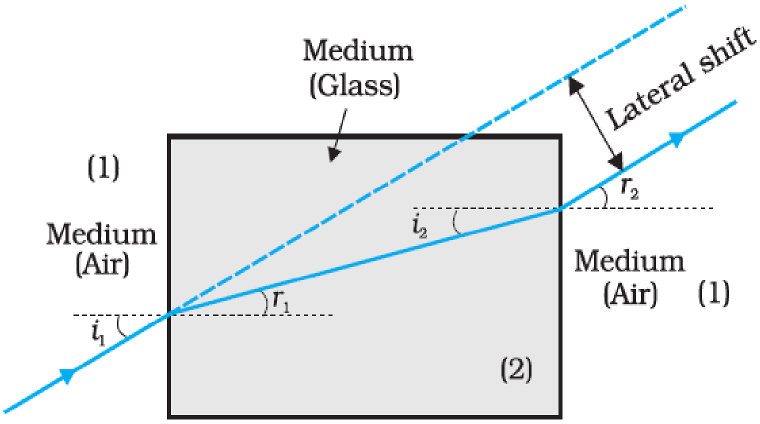
Introduction

A variety of natural phenomena have appeared as mysteries to humankind. Have you ever wondered why stars twinkle?

In order to understand these, we need to recall the phenomenon of refraction - **when light goes from one medium to another, and the optical density changes, there is a change in speed of light.**

There is bending of obliquely incident light rays at the interface of two mediums with different optical densities.

Some elementary results based on the laws of refraction follow immediately. For a rectangular slab, refraction takes place at two interfaces (air-glass and glass-air). It is easily seen in the figure.



That $r_2 = i_1$, i.e., the emergent ray is parallel to the incident ray.here is no deviation, but it does suffer lateral displacement/shift with respect to the incident ray. Another familiar observation is that the bottom of a tank filled with water appears to be raised; a pencil appears broken, far off stars twinkle etc

In this module **we will try to understand the phenomenon we observe and explain it using our ideas of refraction.**

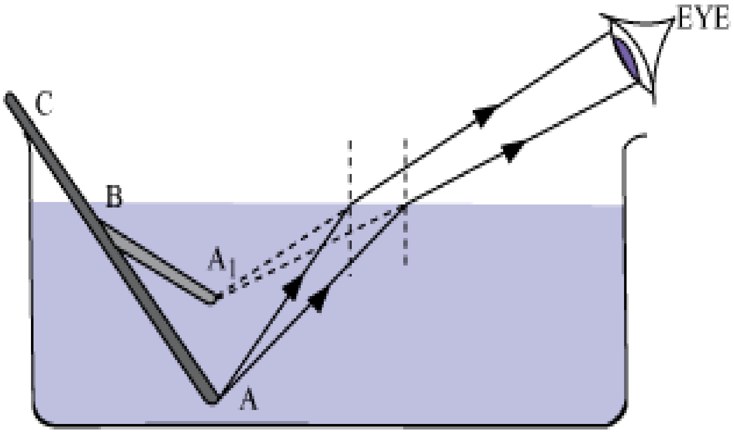
Special Effects Due to Refraction

- **A pencil placed in water seems bent when seen obliquely from above the water surface.**

  You can just observe this effect of refraction by putting a pencil in a glass of water.

Refraction of light at the air-water interface makes us feel that point A lies above the bottom at point A1. Hence we observe two parts of the pencil CB and A1B instead of CBA

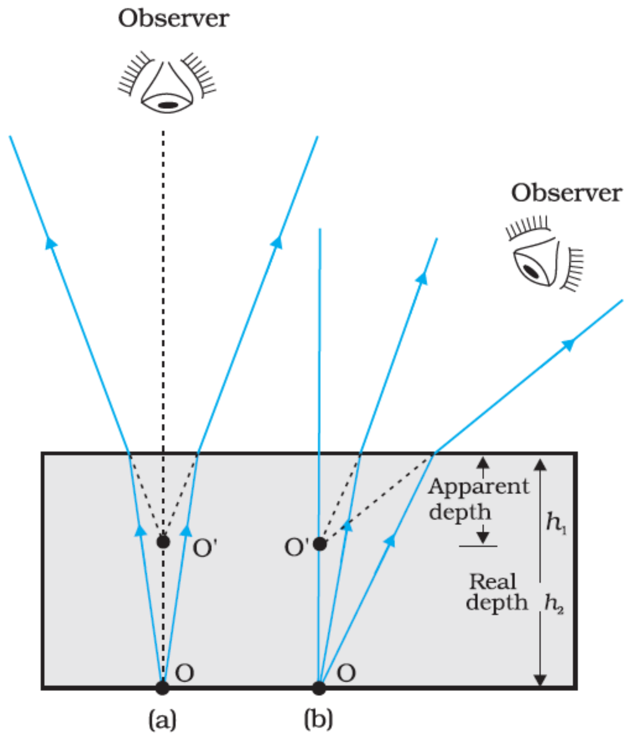
https://www.alamy.com/stock-photo-a-pencil-in-a-glass-of-water-showing-the-optical-distortion-caused-8613204.html



For viewing near the normal direction, it can be shown that the apparent depth(h_1) is real depth (h_2) divided by the refractive index of the medium (water).Because the pencil does not really bend or the base of the container of water does not rise due to water it is called apparent.

Consider the given figure; there are two positions from where the point O on the base is being observed.

- From the top (a)
- From the side (b)



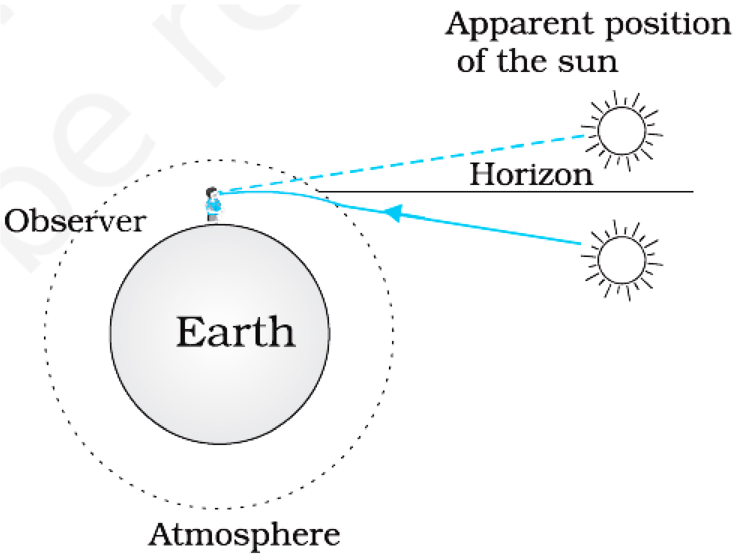
Apparent depth for (a) normal and (b) oblique viewing

For both cases the image is O'. Follow the ray diagram to understand the formation of image of O at O'

- **Apparent shift in position of the sun at sunrise and sunset:**

The sun is visible to us nearly 2 minutes before actual sunrise and remains visible for nearly 2 minutes after actual sun sets.

The refraction of light through the atmosphere is responsible for many interesting phenomena. Considering the time of sunset and sunrise being affected by refraction. Sun is visible a little before the actual sunrise and until a little after the actual sunset due to refraction of light through the atmosphere.By actual sunrise we mean the actual crossing of the horizon by the sun.



- With increase in altitude, the density of atmosphere decreases, nd hence refractive index of air layers decreases.
- The density of air is higher near the surface of earth.

The rays of light from the sun S (which is slightly below the horizon) coming through the space, on entering the earth's atmosphere move (continuously) from an optically rarer medium (the upper layer of the atmosphere) to an optically denser medium (the lower layer of the atmosphere).

They bend slightly towards normal at each refraction and appear to come from S'. Therefore, the sun appears to have risen above the horizon. Hence the sun appears to rise a few minutes before the actual rise. For the same reason the sun remains visible to us a few minutes after it has set or dipped below the horizon.Figure shows the actual and apparent positions of the sun with respect to the horizon.

The figure is highly exaggerated to show the effect.

The refractive index of air with respect to vacuum is 1.00029. Due to this, the apparent shift in the direction of the sun is by about half a degree and the corresponding time difference between actual sunset and apparent sunset is about 2 minutes.

The apparent flattening (oval shape) of the sun at sunset and sunrise is also due to the same phenomenon.

Why should refraction take place at all?

- Atmospheric density, humidity and temperatures are not uniform.

Example

The earth takes 24 h to rotate once about its axis. How much time does the sun take to shift by 1° when viewed from the earth?

Solution

Time taken for 360° shift = 24 h

Time taken for 1° shift = 24/360 h = 4 min.

- **Twinkling of stars**:

The optical density, and hence the refractive index of air increases as we move towards the surface of earth.**As the temperature of air and its humidity is not same everywhere in the atmosphere, the refractive index of air is different at different places even at the same altitude.**

When a ray of light passes through different pockets of air having different refractive indices, it bends due to refraction.

The air pockets however keep on moving the light rays therefore get refracted in different directions.

The direction of the ray reaching at our eye keeps on changing.

Thus the image of the star keeps on shifting its position in a random manner. The amount of starlight, reaching our eye, also keeps changing.

Thus stars appear to be twinkling.

Note

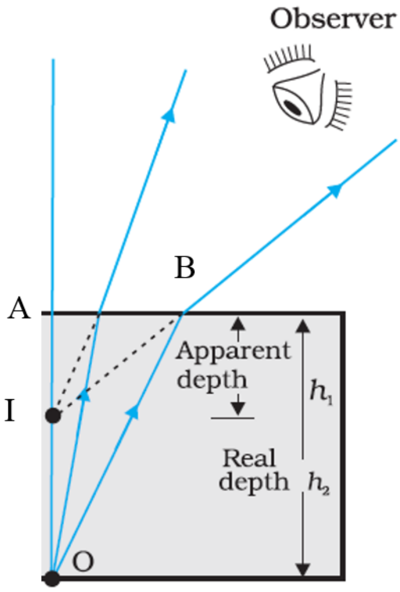
Twinkling effect is more when the stars are near the horizon than when they are overhead. This is because the light coming from the stars near the horizon has to travel more distance in the atmosphere as compared to the light coming from overhead stars.

Relation Between Real Depth and Apparent Depth

Let us now find out the height by which the object seems to be raised

Normal shift

$$d = OA - IA$$



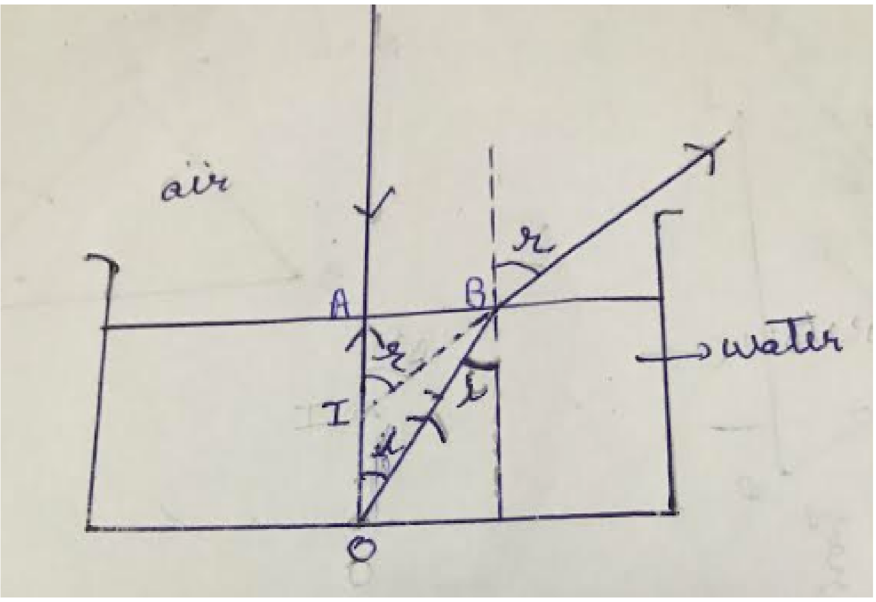
We know

$n_{aw} = \sin i / \sin r$

$n_{aw} = 1 / n_{wa}$

$n_{wa} = \sin r / \sin i$

In the right-angled triangle OAB



$\sin i = \frac{AB}{OB}$

$\angle AIB = \angle NBC = r$

$\sin r = \frac{AB}{IB}$

$n_{wa} = \frac{OB}{IB}$

As the aperture of our eye is very small, so point B lies very close to point A. We can therefore say that OB ≅ OA and IB ≅ IA

$n_{wa} = \frac{OB}{IB} = \frac{real\ depth}{apparent\ depth}$

$shift\ in\ position = d = OA - IA = real\ depth - apparent\ depth$

$Apparent\ depth = real\ depth/n_{wa}$

$d = t - t/n_{wa} = t(1 - 1/n_{wa})$

The shift in position of the object depends upon

- **The real depth of the object**
- **Refractive index of the medium in which the object is placed.**

To Determine the Refractive Index of a Liquid Using a Travelling Microscope

Apparatus required: beaker, water, permanent marker, a travelling microscope, lycopodium powder

Formula used: Refractive index = real depth / apparent depth

$$= (R_3 - R_1) / (R_3 - R_2)$$

Procedure

- Take a beaker put a cross mark with a black colour permanent marker on the outer side of the beaker.
- Place the travelling microscope on the table (near a window) so that sufficient light falls on it.
- Adjust the levelling screws so that the microscope is horizontal
- Adjust the position of the eyepiece so that the cross wires are clearly visible.
- Find the vernier constant of the given microscope.
- Make the microscope vertical and keep the beaker under it.
- Focus the microscope on the cross mark put at the inner bottom of the beaker.
- Note the vernier scale and main scale reading. Let the reading be R_1.
- Pour water in the beaker up to a certain height.
- Raise the microscope upward to focus on the cross mark again.
- Note the vernier scale and main scale reading again. Let the reading be R_2.
- Sprinkle a few particles of lycopodium powder (if not available fine saw dust or chalk powder can be used) on the surface of water.
- Raise the microscope further upward to focus on the lycopodium particles which are on the surface of water.
- Note the vernier scale and main scale reading again. Let the reading be R3.
- The difference, $(R_3 - R_1)$ gives the real depth and $(R_3 - R_2)$ gives the apparent depth of the water put in the beaker.
- Using the formula $n = (R_3 - R_1) / (R_3 - R_2)$ the refractive index of water can be determined.

Example

A glass jar is filled with water to a height of 12.5 cm. The apparent depth of a needle lying at the bottom of the glass jar is measured by a microscope to be 9.4 cm.

- What is the refractive index of water?
- If water is replaced by a liquid of refractive index 1.63 up to the same height, by what distance would the microscope have to be moved to see the needle clearly again?

Solution

Refractive index is $= \frac{real\ depth}{apparent\ depth}$

- $n_w = \frac{12.5}{9.4} = 1.33$
- $n_{liquid} = 1.63$

Apparent height with liquid in the glass jar =

$$\frac{real\ depth}{refractive\ index\ of\ the\ liquid} = \frac{12.5}{1.63} = 7.7\ cm$$

The microscope will have to be displaced by 9.4 - 7.7 = 1.7 cm

Think out whether it will be raised to see the needle through the denser liquid or lowered better

Example

A fish under water is looking obliquely at a fisherman standing on the bank of a lake. Does the man appear taller or shorter than his actual height to the fish?

Solution

Man is in air and fish in water,

$$n_{wa} = \frac{H}{h}$$

H is the real height of the man.

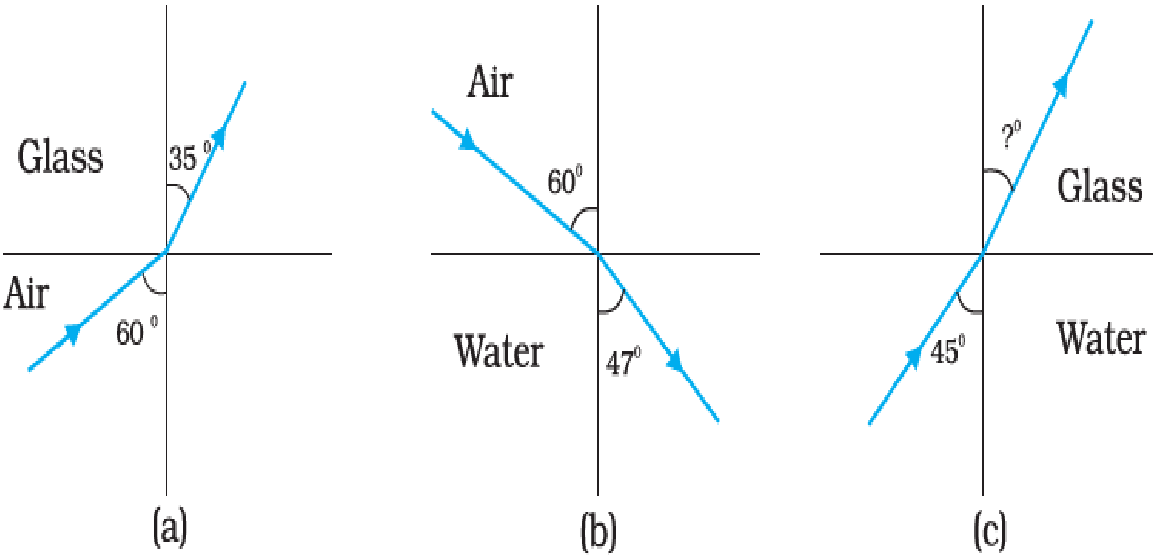
Now refractive index of air with respect to water $= \frac{n_a}{n_w} = \frac{1}{4/3} = \frac{3}{4}$

$$h = \frac{H}{3/4} = \frac{4}{3}H > H$$

So he will appear taller to the fish

Example

Figures (a) and (b) show refraction of a ray in air incident at 60° with the normal to a glass-air and water-air interface respectively.Predict the angle of refraction in glass when the angle of incidence in water is 45° with the normal to a water-glass interface.



Solution

From Snell's law

$$\frac{\sin i}{\sin r} = \frac{n_2}{n_1} = {}_1n_2$$

Using the table for natural sine

- $\frac{\sin 60}{\sin 35} = \frac{n_g}{n_a} = {}_an_g$

  $= \frac{0.8660}{0.5736} = 1.51$

- $\frac{\sin 60}{\sin 41} = \frac{n_w}{n_a} = {}_an_w$

  $= \frac{0.8660}{0.6561} = 1.32$

- $\frac{\sin 45}{\sin r} = \frac{{}^{a}n_{g}}{{}^{a}n_{w}} = \frac{1.51}{1.32}$

$$\sin r = \frac{1.32}{1.51} \times \sin 45 = \frac{1.32}{1.51} \times 0.7071 = 0.6181$$

$$r = \sin^{-1}(0.7071) = 38^{0}$$

Example

A small pin fixed on a table top is viewed from above from a distance of 50 cm.

- By what distance would the pin appear to be raised if it is viewed from the same point through a 15 cm thick glass slab held parallel to the table? Refractive index of glass = 1.5.
- Does the answer depend on the location of the slab?

Solution

- Displacement of the pin due to the glass slab

$$Apparent\ depth = real\ depth/n_{wa}$$

$$d = t - t/n_{wa} = t(1 - 1/n_{wa})$$

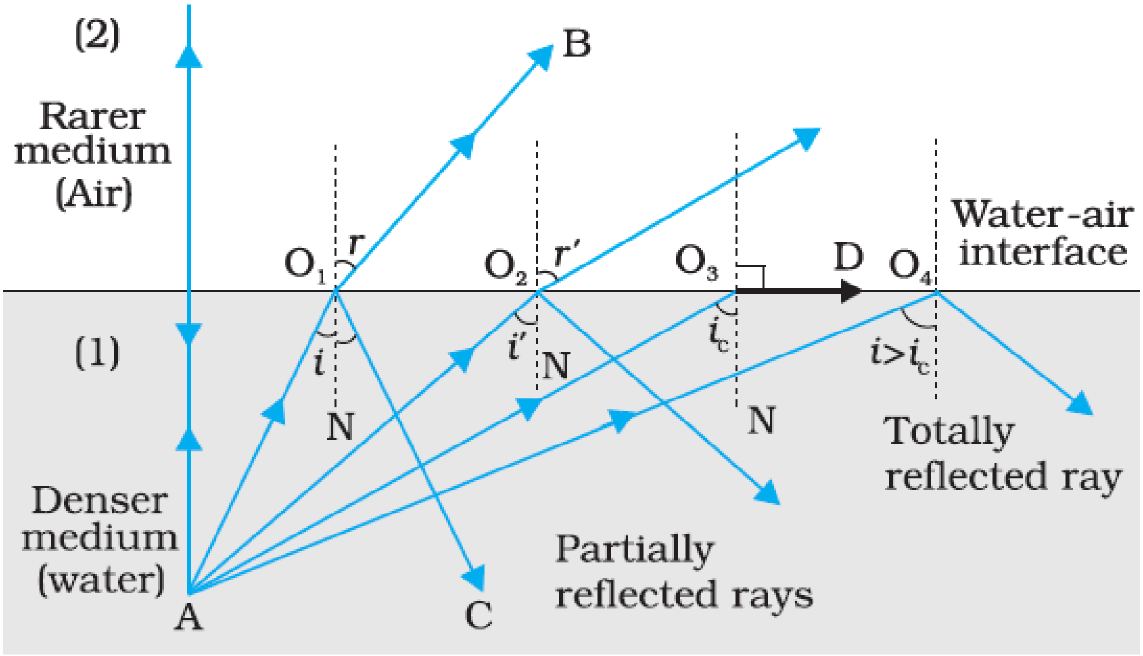
$$d = 15\left(1 - \frac{1}{1.5}\right)cm = 15\left(\frac{1.5-1}{1.5}\right) = 5\ cm$$

The pin appears to be raised by 5 cm

- The location of the slab will not change the image of the pin. So **no change in apparent position of the pin.**

Total Internal Reflection

We know that when a ray of light goes from an optically denser medium to an optically rarer medium it bends away from the normal. The angle of refraction is more than the angle of incidence. As no medium is perfectly transparent the incident ray AO$_1$ is partially reflected along O$_1$C and partially refracted along O$_1$B.



Refraction and internal reflection of rays from a point A in the denser medium (water) incident at different angles at the interface with a rarer medium (air).**As the angle of incidence increases, the angle of refraction also increases in accordance with Snell's law. This would continue to happen till the angle of refraction becomes 90^0 i.e. the refracted ray grazes along the surface of the interface between two media.** This is shown by the ray O$_3$D in the figure.

Now if the angle of incidence is increased further (ray AO$_4$) refraction is not possible and the incident ray gets totally reflected. When light gets reflected from a surface, otherwise some light is always transmitted. Thus the reflected light is less intense. In this case for rays like AO$_4$, no refraction occurs, so this ray is said to have undergone total internal reflection.

Critical angle

That angle of incidence in the optical denser medium for which the refracted ray just grazes the interface of two media is called the critical angle for the given pair of media.

We may also say:

The critical angle is that angle of incidence in an optical denser medium for which the angle of refraction is 90 degree.

The angle AO_3D in the above diagram represents the critical angle for the given pair of media.

The phenomenon, in which a ray of light going from an optically denser medium to an optically rarer medium, at an angle of incidence, greater than the critical angle for the given pair media is totally reflected back into the same medium is called total internal reflection.

Conditions for total internal reflection:

- Light must propagate from the optically denser medium to the optically rarer medium.
- Angle of incidence must be more than the critical angle

A Demonstration for Total Internal Reflection:

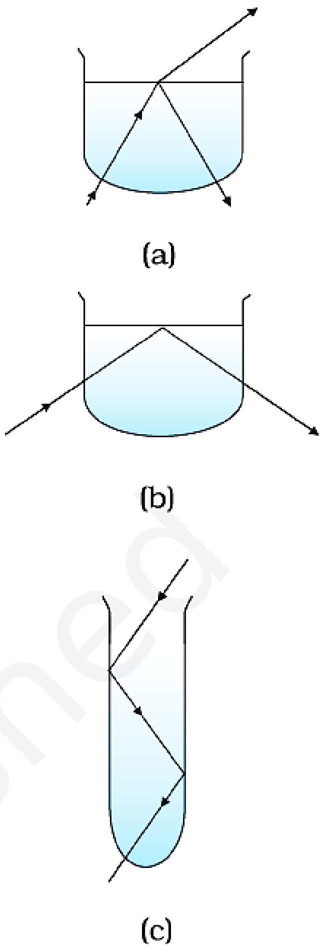
All optical phenomena can be demonstrated very easily with the use of a laser torch or pointer, which is easily available nowadays.

Take a glass beaker with clear water in it; stir it with a few drops of Dettol or washing soap, so that the water becomes turbid. The path of light will be visible in this turbid water.

Now shine the beam of a laser from the bottom of the beaker so that it strikes on the top surface of water. (a)

You will see that the light is partially reflected. Now shine the beam on the water from the side and adjust the angle of incidence so that the beam of light gets totally internally reflected as shown in the figure. (b)

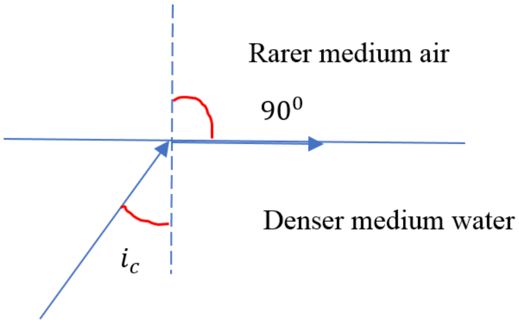
Now pour this water in a glass test tube and shine the laser beam on water from the top. Now adjust the angle of incidence such that the beam of light is totally internally reflected every time it strikes the wall of the test tube. (c)



Observing total internal reflection in water with a laser beam (Refraction due to glass of beaker neglected being very thin).

Relation Between Refractive Index and Critical Angle

Consider a ray of light going from an optically denser medium (medium 1of refractive index n_1) to an optically rarer medium (medium 2 of refractive index n_2) with angle of incidence equal to the critical angle.



$Angle\ of\ incidence\ = i_c$

Angle of refraction = 90^0

According to Snell's law

$$n_1 \sin i_c = n_2 \sin 90^{\ 0}$$

Refractive index of medium 2 w.r.t. medium 1= $n_{21}= n_2/n_1= \sin i_c$

$$n_{21} = \sin i_c$$

$$n_{12} = \frac{1}{n_{21}} = \frac{1}{sin\, i_c}$$

Let us now try to explain some more phenomena: like mirage and sparkling of diamond, with the help of the phenomenon of total internal reflection

Example

A small bulb is placed at the bottom of an aquarium containing water to a depth of 80cm. What is the area of the surface of water through which light from the bulb can emerge? Refractive index of water is 1.33. (Consider the bulb to be a point source.)

Solution

The light rays here are travelling from denser (water) to rarer medium (air)

The rays starting from the bulb will refract into the air if the angle of incidence at the surface of water is less than the critical angle.

If h is the depth of the bulb below the surface

$$the\ radius\ of\ the\ circle\ of\ light\ =\ h\ tan\ i_c$$

$$n_{12} = \frac{1}{n_{21}} = \frac{1}{sin\, i_c}$$

$$sin\ i_c = \frac{1}{n_{wa}} = \frac{3}{4}$$

$$tan\ i_c = \frac{3}{\sqrt{7}}$$

$$r\ =\ 0.80\ m\times\frac{3}{\sqrt{7}}$$

Area of the light patch on the surface of aquarium water

$$=\ \pi r^2\ =\ 3.14\times\left(0.80\ m\times\frac{3}{\sqrt{7}}\right)^2\ =\ 2.6m^2$$

Total Internal Reflection in Nature and its Technological Applications

- **Sparkling of diamond:**

Diamonds are known for their spectacular brilliance. Their brilliance is mainly due to total internal reflection of light inside them. The critical angle for diamond is very small (around 24.4^0).

Because the critical angle is very small, once light enters a diamond, it is very likely to undergo total internal reflection inside it.

Diamonds found in nature rarely exhibit the brilliance for which they are known.
https://www.google.com/search?site=imghp&tbm=isch&q=diamond%20sparkling&tbs=sur:fmc#imgdii=lEnsZnyBRiRDiM:&imgrc=fECQW_dfzQ3XSM:

It is the technical skill of a diamond cutter which makes diamonds sparkle so brilliantly. By cutting the diamond suitably, multiple total internal reflections can be made to occur.

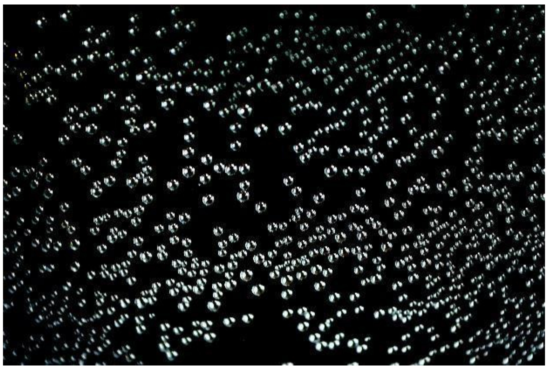
The diamond cutters cut the faces of the diamond in such a way that once light enters the diamond, it is very likely to keep on undergoing total internal reflection inside it. Hence the rays of light, entering the diamond, just stay inside it. This gives diamond its characteristic sparkle.

Diamonds are tested by putting them in water. The increase in their sparkle shows their purity. Artificial stones which look like diamonds show not much change in sparkle.

Think About These

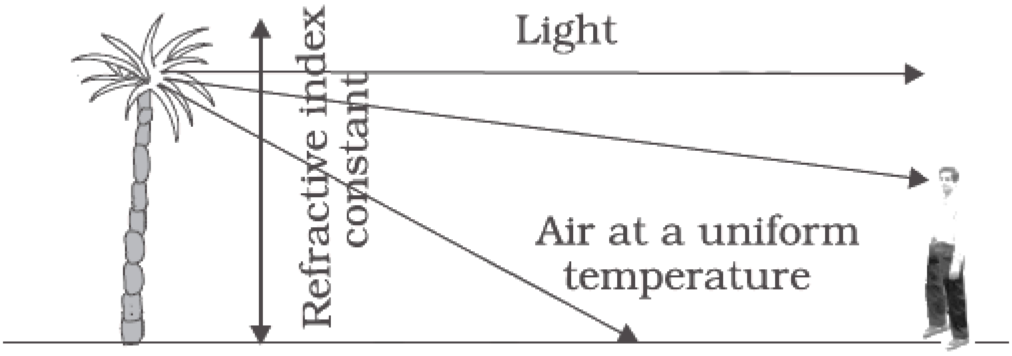
Why

- Diamonds shine in bright light and not in a dark room?
- A crack in glass pane appears silvery?
- Air bubbles are silvery and shiny as they rise in a container boiling water ?



https://www.needpix.com/photo/1341865/bubbles-water-air-background-macro

- **Mirage:**



A tree is seen by an observer at its place when the air above the ground is at uniform temperature. On **hot summer days**,

- **The air near the surface of earth is hotter than the air at higher levels.**
- **If air currents are small, the optical density of different layers of air increases with height.**

When light from a tall object, like a tree passes through air, it is propagating from an optically denser medium to an optically rarer medium. Thus a ray of light, coming from such objects, keeps on bending away from the normal, on refraction from successive layers of air.

The angle of incidence, therefore keeps on increasing after every refraction.

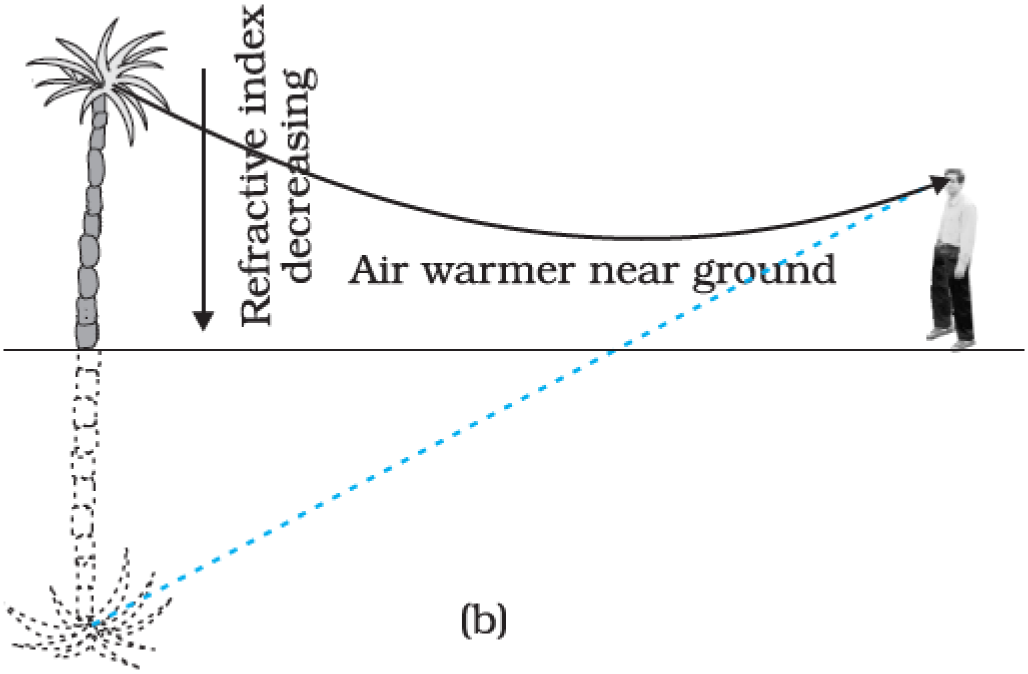
When the angle of incidence becomes more than the critical angle,

The two conditions for total internal reflection get satisfied and the ray of light undergoes total internal reflection.

To a distant observer, the light appears to be coming from somewhere below the ground. The observer sees the inverted image of the tall object, the tree and assumes that the light is being reflected from, say, a pool of water near the tree. This causes an optical illusion to the observer. **This phenomenon is called 'mirage'**

This type of phenomenon is quite common in hot deserts or on cemented roads

Due to this phenomenon only, while going on highway, on a hot summer day, a distant patch of road appears to be wet.



When the layers of air close to the ground have varying temperature with hottest layers near the ground, light from a distant tree may undergo total internal reflection and the apparent image of the tree may create an illusion to the observer that the tree is near a pool of water.

- **Total internal reflection in prisms**

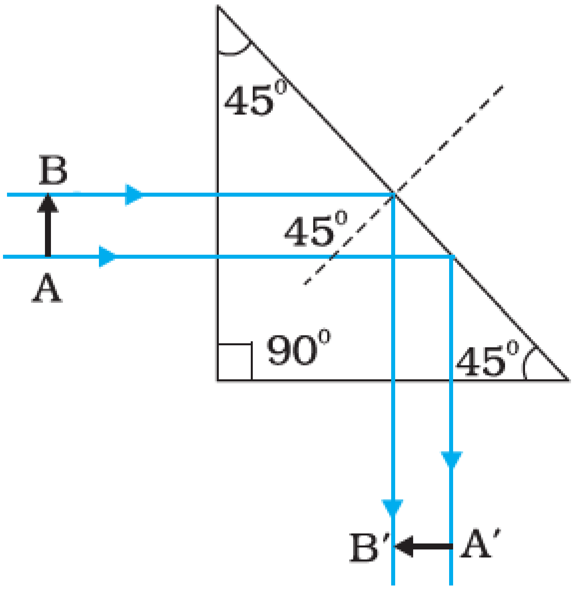
Prisms can be designed to bend light by 90^0 or 180^0 by making use of the phenomenon of total internal reflection.

A right angled isosceles prism made of crown or flint glass prism can be used for these purposes. For crown glass n = 1.5

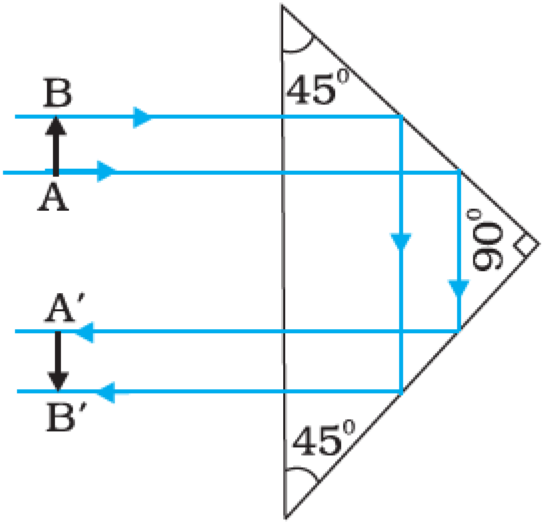
So $\sin i_c = 1/1.5$

$I_c = 42^0$

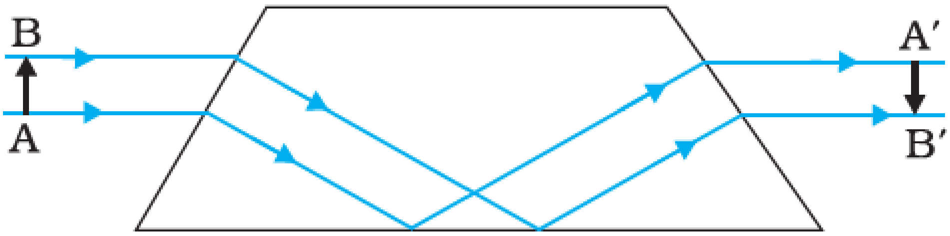
Ray diagram to show the bending of a ray of light by 90^0



Ray diagram to show the bending of a ray of light by 180^0 OR to form an inverted image of an object without changing the size



Or



Prisms designed to bend rays by 90º and 180º or to invert image without changing its size by make use of total internal reflection

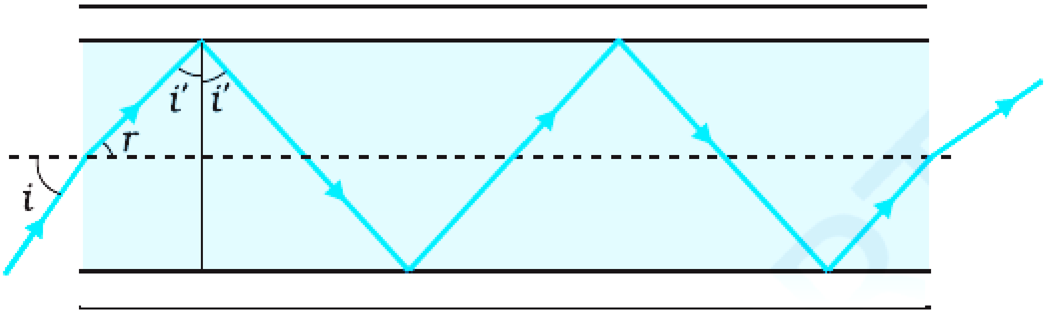
- **Optical fibres:**

Now-a-days optical fibres are extensively used for transmitting audio and video signals through long distances.

Optical fibres to make use of the phenomenon of total internal reflection. Optical fibres are fabricated with high quality composite glass/quartz fibres.

Optical fibres are made of several thousands of very long fine quality fibers of glass or quartz, called **the core.** The refractive index of the material being used is about 1.5.The fibres are coated with a thin layer of a material whose refractive index is slightly less than that of the core i.e. about 1.48.This coating is called **cladding.**

Each fibre consists of a core and cladding.

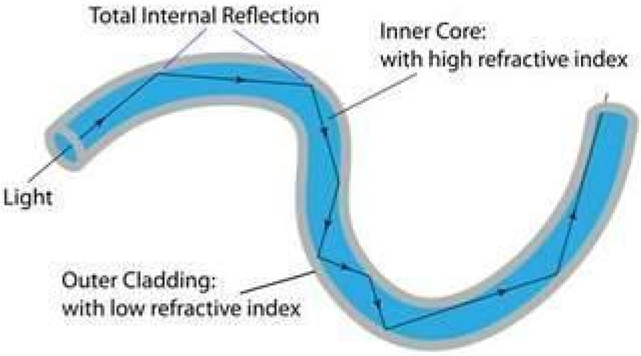


The refractive index of the material of the core is higher than that of the cladding.

When a signal in the form of light is directed at one end of the fibre at a suitable angle, it undergoes repeated total internal reflections along the length of the fibre and finally comes out at the other end.Since light undergoes total internal reflection at each stage, **there is no appreciable loss in the intensity of the light signal.**

Optical fibres are fabricated such that light reflected at one side of the inner surface strikes the other at an angle larger than the critical angle. Even if the fibre is bent, light can easily travel along its length. Thus, an optical fibre can be used to act as an optical pipe. Optical fibres also make use of the phenomenon of total internal reflection.

Optical fibres are fabricated in such a way that a light ray which enters it, keeps on undergoing total internal reflection repeatedly, and that there should be very little absorption of light as it often travels over long distances inside them.



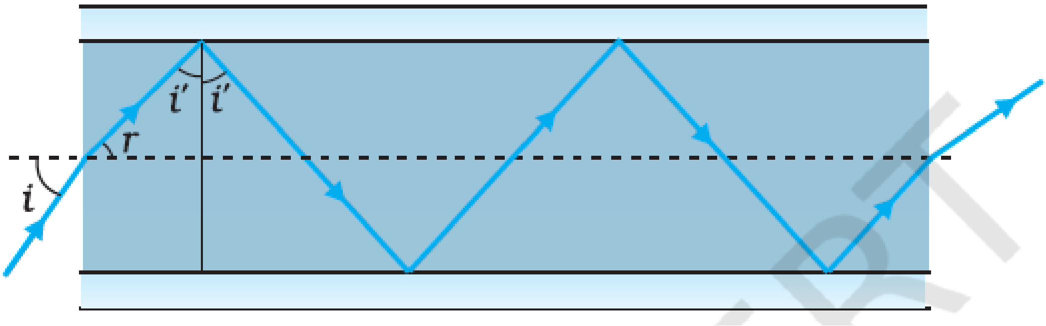
Working: Let a signal; in the form of a light ray enter through one end of the fibre at a small angle. After refraction it strikes the core and cladding interface at an angle of incidence greater than the critical angle and gets totally internally reflected.

Light thus undergoes repeated total internal reflection along the length of the fibre and finally comes out of the other end. Even if the fibre is twisted or bent, the incident light ray finally comes out of the other end.

Example

Figure shows a cross-section of a ‘light pipe’ made of a glass fibre of refractive index 1.68. The outer covering of the pipe is made of a material of refractive index 1.44.

- What is the range of the angles of the incident rays with the axis of the pipe for which total reflections inside the pipe take place, as shown in the figure.
- What is the ANSWER if there is no outer covering of the pipe?



Solution

The critical angle core and cladding will be given by

$$\sin i_c = \frac{refractive\ index\ of\ cladding}{refractive\ index\ of\ core}$$

$$\sin i_c = \frac{1.44}{1.68} = 0.8571$$

$$i_c = \sin^{-1} 0.8571 = 59^0$$

Hence total internal reflection will take place if angle $i^{'}$ lies between 59^0 and 90^0

From the figure **we see that maximum value of r =31^0**

,We can find the value of i

From Snell's law $\frac{\sin i}{\sin r} = \frac{n_{core}}{n_{air}} = \frac{1.68}{1}$

Or

$$\frac{\sin i_{max}}{\sin r_{max}} = \frac{\sin i_{max}}{\sin 31^0} = \frac{1.68}{1}$$

$$\sin i_{max} = 1.68 \times (0.5150 = 0.8652)$$

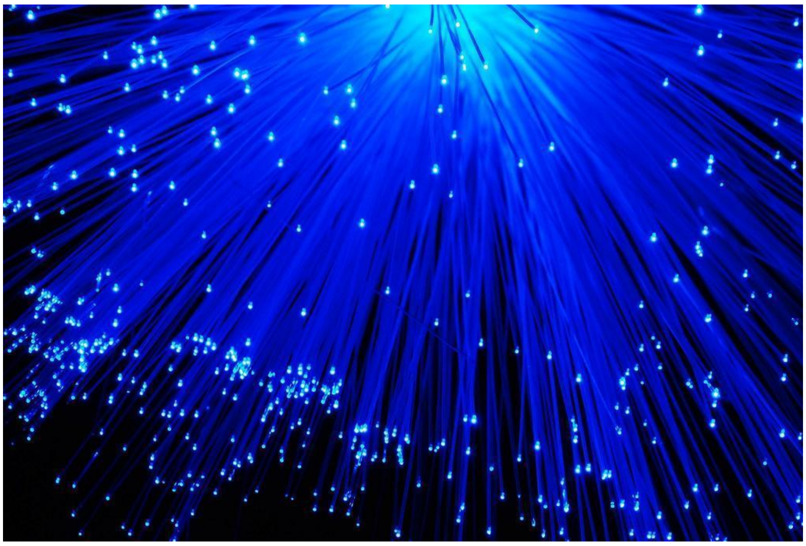
$$i_{max} \approx 60^0$$

Use/Applications of Optical Fibers

- **In the medical field**: A bundle of optical fibres called a light pipe can be used to examine the inaccessible parts of the human body, like the esophagus, stomach and intestine.

Laparoscopy is a type of surgical procedure in which a small incision is made usually in the navel through which a viewing tube (laparoscope) is inserted. The viewing tube (optic fibre) has a small camera on the eyepiece. This allows the doctor to examine the abdominal and pelvic organs on a video monitor connected to the tube. Other small incisions can be made to insert instruments to perform procedures. Laparoscopy can be done to diagnose conditions or to perform certain types of operations. It is less invasive than regular open abdominal surgery.

- Optical fibres can be used for **transmitting audio and video signals** through long distances without much loss in signal strength. The electrical signals, to be transmitted, are converted into light signals using suitable transducers. They can then be transmitted (using the phenomenon of total internal reflection) through optical fibres.
- **Decorative lamps**



https://www.google.com/search?site=imghp&tbm=isch&q=fibre%20optic%20lamp&tbs=sur:fmc#imgdii=Fvos4Pvk8yMz3M:&imgrc=_pZLu-PNU5gEeM:

These decorative lamps make use of fine plastic fibres having their one end fixed over the electric lamp. The other end is free. When the lamp is switched on the light goes from the bottom of each fibre and appears at the tip of its free end as a dot of light. Light is able to reach the other end even if the fibre is bent because of total internal reflection.

Summary

- We have seen that some observations in daily life can be explained using the phenomenon of refraction of light. We have considered
  - A pencil, placed in water, seems bent when seen from above the water surface.
  - A pond appears shallower than what it actually is.
  - Sun is visible nearly two minutes before it actually comes above horizon.
  - Sun remains visible for nearly two minutes after it has gone below horizon.
  - Twinkling of stars.
  - Refractive index = real depth/ apparent depth
- **Critical angle:** That angle of incidence in denser medium for which the refracted ray just grazes the interface of two media is called the critical angle.
- **Total internal reflection:**

  The phenomenon in which a ray of light going from an optically denser medium to an optically rarer medium at an angle of incidence greater than critical angle gets totally reflected back into the denser medium is called total internal reflection.
- **Conditions for total internal reflection:**
  - Light must travel from an optically denser medium to an optically rarer medium.
  - Angle of incidence must be more than the critical angle
- **Relation between refractive index and critical angle:**

  $$n = 1/\sin i_c$$
- Brilliance of diamonds, mirage and working of optical fibres are among the main phenomena that can be explained using the concept of total internal reflection.