Chapter

5

Refraction of Light at Plane Surfaces

We have learnt about the reflection of light in an earlier chapter. Beauty of the nature is made apparent with light. Light exhibits many interesting phenomena.

Let us try to explore a few of them.

You might have observed that a coin kept at the bottom of a vessel filled with water appears to be raised. Similarly, a lemon kept in a glass of water appears to be bigger than its size. When a thick glass slab is placed over some printed letters, the letters appear raised when viewed through the glass slab.

- What could be the reasons for the above observations?

Activity 1

Take some water in a glass tumbler. Keep a pencil in it. Look at the pencil from one side of the glass and also from the top of the glass.

- How does it look?
- Do you find any difference between the two views?

Activity 2

Go to a long wall (of length about 30 feet) facing the Sun. Go to one end of a wall and ask your friend to bring a bright metal object near the other end of the wall. When the object is a few inches from the wall it appears distorted and you will see a reflected image in the wall as though the wall were a mirror.

- Why is there an image of the object on the wall?

To answer the above questions and to give reasons for the situations mentioned we need to understand the phenomenon of refraction of light.

Refraction

Activity 3

Take a shallow vessel with opaque walls such as a mug. (A tin or a pan is suitable). Place a coin at the bottom of the vessel. Move away from the vessel until you cannot see the coin. See figure 1(b). Stand there. Ask your friend to fill the vessel with water. When the vessel is filled with water the coin comes back into view. See figure 1(c).

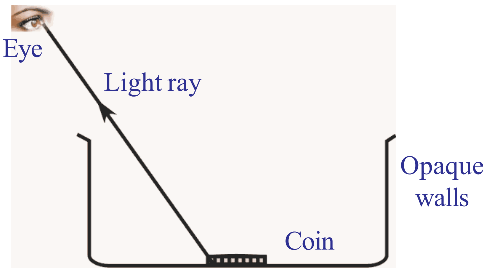

fig-1(a)

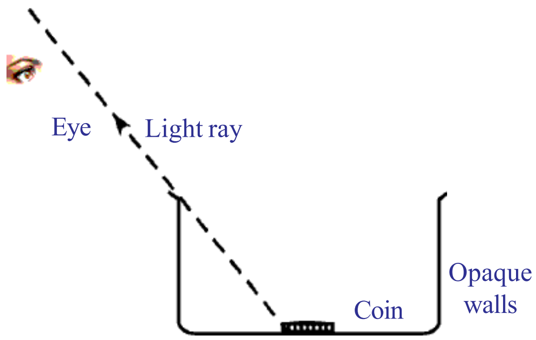

fig-1(b)

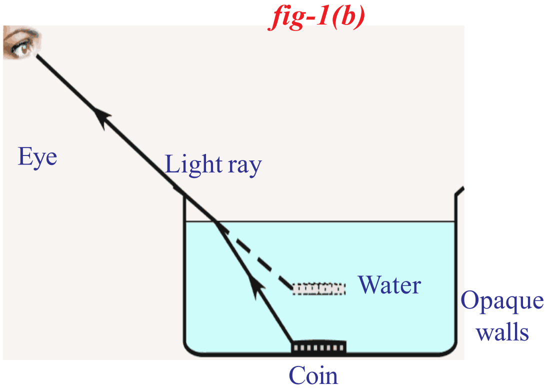

fig-1(c)

- Why are you able to see the coin when the vessel is filled with water?

You know that the ray of light originating from the coin, doesn't reach your eye when the vessel is empty (see figure1b). Hence you couldn't see the coin. But the coin becomes visible to you after the vessel is filled with water.

- How is it possible?
- Do you think that the ray reaches your eye when the vessel is filled with water?

If yes, draw a ray diagram from the coin to the eye. Keep in mind that the light ray travelling in a medium takes a straight line path.

- What happens to the light ray at the interface between water and air?
- What could be the reason for this bending of the light ray in the second instance?

The above questions can be answered by Fermat's principle, which states that the light ray always travels between two points in a path which needs the shortest possible time to cover. Let us apply this principle to our activity.

By observing the path of the ray, it is clear that the light ray changes its direction at the interface separating the two media i.e, water and air. This path is chosen by the light ray so as to minimize time of travel between coin and eye. This is possible only if the speed of the light changes at interface of two media. Thus we can conclude that the speed of the light changes when light propagates from one medium to another medium.

“The process of changing speed at an interface when light travels from one medium to another resulting in a change in direction is refraction of light. The process of refraction involves bending of light ray except when it is incident normally”.

Consider that light travels from medium 1with speed v_1 to medium 2 with speed v_2 as shown in figures 2(a) and (b).

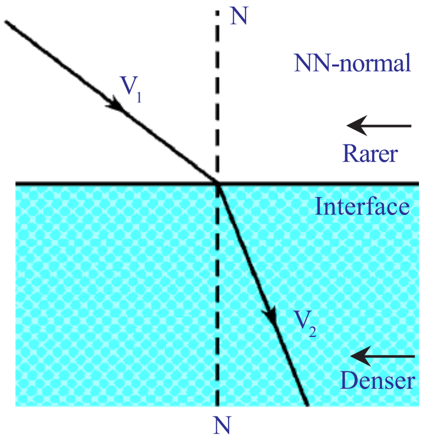

fig-2(a)

- What difference do you notice in fig 2(a) and Fig 2(b) with the respect to refracted rays?
- Is there any relation between behaviour of refracted rays and speeds of the light?

Experiments have showed that refraction occurs due to change in the speed of the light in the medium.

If v_2 is less than v_1 then medium 2 is said to be denser with respect to medium 1.

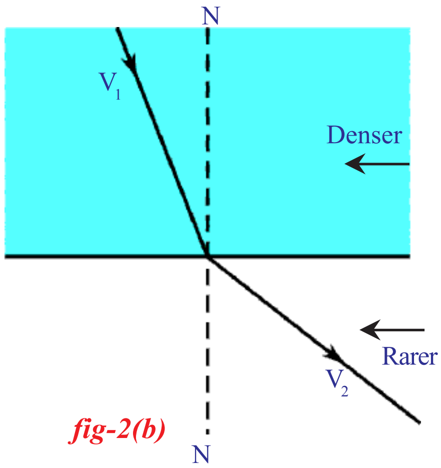

fig-2(b)

If v_2 is greater than v_1 then medium 2 is said to be rarer with respect to medium 1.

If light ray enters from rarer medium to denser medium then refracted ray moves towards the normal drawn at the interface of separation of two media. When it travels from denser medium to rarer medium it bends away from normal. We have seen that the ray of light deviates from its path at the interface. Draw a normal at the point of incidence as shown in figure (3).

Let ‘i’ be the angle made by incident ray with normal and r be the angle made by refracted ray with the normal. These angles are called angle of incidence and angle of refraction respectively.

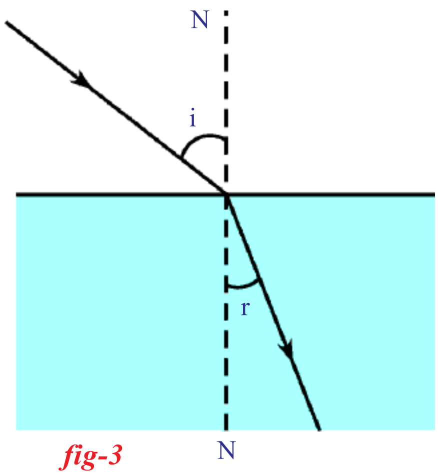

fig-3

To explain the process of refraction we need to know about a constant called refractive index which is the property of a transparent medium. Let us learn about it.

The extent of the change in direction that takes place when a light ray propagates through one medium to another medium is expressed in terms of refractive index.

Refractive index

Light travels in vacuum with a speed nearly equal to 3×10^8 m/s (denoted by letter 'c'). The speed of light is smaller than 'c' in other transparent media.

Let 'v' be the speed of light in a certain medium. Then the ratio of speed of light in vacuum to the speed of light in that medium is defined as refractive index 'n'. It is called absolute refractive index.

Absolute refractive index = Speed of light in vacuum/ Speed of light in medium.

$$n = c/v \qquad \text{...............(1)}$$

It is a dimensionless quantity because it is a ratio of the same physical quantities. Refractive index gives us an idea of how fast or how slow light travels in a medium. The speed of light in a medium is low when refractive index of the medium is high and vice versa. The refractive index 'n' means that the speed of light in that medium is nth part of speed of light in vacuum.

For example the refractive index of glass is 3/2 .Then the speed of light in glass is (2/3) of 3×10^8 m/s equal to 2×10^8 m/s.

Table:1 Refractive indices of some material media.

Material medium	Refractive index	Material medium	Refractive index
Air	1.0003	Canada balsam	1.53
Ice	1.31	Rock salt	1.54
Water	1.33	Carbon Diasulphide	1.63
Kerosene	1.44	Dense flint glass	1.65
Fused quartz	1.46	Ruby	1.71
Turpentine oil	1.47	Sapphire	1.77
Crown glass	1.52	Diamond	2.42
Benzene	1.50		

Note : From table 1, you know that an optically denser medium may not possess greater mass density. For example, kerosene with high refractive index is optically denser than water although its mass density is less than water.

- Why do different material media possess different values of refractive Indices?

- On what factors does the refractive index of a medium depend?

  Refractive index depends on the following factors.

  (1) nature of material (2) wavelength of light used. (You will learn about this in the chapter Human-eye-and Colourful world)

Relative refractive index

The refractive index of a medium with respect to another medium is defined as the ratio of speed of light in the first medium to the speed of light in the second medium. Let v_1 and v_2 be the speeds of light in the first and second media respectively. Then,

Refractive index of second medium with respect to first medium is given by

n_{21} = speed of light in medium -1 / speed of light in medium – 2

$n_{21} = v_1/v_2$

Dividing both numerator and denominator by c we get

$n_{21} = (v_1/c) / (v_2/c) = (1/n_1)/(1/n_2)$

$\Rightarrow n_{21} = n_2 / n_1$ ....(2)

This is called relative refractive Index. We define relative Refractive index as follow

$$\text{Relative refractive index, } (n_{21}) = \frac{\text{Refractive index of second medium } (n_2)}{\text{Refractive index of first medium } (n_1)}$$

Lab Activity 1

Aim: Obtaining a relation between angle of incidence and angle of refraction.

Materials required: A plank, white chart, protractor, scale, small black painted plank, a semi circular glass disc of thickness nearly 2cm, pencil and laser light.

Procedure

Take a wooden plank which is covered with white chart. Draw two perpendicular lines, passing through the middle of the paper as shown in the figure 4(a). Let the point of intersection be O. Mark one line as NN which is normal to the another line marked as MM. Here MM represents the line drawn along the interface of two media and NN represents the normal drawn to this line at 'O'.

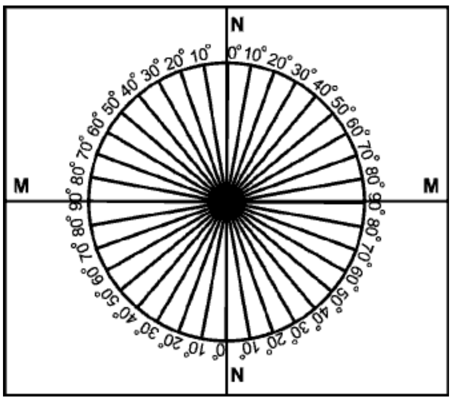

fig-4(a)

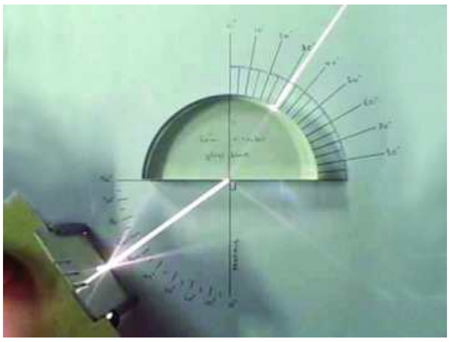

fig-4(b)

Take a protractor and place it along NN in such way that its centre coincides with O as shown in figure 4(a). Then mark the angles from 0^0 to 90^0 on both sides of the line NN as shown in figure 4(a). Repeat the same on the other side of the line NN. The angles should be indicated on the curved line.

Now place a semi-circular glass disc so that its diameter coincides with the interface line (MM) and its center coincides with the point O. Point a laser light along NN in such a way that the light propagates from air to glass through the interface at point O and observe the path of laser light coming from other side of disc as shown in figure 4 (b). (If you cannot observe the path of laser light put a black-coloured plank against the curved line and observe the light point and imagine the light path).

- Is there any deviation?

Send Laser light along a line which makes 15^0 (angle of incidence) with NN and see that it passes through point O. Measure its corresponding angle of refraction, by observing laser light coming from the other side (Circular side) of the glass slab. Note these values in table (2). Do the same for the angles of incidence such as 20^0,30^0,40^0,50^0 and 60^0 and note the corresponding angles of refraction.

Table 2

i	r	Sin i	Sin r	Sin i / Sin r

Find sin i, sin r for every 'i' and 'r' and evaluate sin i/ sin r for every incident angle 'i'.

Note : Take the help of your teacher to find the values of sin i and sin r for each case.

Finally, we will get the ratio sin i / sin r as a constant.

- Is this ratio equal to refractive index of glass? Why?

This ratio gives the value of refractive index of glass. In the above experiment you might have noticed that 'r' is less than 'i' in all cases and the refracted ray bends towards normal in each case.

- What do you conclude from these observations?

From the above experiment we can conclude that when light ray travels from a rarer medium (air) to a denser medium (glass) the value of r is less than the value of 'i' and the refracted ray bends towards the normal.

- Can you guess what happen when light ray travels from a denser medium to a rarer medium?

  Let us take up another activity to find this.

Actitivy 4

Take a metal disk. Use a protractor and mark angles along its edge as shown in the figure 5(a). Arrange two straws at the centre of the disk in such a way that they can be rotated freely about the centre of the disc.

fig-5(a)

Adjust one of the straws to make an angle 10^0. Immerse half of the disc vertically into the water, filled in a transparent vessel. While dipping, verify that the straw at 10^0 is inside the water. From the top of the vessel try to view the straw which is inside the water as shown in figure 5(b). Then adjust the other straw which is outside the water until both straws appear to be in a single straight line.

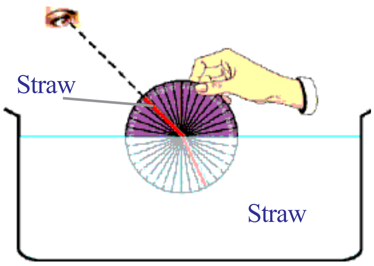

fig5(b)

Then take the disc out of the water and observe the two straws on it. You will find that they are not in a single straight line.

- Why do the straws appear to be in a straight line when we view them from the top?

Measure the angle between the normal and second straw. Draw table (2) again in your notebook and note the value. Do the same for various angles. Find the corresponding angles of refraction and note them in the table drawn. Use the data in the table and find refractive index of water. Do not take up this activity for angles of incidence greater than 48 degrees. You will learn the reasons for this in the following sections.

You will observe that in the above activity, 'r' is greater than 'i' in all cases that means when light travels from water (denser) to air (rarer). It behaves in an opposite way to that we observed in lab activity 1.

From this activity we can generalize that when the light ray travels from denser to rarer, it bends away from the normal and r > i.

- Can we derive the relation between the angle of incidence and the angles of refraction theoretically?

Consider the following analogy to derive it.

Let us imagine that a person has fallen out of boat and is screaming for help in the water at point B as shown in figure 6(a).

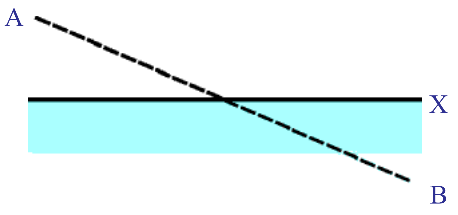

fig-6(a)

The line marked through point 'X' is the shore line. Let us assume that we are at a point 'A' on the the shore and we saw the accident. In order to save the person we need to travel a certain distance on land and a certain distance in water. We know that, we can run faster on land than we can swim in water.

- What do we do to save the person?
- Which path enables us to save the person in the shortest possible time?
- Do we go in a straight line?

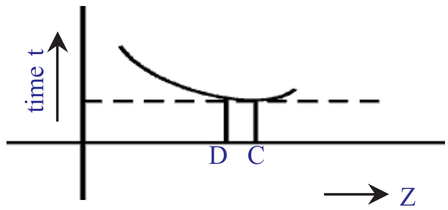

fig-6(b)

By careful thought we would realize that it would be advantageous to travel a greater distance on the land in order to decrease the distance in water because we go much slower in water. For whatever speeds on land and in water, the final path that one has to follow to reach the person is ACB, and that this path takes the shortest time of all the possible paths (see figure 6c). If we take any other route, it will be longer. If we plot a graph for the time taken to reach the girl against the position of any point when we cross the shore line, we would get a curve something like that shown in figure 6(b).

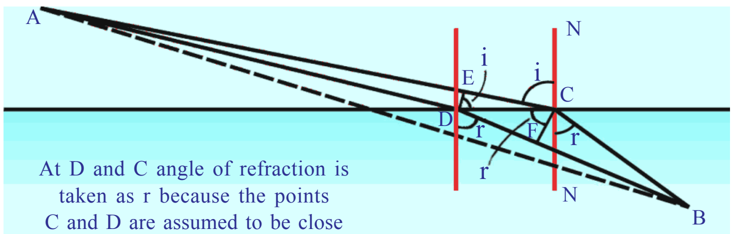

fig-6(c)

Where 'C', the point on shore line, corresponds to the shortest of all possible times. Let us consider a point 'D' on shore line which is very close to point 'C' such that there is essentially no change in time between path ACB and ADB.

Let us try to calculate how long it would take to go from A to B by the two paths one through point D and another through point C (see figure 6c). First look at the paths on the land as shown in figure 6(c). If we draw a perpendicular DE; between two paths at D, we see that the path (AD) on land is shortened by the amount EC. On the other hand, in the water, by drawing a corresponding perpendicular CF we find that we have to go the extra distance DF in water. In other words, we gain a time that is equal to go through distance EC on land but we lose the time that is equal to go extra distance DF in water. These times must be equal since we assumed there no change in time between the two paths.

Let the time taken to travel from E to C and D to F be Δt and v_1 and v_2 be the speeds of running and swimming. From figure 6(c) we get,

$EC = v_1 \ \Delta t$ and $DF = v_2 \ \Delta t$

$\Rightarrow EC / DF = v_1/v_2$ ——————(3)

Let i and r be the angles measured between the path ACB and normal NN, perpendicular to shore line X.

- Can you find sin i and sin r from figure 6(c)?

(Note: Take the help of your teacher)

From figure 6(c), we get;

$\sin i = EC / DC$ and $\sin r = DF / DC$

Therefore,

$\sin i / \sin r = EC / DF$ ——————(4)

from equations (3) and (4), we have

$\sin i / \sin r = v_1 / v_2$ ——————(5)

Thus to save the person, one should take such a path to satisfy the above equation. We used the principle of least time to derive the above result. Hence we can apply the same for the light ray also. From (5) we get,

$\sin i / \sin r = v_1 / v_2 = n_2 / n_1$, (since $v_1 / v_2 = n_2 / n_1$)

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

This is called **Snell's law**.

From the above discussion we can conclude that when light travels from one medium to another, the ratio of speeds v_1/v_2 is equal to n_2 / n_1. The light should enter at such an angle that the ratio of sine of the angles 'i' and 'r' is equal to ratio of speeds v_1/v_2 in the two media.

Above experiments and activities show that refraction of light occurs according to certain laws.

Following are the laws of refraction.

1. The incident ray, the refracted ray and the normal to interface of two transparent media at the point of incidence all lie in the same plane.
2. During refraction, light follows Snell's law

$n_1 \sin i = n_2 \sin r$ (or) $\sin i / \sin r = \text{constant}$.

- Is there any chance that angle of refraction is equal to 90^0? When does this happen?

Let us find out

Total Internal Reflection

Activity 5

Use the same materials as used in lab activity 1. Place the semi circular glass disc in such a way that its diameter coincides with interface line MM and its centre coincides with point 'O' as we have done in lab activity. Now send light from the curved side of the semicircular glass disc. This means that we are making the light travel from denser medium to rarer medium. Start with angle of incidence (i) equal to 0^0 i.e., along the normal and look for the refracted ray on the other side of the disc.

- Where do you find the refracted ray?
- Does it deviate from its path when it enters the rarer medium?

You might have noticed that it doesn't deviate.

Send laser light along angles of incidence 5^0, 10^0, 15^0 etc.., and measure the angle of refraction. Tabulate the results in table (3) as shown below and note the values 'i' and 'r' in the table.

Table 3

i	r

- At what angle of incidence do you notice that the refracted ray grazes the interface separating the two media (air and glass)?

You will observe that at a certain angle of incidence the refracted ray does not come out but grazes the interface separating air and glass. Measure the angle of incidence for to this situation. This angle of incidence is known as **critical angle**.

The above results can be explained using Fermat's principle.

Let us consider the light ray that travels from medium 1 with refractive index n_1 to medium 2 with refractive index n_2.See figure (7). It is already found that the angle of refraction is more than angle of incidence when a light ray travels from denser(n_1) to rarer medium (n_2).

For the angle of incidence i, let r be the angle of refraction.

From Snell's law

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

we know that, n_1/n_2 is greater than 1, so that sin r/ sin i is greater than 1.So we conclude that the angle of refraction is greater than the angle of incidence, i.e, r is greater than i.

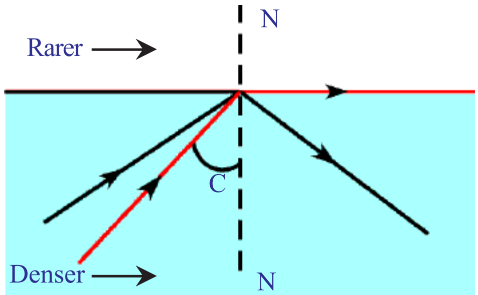

fig-7

The angle of incidence at which the light ray, travelling from denser to rarer medium, grazes the interface is called critical angle for denser medium. It is shown in figure7.

Let C be the critical angle. Then r becomes 90^0

we get, $n_1/n_2 = \sin 90^0/ \sin c \Rightarrow n_1/n_2 = 1/\sin c$.

We get $\sin c = n_2/ n_1$ .We know that n_1/n_2 i.e., n_{12} is called *refractive index* of denser medium with respect to rarer medium

$\sin c = 1/n_{12}$

- Can you find the critical angle of water using the above equation? Discuss it in your class.
- What happens to light when the angle of incidence is greater than critical angle?

When the angle of the incidence is greater than critical angle, the light ray gets reflected into the denser medium at the interface i.e., light never enters the rarer medium. This phenomenon is called *total internal reflection*. It is shown in figure 7.

Discuss these ideas in your class and find out the critical angle of water.

Let us see an example on total internal reflection.

Example

A rectangular glass wedge (prism) is immersed in water as shown in figure E-a. For what value of angle α, will the beam of light, which is normally incident on AB, reach AC entirely as shown in figure E-b. Take the refractive index of water as 4/3 and the refractive index of glass as 3/2.

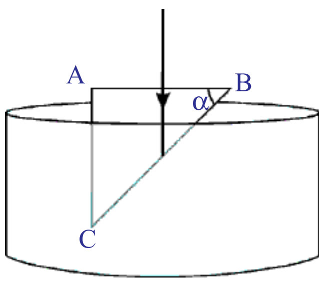

fig E-a

Solution: From the geometry of figure E-b it is clear that, the angle of incidence on the side BC is equal to α (dotted line is a normal drawn at the point of incidence). The ray should undergo total internal reflection to reach AC. For occurence of total internal reflection, the value of α must be greater than the critical angle at interface of water and glass.

Let 'C' be the critical angle for the interface of glass and water.

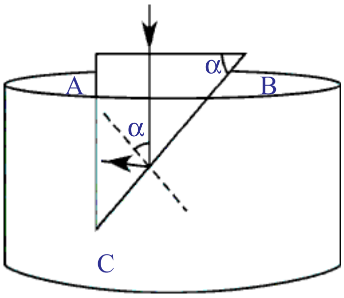

fig E-b

From the given condition, $\alpha > C$ ———(1)

We know, $\sin C = 1/n_{12}$ ———(2)

$n_{12} = n_1/n_2 = (3/2)/(4/3) = 9/8$.

From equation 2, we get

$\sin C = 8/9 \Rightarrow C = 62^0 30^1$

Hence α is greater than $C = 62^0 30^1$

Let us see few activities of total internal reflection.

Activity 6

Take a transparent glass tumbler and coin. Place the coin on a table and place glass tumbler on the coin. Observe the coin from the side of the glass.

- Can you see the coin?

Now fill the glass tumbler with water and observe the coin from the side of the glass tumbler.

- Can you see the coin?
- Explain why the coin disappears from view.

Activity 7

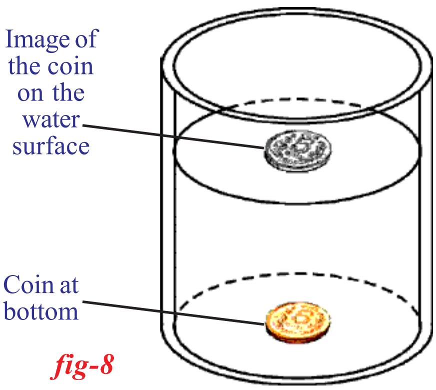

fig-8

Take a cylindrical transparent vessel (you may use 1 L beaker). Place a coin at the bottom of the vessel. Now pour water until you get the image of the coin on the water surface (look at the surface of water from a side). See figure 8.

- Can you explain why the image of the coin is formed?

There are many interesting situations around us which involve the phenomenon of total internal reflection. One of that is a mirage which we witness while driving or while walking on a road during a hot summer day.

Mirages

fig-9(a)

Mirage is an optical illusion where it appears that water has collected on the road at a distant place but when we get there, we don't find any water.

- Do you know the reason why it appears so?

The formation of a mirage is the best example where refractive index of a medium varies throughout the medium.

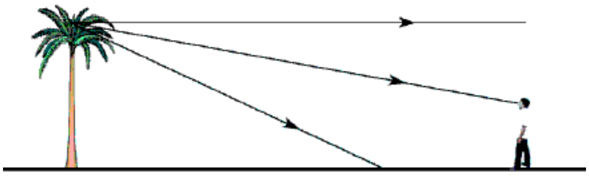

fig-9(b): The paths of light rays when there is no change in density of air

During a hot summer day, air just above the road surface is very hot and the air at higher altitudes is cool. It means that the temperature decreases with height. As a result density of air increases with height. We know that refractive index of air increases with density. Thus the refractive index of air increases with height. So, the cooler air at the top has greater refractive index than hotter air just above the road. Light travels faster through the thinner hot air than through the denser cool air above it.

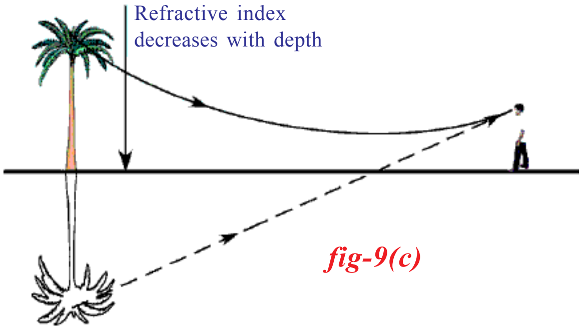

fig-9(c)

When the light from a tall object such as tree or from the sky passes through a medium just above the road, whose refractive index decreases towards ground, it suffers, refraction and takes a curved path because of total internal reflection. See figure 9(c).

This refracted light reaches the observer in a direction shown in Figure-9c. This appears to the observer as if the ray is reflected from the ground. Hence we feel the illusion of water being present on road (shown in figure 9a) which is the virtual image of the sky (mirage) and an inverted image of tree on the road (shown in figure 9c).

Think and discuss

- Why should you see a mirage as a flowing water?
- Can you take a photo of a mirage?

Applications of total internal reflection

i) **Brilliance of diamonds:** Total internal reflection is the main reason for brilliance of diamonds. The critical angle of a diamond is very low(24.4^o). So if a light ray enters a diamond it is very likely to undergo total internal reflection which makes the diamond shine.

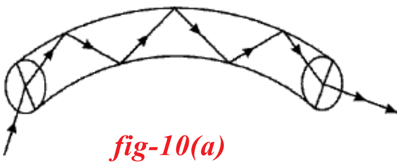

fig-10(a)

fig-10(b)

ii) **Optical fibres:** Total internal reflection is the basic principle behind working of optical fibre. An optical fibre is very thin fibre made of glass (or) plastic having radius about a micrometer (10^{-6} m). A bunch of such thin fibres form a light pipe.

Figure 10(a) shows the principle of light transmission by an optical fibre. Figure 10(b) sketches a optical fibre cable. Because of the small radius of the fibre, light going into it makes a nearly glancing incidence on the wall. The angle of incidence is greater than the critical angle and hence total internal reflection takes place. The light is thus transmitted along the fibre.

All organs of the human body are not accessible to the naked eye of the doctor, for example intestines. The doctor inserts an optical fiber pipe into the stomach through the mouth. Light is sent down through one set of fibres in the pipe. This illuminates the inside of the stomach. The light from the inside travels back through another set of fibres in the pipe and the viewer gets the image at the outer end (generally fed to the computer screen).

The other important application of fibre optics is to transmit communication signals through light pipes. For example, about 2000 telephone signals, appropriately mixed with light waves, may be simultaneously transmitted through a typical optical fibre. The clarity of the signals transmitted in this way is much better than other conventional methods.

- How does light behave when a glass slab is introduced in its path? Let us see

Refraction Through a Glass Slab

A thin glass slab is formed when a medium is isolated from its surroundings by two plane surfaces parallel to each other. Let us determine position and nature of the image formed when the slab is placed in front of

Lab Activity 2

an object. Let us do an activity.

Aim: Determination of position and nature of image formed by a glass slab.

Material required: plank, chart paper, clamps, scale, pencil, thin glass slab and pins.

Procedure:

Place a piece of chart (paper) on a plank. Clamp it. Place a glass slab in the middle of the paper. Draw border line along the edges of the slab by using a pencil. Remove it. You will get a figure of a rectangle. Name the vertices of the rectangle as A, B, C and D.

Draw a perpendicular at a point on the longer side (AB) of the rectangle. Again keep the slab on paper such that it coincides with the sides of the rectangle ABCD. Take two pins. Stick them on the perpendicular line to AB. Take two more pins and stick them on the other side of the slab in such a way that all pins come to view along a straight line. Remove the slab from its place. Take out the pins. Draw a straight line by using the dots formed by the pins such that it reaches first edge (AB) of the rectangle. You will get a long straight line.

- What does it mean?

The light ray that falls perpendicular to one side of the slab surface comes out with out any deviation.

Now take another piece of white chart on the plank. Clamp it. Place a glass slab in the middle of the paper. Again draw a border line along the edges of the slab by using a pencil. Remove the slab and name the vertices of the rectangle formed as A,B,C and D. Draw a perpendicular at a point on the longer side AB. Now draw a line, from the point of intersection where side AB of rectangle and perpendicular meet, in such a way that it makes 30^0 angle with normal. This line represents the incident ray falling on the slab and the angle it makes with normal represents the angle of incidence.

Now place the slab on the paper in such way that it fits in the rectangle drawn. Fix two identical pins on the line making 30^0 angle with normal such that they stand vertically with equal height. By looking at the two pins from the other side of the slab, fix two pins in such a way that all pins appear to be along

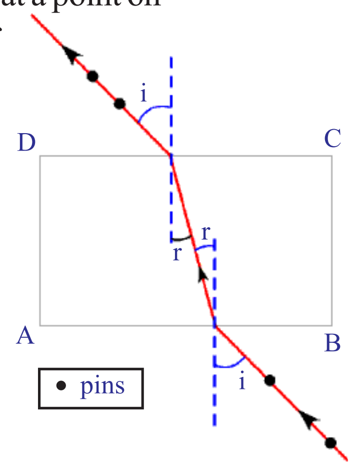

fig-11

a straight line. Remove slab and take out pins. Draw a straight line by joining the dots formed by the pins up to the edge CD of the rectangle. This line represents emergent ray of the light.

Draw a perpendicular ON to the line CD where our last line drawn meets the line CD. Measure the angle between emergent ray and normal. This is called angle of emergence. (Check your drawing with the figure 11).

- Is the line formed a straight line?
- Are the angles of incidence and emergence equal?
- Are the incident and emergent rays parallel?

You will notice an important result that the incident and emergent rays are parallel.

- Can you find the distance between the parallel rays?

The distance between the parallel rays is called lateral shift. Measure this shift. Repeat the experiment for different angles of incidence and tabulate the values of angle of incidence and shift corresponding to each angle of incidence in table (4).

Table 4

Agle of Inciddene	Shift

- Can you find any relation between the angle of incidence and shift?
- Can you find the refractive index of the slab?

Let us find the refractive index of the slab.

Activity 8

Measure the thickness of the slab. Note it in your notebook. Take a white chart and fix it on the table. Take the slab and place it in the middle of the chart. Draw its boundary. Remove the slab from its place. The lines form a rectangle. Name the vertices as A,B,C and D. Draw a perpendicular to the longer line AB of the rectangle at any point on it. Place slab again in the rectangle ABCD. Take a pin. Place at a point P in such a way that its length is parallel to the AB on the perpendicular line at a distance of 15cm from the slab. Now take another pin and by looking at the first pin from the other side of the slab try to place the pin so that it forms a straight line with the first pin. Remove the slab and observe the positions of the pins.

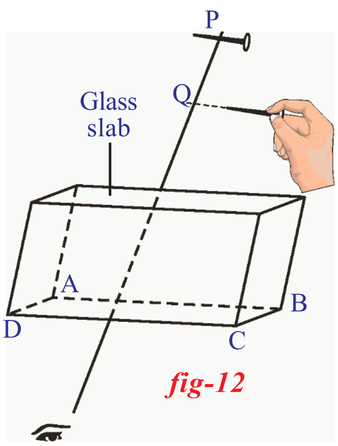

fig-12

- Are they in the same line?

Draw a perpendicular line from the second pin to the line on which first pin is placed. Call the intersection point Q. Find the distance between P and Q. We may call it vertical shift.

- Is this shift independent of distance of first pin from slab?

To find this, do the same activity for another distance of the pin from the slab. You will get the same vertical shift. We could use a formula to find out refractive index of the glass.

R.I = Thickness of the slab / (thickness of slab – vertical shift)

Key words

Refraction, Incident ray, Refracted ray, Angle of incidence, Angle of Refraction, Absolute refractive index, Relative refractive index, Snell's law, Critical angle, Total internal Reflection, Mirage, Shift, Optical fibre.

What we have learnt

- When light travels from one medium to another, its direction changes at the interface. The phenomenon of changing direction at the interface of the two media is known as refraction.
- Refraction is a result of change in speed of light at the interface.
- Absolute refractive index = Speed of light in vacuum/ Speed of light in medium ⇨ n=c/v.
- Relative refractive index , $n_{21} = v_1/v_2 = n_2/n_1$.
- Snell's law is given by, $n_1 \sin i = n_2 \sin r$.
- The angle of incidence, at which the light ray travelling from denser to rarer medium grazes the interface, is called the critical angle for those media. $\sin C = n_2/ n_1$, where n_1 is the refractive index of denser medium and n_2 is the refractive index of rarer medium. ($n_1 > n_2$)
- When the angle of incidence is greater than the critical angle, the light ray is reflected into denser medium at interface. This phenomenon is called total internal reflection.

Improve your learning

1. Why is it difficult to shoot a fish swimming in water? (AS1)
2. The speed of the light in a diamond is 1, 24, 000 km/s. Find the refractive index of diamond if the speed of light in air is 3,00,000 km/s. (AS1) (Ans: 2.42)
3. Refractive index of glass relative to water is 9/8. What is the refractive index of water relative to glass? (AS1) (Ans: 8/9)
4. The absolute refractive index of water is 4/3. What is the critical angle? (AS1) (Ans: 48.5^0)
5. Determine the refractive index of benzene if the critical angle is 42^0.(AS1) (Ans: 1.51)
6. Explain the formation of mirage? (AS1)

7. How do you verify experimentally that sin i /sin r is a constant? (AS1)
8. Explain the phenomenon of total internal reflection with one or two activities. (AS1)
9. How do you verify experimentally that the angle of refraction is more than angle of incidence when light rays travel from denser to rarer medium. (AS1)
10. Take a bright metal ball and make it black with soot in a candle flame. Immerse it in water. How does it appear and why? (Make hypothesis and do the above experiment). (AS2)
11. Take a glass vessel and pour some glycerine into it and then pour water up to the brim. Take a quartz glass rod. Keep it in the vessel. Observe the glass rod from the sides of the glass vessel.
    - What changes do you notice?
    - What could be the reasons for these changes?(AS2)
12. Do activity-7 again. How can you find critical angle of water? Explain your steps briefly. (AS3)
13. Collect the values of refractive index of the following media. (AS4)
    Water, coconut oil, flint glass, crown glass, diamond, benzene and hydrogen gas.
14. Collect information on working of optical fibres. Prepare a report about various uses of optical fibres in our daily life. (AS4)
15. Take a thin thermocol sheet. Cut it in circular discs of different radii like 2cm, 3cm, 4cm, 4.5cm, 5cm etc and mark centers with sketch pen. Now take needles of length nearly 6cm. Pin a needle to each disc at its centre vertically. Take water in a large opaque tray and place the disc with 2cm radius in such a way that the needle is inside the water as shown in fig-Q15.

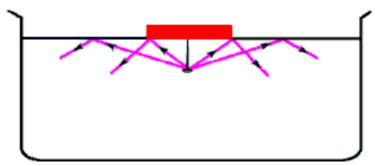

fig-Q15

    Now try to view the free end (head) of the needle from surface of the water.
    - Are you able to see the head of the needle?

    Now do the same with other discs of different radii. Try to see the head of the needle, each time.

    Note: the position of your eye and the position of the disc on water surface should not be changed while repeating the activity with other discs.
    - At what maximum radius of disc, were you not able to see the free end of the needle?
    - Why were you not able to view the head of the nail for certain radii of the discs?
    - Does this activity help you to find the critical angle of the medium (water)?
    - Draw a diagram to show the passage of light ray from the head of the nail in different situations. (AS4)
16. Explain the refraction of light through a glass slab with a neat ray diagram. (AS5)
17. Place an object on the table. Look at the object through the transparent glass slab. You will observe that it will appear closer to you. Draw a ray diagram to show the passage of light ray in this situation. (AS5)
18. What is the reason behind the shining of diamonds and how do you appreciate it? (AS6)
19. How do you appreciate the role of Fermat principle in drawing ray diagrams. (AS6)

20. A light ray is incident on air-liquid interface at 45^0 and is refracted at 30^0. What is the refractive index of the liquid? For what angle of incidence will the angle between reflected ray and refracted ray be 90^0? (AS7) (Ans: 1.414, 54.7^0)
21. Explain why a test tube immersed at a certain angle in a tumbler of water appears to have a mirror surface for a certain viewing position? (AS7)
22. What is the angle of deviation produced by a glass slab? Explain with ray diagram. (AS7)
23. In what cases does a light ray not deviate at the interface of two media?(AS7)
24. A ray of light travels from an optically denser to rarer medium. The critical angle of the two media is 'c'. What is the maximum possible deviation of the ray? (AS7) (Ans:π-2c)
25. When we sit at a camp fire, objects beyond the fire are seen swaying. Give the reason for it. (AS7)
26. Why do stars appear twinkling? (AS7)
27. Why does a diamond shine more than a glass piece cut to the same shape? (AS7)

Fill in the blanks

1. At critical angle of incidence, the angle of refraction is ....
2. $n_1 \sin i = n_2 \sin r$, is called.................
3. Speed of light in vaccum is ....
4. Total internal reflection takes place when a light ray propagates from .... to .... medium.
5. The refractive index of a transparent material is 3/2. The speed of the light in that medium is ....
6. Mirage is an example of ....

Multiple choice questions

1. Which of the following is Shell's law. [ ]
   a) $n_1 \sin i = \sin r / n_2$ b) $n_1/n_2 = \sin r / \sin i$
   c) $n_2 / n_1 = \sin r / \sin i$ d) $n_2 \sin i = \text{constant}$
2. The refractive index of glass with respect to air is 2. Then the critical angle of glass-air interface is .... [ ]
   a) 0^o b) 45^o c) 30^o d) 60^o
3. Total internal reflection takes place when the light ray travels from.............. [ ]
   a) rarer to denser medium b) rarer to rarer medium
   c) denser to rarer medium d) denser to denser medium
4. The angle of deviation produced by the glass slab is .... [ ]
   a) 0^o b) 20^o c) 90^o
   d) depends on the angle formed by the light ray and normal to the slab