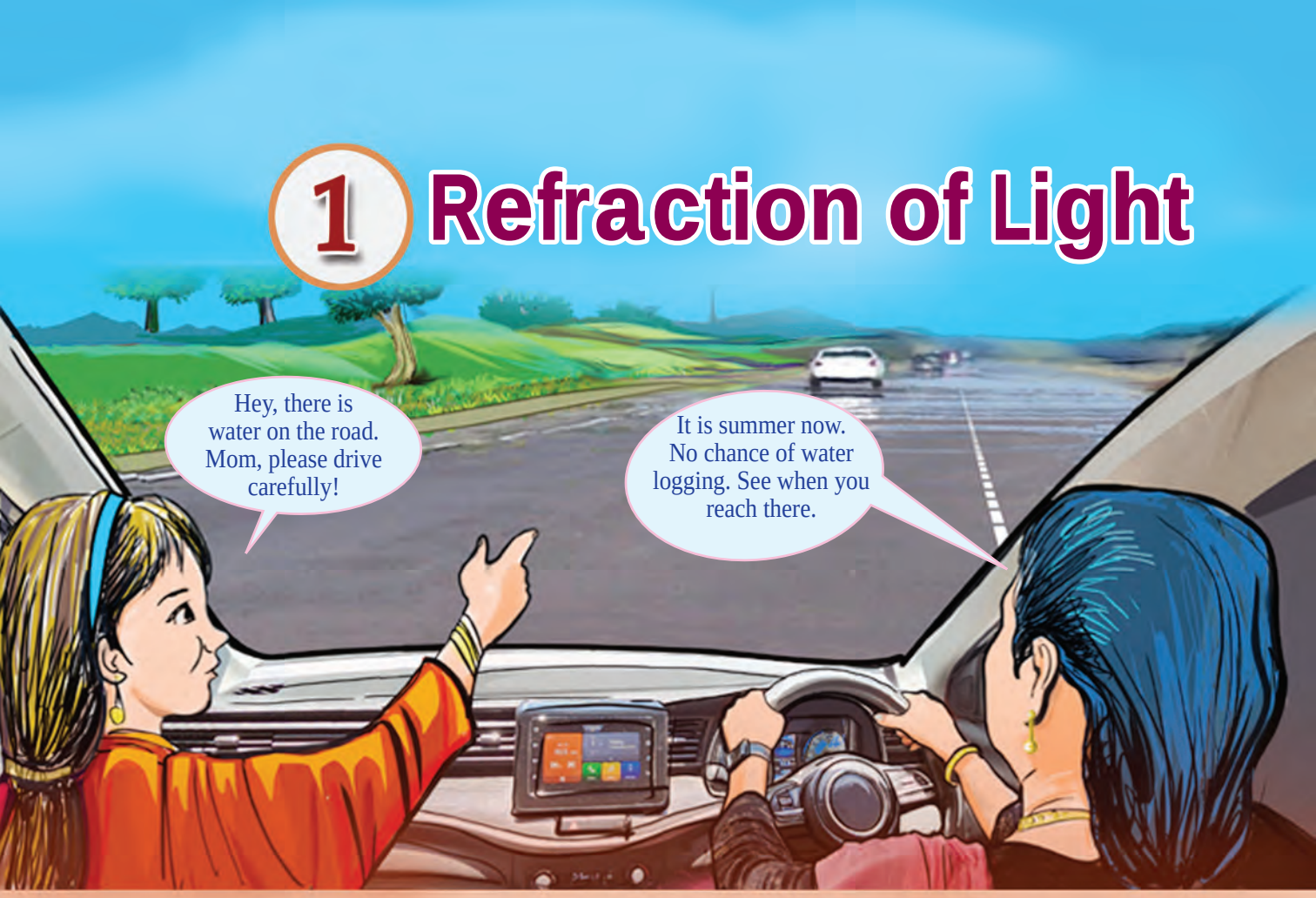
1 Refraction of Light



Have you had such an experience?

Many of such experiences are related to the various phenomena of light.

- Have you ever observed the straw in a glass of lemonade? Does it appear bent? What could be the reason?

We see an object when the light falling on the object gets reflected and falls on our eyes. Don't you think the light rays reflected from the straw dipped in lemonade travel through different mediums before they reach our eyes?

Fig. 1.1

Let's do an activity.

Fill three-fourth of a trough with water. Add two or three drops of milk into it. Cover the trough with a transparent sheet of paper. Fill the remaining space in the trough with smoke. Then flash the light from a laser torch as shown in figure 1.2 (a) and observe the path of light. Draw your observation in the science diary.

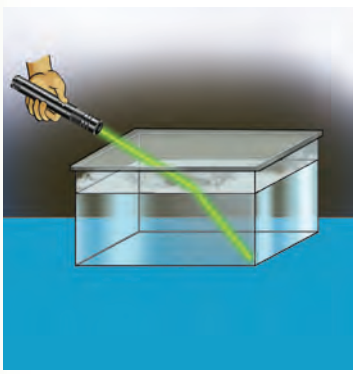
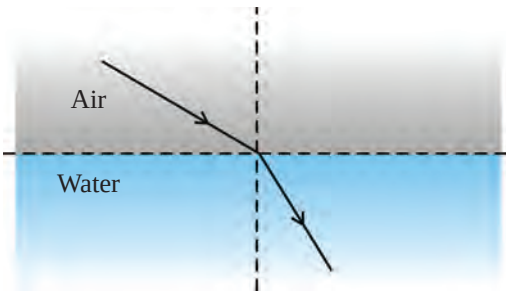


Fig. 1.2 (a)



Ray diagram showing the path of light

Fig. 1.2 (b)

- Which are the mediums through which light travels within the trough?
- How will the path of light ray be, when it passes through only one medium?

- Is there any deviation in the direction of the ray of light when it enters obliquely from one medium to another?
- Where does the ray of light undergo a change in direction?

Will there be a deviation in the direction of a ray of light incident normally?

Allow light from a laser torch to fall perpendicular to the surface of the water taken in the trough.

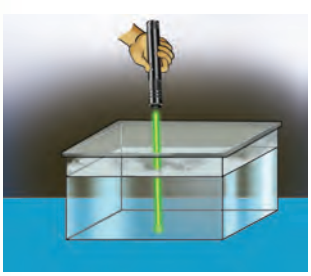


Fig. 1.3 (a)

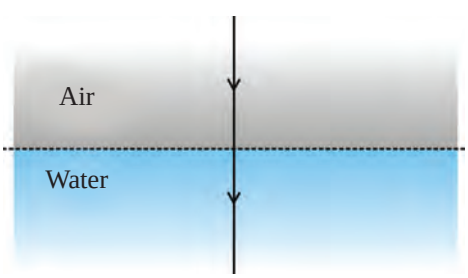


Fig. 1.3 (b)

- Is there a deviation in the path of the ray of light? Record your observation in the science diary.

When light travels through a single medium, the path of light will be a straight line. A ray of light undergoes a deviation at the surface of separation when it enters obliquely from one medium to another. There will be no deviation in the path of the ray of light incident normally.

What causes a deviation in the path of the light ray when it passes from one medium to another?

Observe the speed and direction of a toy car moving from a smooth surface to a rough surface.

- Is there a change in the direction of motion of the car?
- Where does this change occur?
- Did the car move with the same speed on both surfaces?

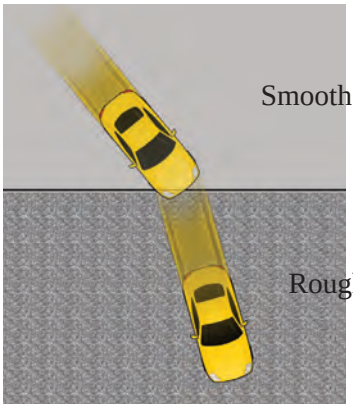


Fig. 1.4 (a)

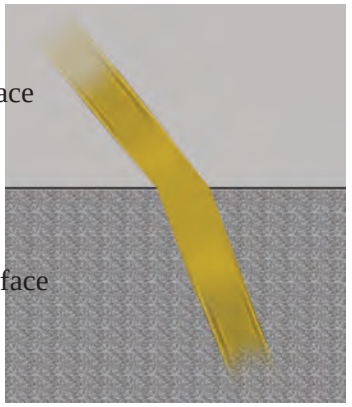


Fig. 1.4 (b)

The change in direction is caused by the change in the speed of the car as it moves from one surface to the other.

The speed of light is different in different mediums. The change in the speed of light causes the change in the direction of the ray of light, when it passes from one medium to another. Examine the table showing the speed of light through various mediums.

Medium	Speed of light (approximate)
Air	3×10^8 m/s
Water	2.25×10^8 m/s
Glass	2×10^8 m/s
Diamond	1.25×10^8 m/s

Table 1.1

The speed of light differs in various mediums due to the difference in their optical densities.

The ability of a medium to influence the speed of light through the medium is its optical density.

The speed of light will be lower in a medium of higher optical density (optically denser medium). The speed of light will be higher in a medium of lower optical density (optically rarer medium). Note that optical density has no relation with material density.

Arrange the mediums in Table 1.1 in the increasing order of their optical densities.

Air < -------- < -------- < Diamond

Refraction

Let's do an activity to understand the reason behind a straw appearing bent when dipped in lemonade.

Fig. 1.5 (a)

Fig. 1.5 (b)

A straw is kept obliquely in a glass as shown in the figure 1.5 (a). Then the glass is filled with water. What difference do you observe? Draw your observations in the science diary.

- Why does the straw appear bent?

A straw is kept in a trough. Observe the path of the rays of light from the straw falling on the eyes before and after filling the trough with water.

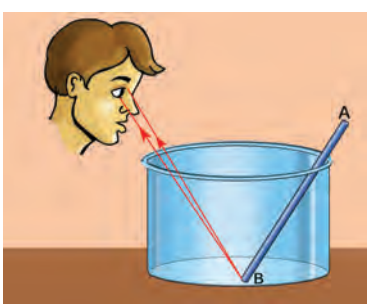


Fig. 1.6 (a)

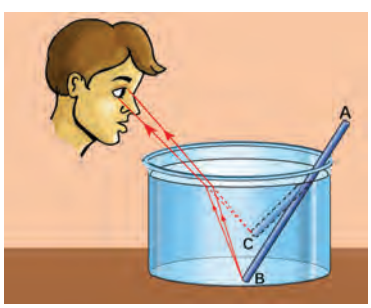


Fig. 1.6 (b)

- Is there a deviation for the ray of light falling on the eye from point B of the straw before pouring water?

After the water is poured, the ray of light from the immersed part of the straw entering air from water is deviated at the surface of separation.

- Doesn't the ray of light appear to come from C, though it is actually coming from B?

The straw appears bent, as the actual position B seems to have risen to the position C.

PhET→ Bending Light → Intro

When a ray of light enters obliquely from one medium to another of different optical densities, it undergoes a deviation at the surface of separation of the mediums. This phenomenon is refraction.

The ability of light to undergo refraction in a medium depends on the optical density of the medium. The optical density is in turn, related to the refractive index of the medium. The role of refractive index is very important in designing various optical devices. Let's see what refractive index of a medium is.

Refractive index

Refractive index of a medium is the ratio of the speed of light in vacuum to the speed of light in the medium.

If c denotes the speed of light in vacuum and v the speed of light in a medium, then

$$\text{Refractive index } (n) = \frac{\text{The speed of light in vacuum } (c)}{\text{The speed of light in the medium } (v)}$$

$$n = \frac{c}{v}$$

The speed of light in vacuum $(c) = 3 \times 10^8$ m/s

The speed of light in different mediums is given in the table below. Find the refractive index of each medium and complete the table.

Medium	Speed of light (v)	Refractive index (n)
Air	3×10^8 m/s	$n = \frac{c}{v} = \frac{3 \times 10^8 \text{ m/s}}{3 \times 10^8 \text{ m/s}} = 1$
Glass	2×10^8 m/s	
Water	2.25×10^8 m/s	

Table 1.2

If the refractive index of diamond is 2.4, what is the speed of light that passes through it?

How is the speed of light related to refractive index?

The speed of light is less in a medium of higher refractive index. Don't you know the relationship between the speed of light and optical density? If so, write down how optical density is related to refractive index in the science diary.

You have understood that a ray of light entering obliquely from one medium to another with different optical densities undergoes deviation at the surface of separation of the two mediums.

Is the deviation of light the same when it enters from air to water and from water to air when the angle of incidence is the same?

Observe the figures.

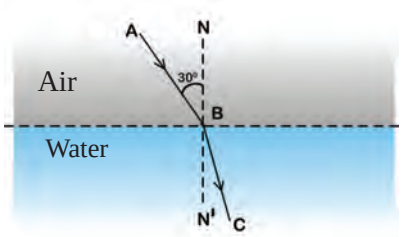


Fig. 1.7 (a)

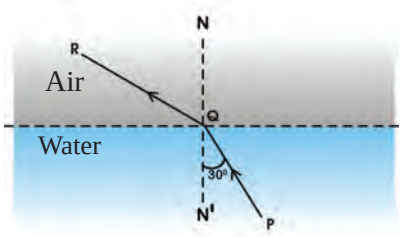


Fig. 1.7 (b)

The ray falling on the surface of separation of the two mediums is the incident ray. The ray which undergoes refraction is the refracted ray. The angle between refracted ray and the normal (NN′) is the angle of refraction. If so,

- find the incident ray, refracted ray, angle of incidence and angle of refraction from each figure and complete the table.

	Figure 1.7 (a)	**Figure 1.7 (b)**
Incident ray	AB	
Refracted ray		
Angle of incidence (i)	∠ABN	
Angle of refraction (r)	∠CBN′	
The angle of refraction is greater than/less than the angle of incidence		

Table 1.3

What peculiarities do you see in the deviation of refracted ray of light when it enters from air to water and from water to air? Record them in the science diary.

- How does the direction of light change when a ray of light enters obliquely from air to water?

  (deviates towards the normal / deviates away from the normal)

- How does the direction of light change when a ray of light enters obliquely from water to air?

  (deviates towards the normal / deviates away from the normal)

Observe the figures that show light passing through different pairs of mediums.

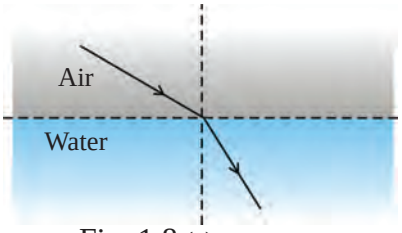


Fig. 1.8 (a)

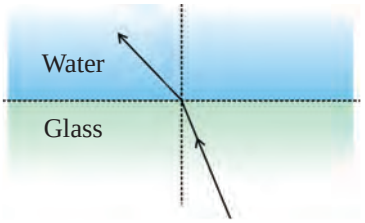


Fig. 1.8 (b)

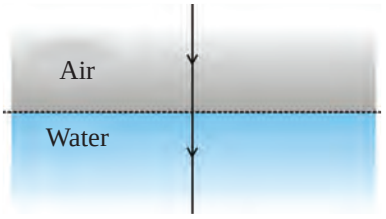


Fig. 1.8 (c)

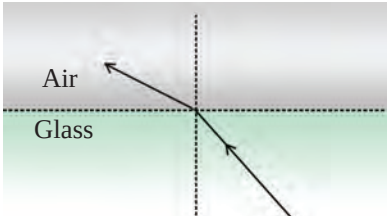


Fig. 1.8 (d)

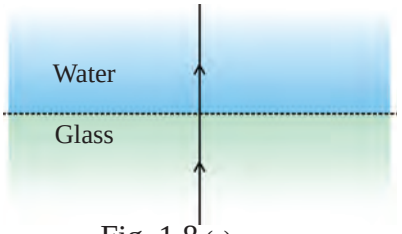


Fig. 1.8 (e)

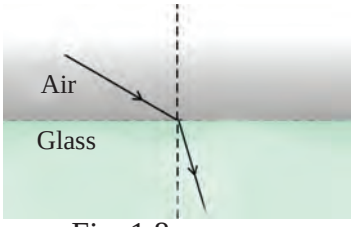


Fig. 1.8 (f)

Find answers to the following questions based on the optical densities of mediums and record them in the science diary.

a) Which are the figures in which the ray of light enters obliquely from an optically denser medium to a rarer medium?

b) In this case, to which direction does the refracted ray deviate?

(towards the normal / away from the normal)

c) Choose the figures in which the refracted ray deviates towards the normal.

d) In which situation will a ray of light deviate towards the normal as it passes from one medium to another?

(from an optically denser medium to a rarer medium/from an optically rarer medium to a denser medium)

e) There is no refraction of light in figures 1.8 (c) and 1.8 (e). What may be the reason?

- When light enters from one medium to another, the incident ray, the refracted ray and the normal at the point of incidence, will be on the same plane.
- When light enters from an optically rarer medium to a denser medium, it deviates towards the normal.
- When light enters from an optically denser medium to a rarer medium, it deviates away from the normal.
- A ray incident normally at the surface of separation of mediums does not undergo refraction.

Refraction in a glass slab

Allow light from a laser torch to fall on a glass slab as shown in the figure.

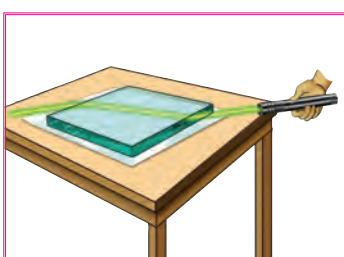


Fig. 1.9 (a)

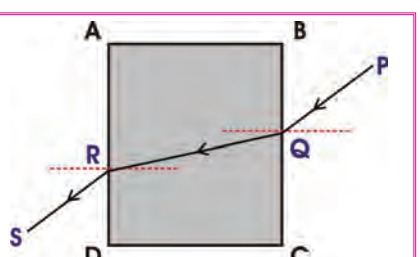


Fig. 1.9 (b)

Did you observe the path of light?

- At which points do refraction occur for the ray of light?
- Draw the ray diagram showing the refraction of a ray of light in a glass slab in the science diary.
- Allow light to incident normally on the glass slab. Does refraction occur?

Refraction – Some Practical Activities

Put a coin in a vessel. Walk backwards looking at the coin. When the coin disappears, ask one of your classmates to pour water into the vessel.

- What do you observe? Analyse the figure and find out the reason.

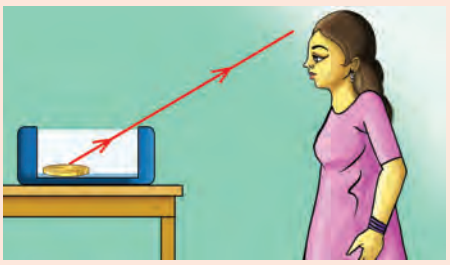


Fig. 1.10 (a)

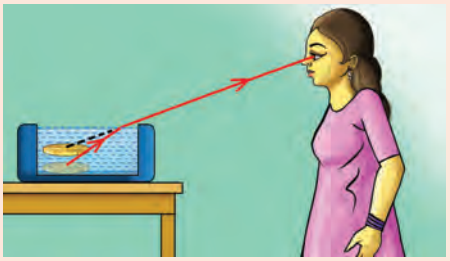


Fig. 1.10 (b)

On pouring water, the ray of light coming from the coin undergoes refraction and reaches the eye. Hence, the coin becomes visible again.

Place a glass slab on the letters in a textbook. The letters appear raised. What may be the reason? Find out.

Observe the figure 1.11 and let's do a similar activity.

You can see a coin lying under the water in a trough. Try to take the coin out by looking through any one side of the trough. Can you do it with ease? What may be the reason?

Fig. 1.11

The bottom of a pond appears elevated when viewed from a distance than from a nearer point. Why?

People who engage in bow fishing aim at a point slightly below the perceived position of the fish. Why?

Are you now familiar with certain situations related to refraction? Let's familiarise ourselves with some situations related to atmospheric refraction.

Atmospheric Refraction

Why do stars at a greater distance twinkle?

Observe the figures.

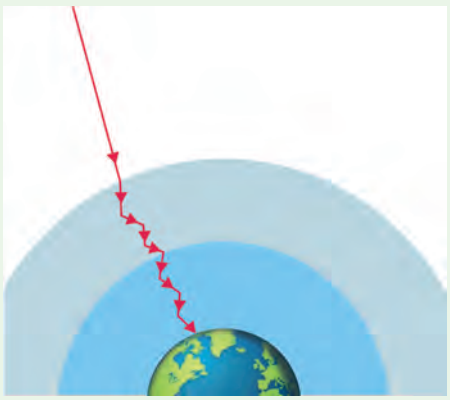


Fig. 1.12 (a)

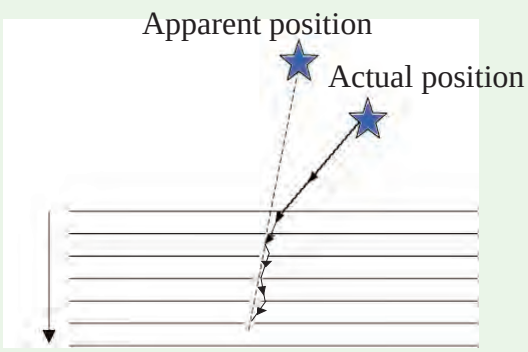


Fig. 1.12 (b)

- Does the ray of light from the star reach our eyes by travelling in a straight line?
- An illustration of the path of a ray of light from a distant star through the Earth's atmosphere is given in figure 1.12 (a). Doesn't the ray of light undergo irregular deviations? What may be the reason?

Stars appear as point sources of light because they are at a greater distance from the Earth compared to the planets. The light coming from the stars reaches our eyes by traversing through the atmosphere. The optical density of the medium through which the light travels goes on changing as the physical conditions (pressure, temperature etc.) of the layers of atmosphere change continuously. Hence, the light undergoes an irregular refraction. Therefore, when the light rays from the stars reach the eyes after refracted several times, the star cannot be seen continuously at the same position. This is the reason for the twinkling of stars.

Even after the Sun has passed the western horizon, the Sun is visible for some more time. Similarly, the Sun can be seen a few seconds before it reaches the eastern horizon in the morning. What is the reason?

Analyse figure 1.13 and record the explanation in the science diary.

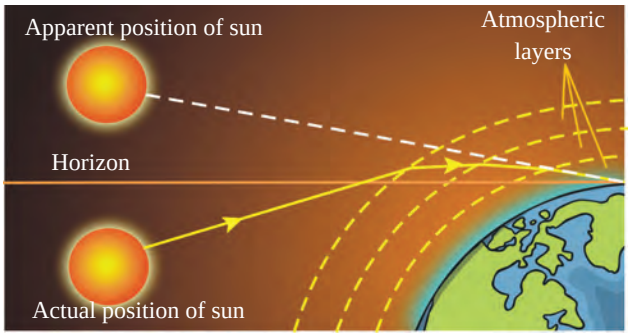


Fig. 1.13

You are now familiar with many situations related to refraction.

Will refraction occur whenever light enters obliquely from one medium to another?

Total Internal Reflection

Fig. 1.14

Haven't you seen decorative lamps as shown in figure 1.14? When light passes through these fibres, it emerges only through the fibre tips. What may be the reason?

Let's do some activities to understand this.

Allow light from a laser torch to fall at different angles on the surface of water taken in a trough.

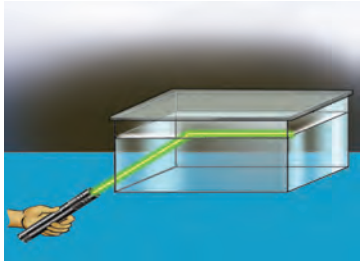


Fig. 1.15 (a)

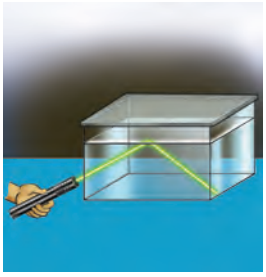


Fig. 1.15 (b)

- Which are the mediums through which light passes inside the trough?
- Does the light enter from an optically denser medium to a rarer medium or from an optically rarer medium to a denser medium?

- Increase the angle of incidence gradually. What do you observe?

Here the light enters from an optically denser medium to a rarer medium. The angle of refraction goes on increasing with the increase in the angle of incidence. The incident ray reflects back to the water completely when the angle of incidence is above a specific value.

- When does the light reflect completely to the same medium, without refraction?

Try out an experiment.

Fig. 1.16

Draw a circle on a chart paper. Mark angles on the paper as if two protractors are placed together. Keeping this on the surface of a table, place a thick semicircular glass slab on the circle drawn on the chart paper as shown in figure 1.16. Allow the light from a laser torch to fall on this slab at different angles. Observe the angle of incidence and angle of refraction in each case. Draw the ray diagram in the science diary.

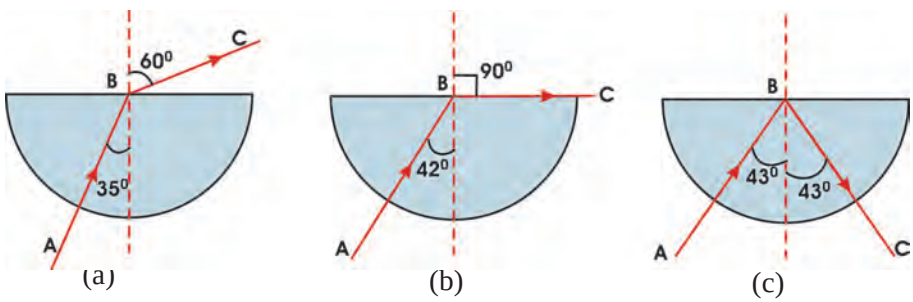


Fig. 1.17

- From which medium to which does the ray of light enter?

  (from an optically denser medium to a rarer medium / from an optically rarer medium to a denser medium)

- What is the change in the angle of refraction when the angle of incidence increases?
- What is the angle of incidence when the angle of refraction is 90^{o}?
- What peculiarity do you notice when the light is incident at an angle greater than this angle of incidence?

When a ray of light enters from an optically denser medium to a rarer medium, the angle of incidence at which the angle of refraction becomes 90° is the critical angle. In the glass-air pair, the critical angle is 42°.

When a ray of light enters from an optically denser medium to a rarer medium, at an angle of incidence greater than the critical angle, the ray is reflected back completely to the same medium without undergoing refraction. This phenomenon is total internal reflection.

The path of light through different mediums is given. Analyse the figures and answer the following questions.

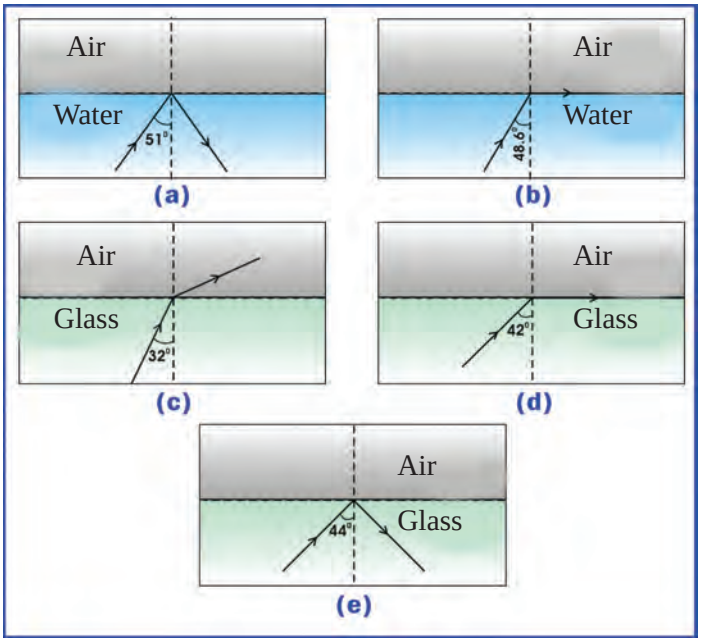


Fig. 1.18

If only one medium is mentioned while stating the critical angle, the second medium will be either air or vacuum.

a) Which of the above figures represent total internal reflection?

b) What is the critical angle of glass in this case?

c) Will total internal reflection occur for a ray of light entering from water to air at an angle of 50°? Why? What is the critical angle for the water-air pair?

d) What are the two conditions required for total internal reflection to occur?

Observe figure 1.19

- The bottom of the aquarium is seen above the surface of water. What may be the reason?

Fig. 1.19

The light coming from the bottom of the aquarium undergoes total internal reflection at the surface of water. Hence, the bottom is seen above the surface of water. Isn't the distance from the surface of the water to the bottom of the aquarium the same as the distance from the surface to the image caused by total internal reflection?

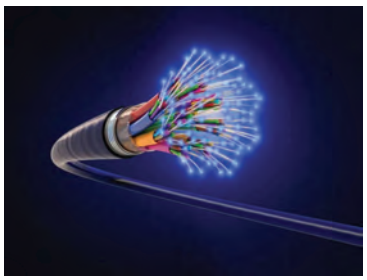


Fig. 1.20 (a)

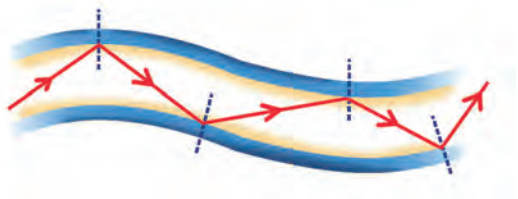


Fig. 1.20 (b)

Charles. K. Kao was awarded the Nobel Prize in Physics in 2009 for his achievements in the field of transmission of light through optical fibres.

One end of each optical fibre in the decorative lamp is connected to a suitable source of light. Light rays from this source travel through the fibre. While travelling through the fibre, as shown in figure 1.20 (b) it makes an angle of incidence greater than the critical angle with the walls of the fibre. Hence the light undergoes successive total internal reflection and emerges through the other end.

Let's observe the optical illusions caused by total internal reflection in our surroundings.

- During summer season there seems to be water logging on roads when viewed from a distance. What may be the reason?

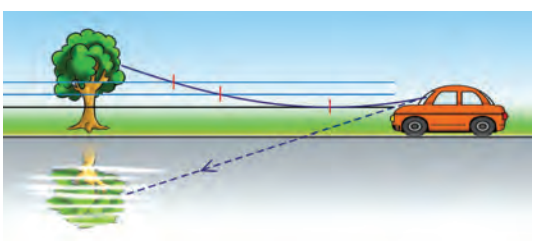


Fig. 1.21 (a)

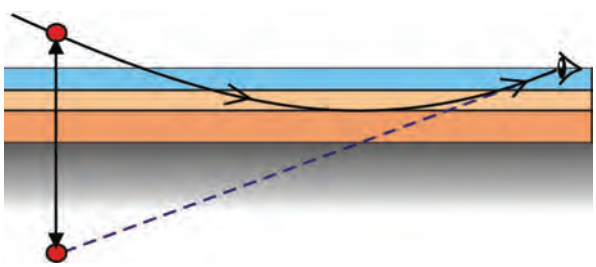


Fig. 1.21 (b)

The layers of air closer to the road have a low optical density as it is warmer than the upper layers. The optical density of the air increases gradually as we go higher.

When light rays coming from the surrounding objects pass through different layers of air with different optical densities, they undergo refraction and then total internal reflection as seen in the figure. Such deviated light rays fall on our eyes. Hence their image appears to have

formed on roads. This phenomenon is known as mirage. Such familiar images are usually seen on the surface of water. Now do you understand why water seems to be logged on roads when viewed from a distance?

Applications of Total Internal Reflection

Reflector :

Haven't you observed reflectors in the tail lamps of vehicles? A large number of small prisms are fixed inside them (figure 1.22 (a)). How does a ray of light incident on a prism get reflected? It can be explained on the basis of the critical angle of glass.

Cycle reflector
Fig.1.22 (a)

The light ray is incident normally on the side PQ. Hence, there is no refraction. You know that the critical angle of glass is 42°. The angle of incidence at A and B is 45°. Hence the light falling on A undergoes total internal reflection and reaches B. There it undergoes total internal reflection again and comes out of the reflector as shown in the figure. Doesn't the same process happen in other prisms in the reflector as well?

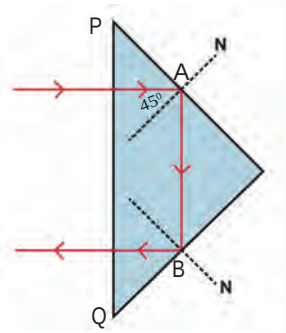


Fig. 1.22 (b)

Periscope :

You are familiar with periscopes made of mirrors. Periscopes are also made using prisms to increase visual clarity.

Observe how the total internal reflection is made use of in a periscope (figure 1.23).

Based on the figure, examine how prisms are used in periscopes and record in the science diary.

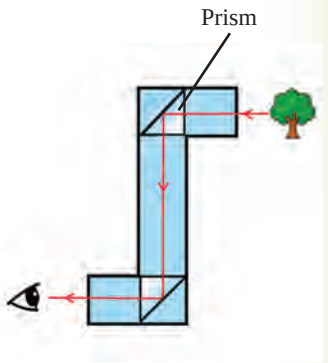


Fig. 1.23

Optical Fibre :

The invention of optical fibres brought about revolutionary changes in the field of telecommunications. You have already learned how total internal reflection of light is made use of in optical fibre cables (OFC). Based on this phenomenon, communication signals (optical signals) also travel through optical fibres in the form of light rays.

Thousands of optical signals can be sent simultaneously through a single cable without the loss of intensity. Such signals can be sent

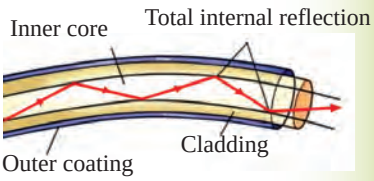
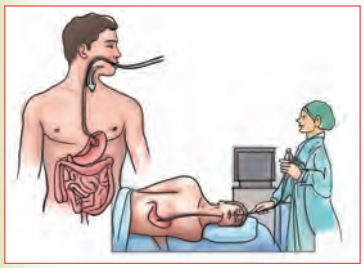


Fig.1.24

to distant places with the speed of light. This is the reason for using optical fibre cables in communication.



Endoscopy

Fig. 1.25

The use of optical fibres in the medical field is increasing day by day. Collect information regarding this and present in the class.

? Statements regarding total internal reflection and reflection from plane mirror are given. Tabulate them suitably.

- Occurs only when a ray of light enters from an optically denser medium to a rarer medium at an angle greater than the critical angle.
- The ray of light is not completely reflected.
- Reflection occurs on a surface at any angle of incidence.
- The ray of light is completely reflected.

Reflection from a plane mirror	Total internal reflection
• The ray of light is not completely reflected. •	• •

Table 1.4

Let's Assess

1. Ray diagram showing the path of light through mediums A and B is given.

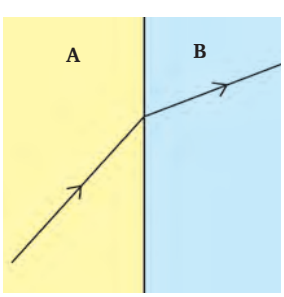


Fig. 1.26

a) In which medium will the speed of light be less – A or B ?

b) Which will be the optically denser medium? Justify your answer.

2. Complete the given diagram. Mark the angle of incidence and angle of refraction.

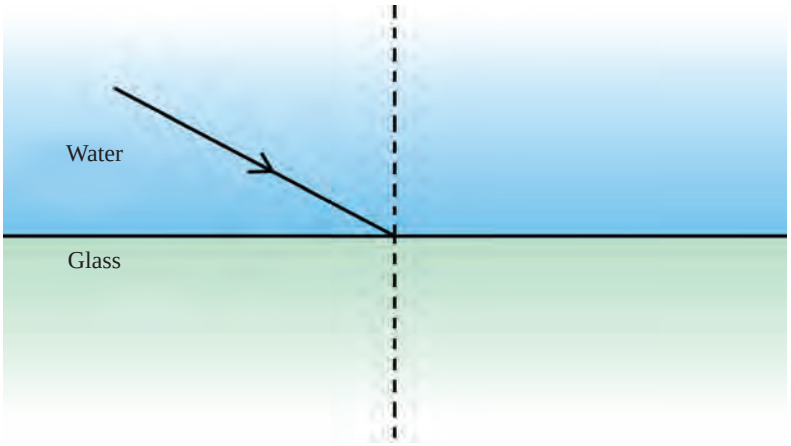


Fig. 1.27

3. Light passes from medium X to Y.

Here, the angle of refraction is greater than the angle of incidence.

a) In which medium is the speed of light more?

b) Which is the medium of larger refractive index?

c) Draw the path of light.

4. Refractive index of different mediums are given in the table.

Medium	Refractive index
Crown glass	1.52
Glycerine	1.47
Sunflower oil	1.47
Water	1.33
Flint glass	1.62

Table 1.5

a) In which medium does light travel with maximum speed?

b) Will a ray of light entering obliquely from glycerine to sunflower oil deviate? Explain the reason.

c) Light is transmitted from glass to each medium listed in Table 1.5. If light is incident at an angle of 30°, which medium will have the largest angle of refraction? Why?

5. Observe the figure. Ray of light incident on two mediums is depicted.

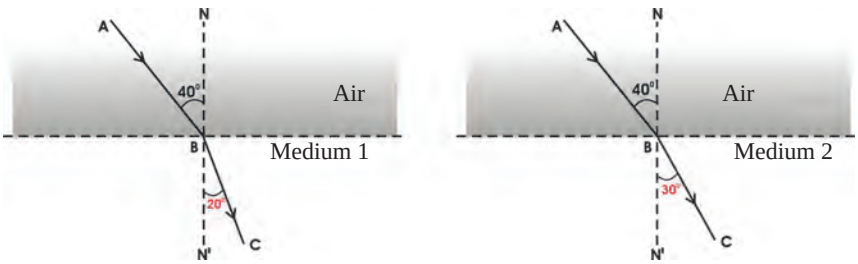


Fig. 1.28

a) Which is the medium of higher optical density? Why?

b) Which is the medium of greater refractive index?

6. Observe the figures.

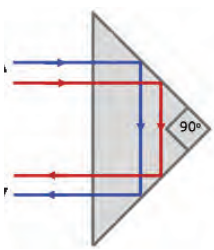


Fig. 1.29 (a)

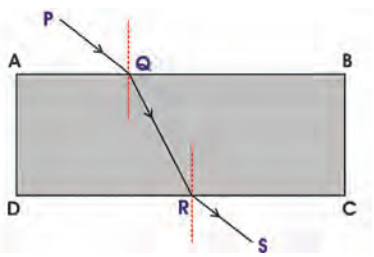


Fig. 1.29 (b)

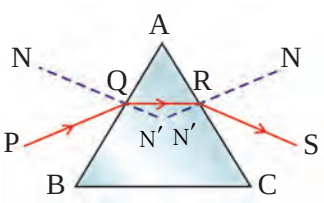


Fig. 1.29 (c)

a) Which figure indicates total internal reflection?

b) Which figures indicate refraction?

7. The critical angle of glass is 42°. Choose the angle of incidence for which total internal reflection takes place.

a) 40° b) 49° c) 38° d) 42°

8. We can see many small prisms in the reflectors used in motorcycles. Describe the benefits of using them.

9. Observe the table.

Medium	Refractive index
Air	1.0003
Water	1.33
Kerosene	1.44
Turpentine oil	1.47
Crown glass	1.52
Diamond	2.42

Table 1.6

a) Choose the medium in which light has the least speed.

b) The speed of light in air is 3×10^8 m/s. What is the speed of light in kerosene?

c) When a ray of light enters obliquely from air to diamond, will the refracted ray deviate towards the normal, or away from the normal? Justify your answer.

10. The path of light through mediums A, B, C and D are given. Choose the correct figures. (The optical density of the mediums are in the order A<B<C<D)

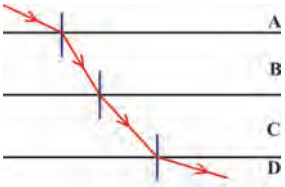


Fig. 1.30 (a)

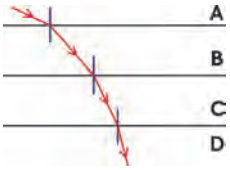


Fig. 1.30 (b)

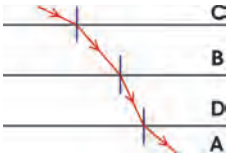


Fig. 1.30 (c)

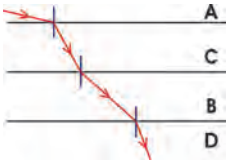


Fig. 1.30 (d)

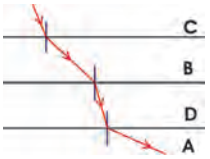


Fig. 1.30 (e)

11. Speed of light in ethanol is lesser than that in methanol. Which medium has lower refractive index? Why?

Extended Activities

1. Make periscopes using prisms instead of mirrors. Exhibit them.
2. Find out the critical angle in different mediums like glycerine, water, coconut oil, glass etc., through an experimental project and compare them. Prepare a project report including different stages like objective, materials, method of study, results etc.
3. Can the angle of refraction be 90^{o} when light enters from an optically rarer medium to a denser medium? Do an activity and write it down in the science diary.