Students' Learning Outcomes

After completing this chapter, the students will be able to:

- Explain refraction of light and its causes.
- Discuss the effects of refraction with examples.
- List the colours of light using a prism.
- Describe the dispersion of light by a prism.
- Identify different uses of light of different colours at home, school and country and explain the relationship of choice of colours to their purpose.
- Define spectrum of light.
- Identify primary colours and show how they are combined to form secondary colours.
- Identify a device in their surroundings that uses different combination of colours.
- Demonstrate how spinning of a rainbow disc results in the appearance of white disc.
- Explain why an opaque or non-luminous object appears to be of certain colour.

Animation 9.2 : Refraction
Source and Credit: District196

We have learnt a few properties of light in class VI. In this chapter we shall discuss some more properties of light. You may have seen some of these scenes around you:

- A deep tub filled with water appears less deep.
- A puddle of water on the road on a hot, sunny day
- A beautiful rainbow in the sky after rain

All these phenomena are the result of a property of light, called refraction.

9.1: Refraction

We know that light does not need a material medium to travel. Light travels at different speeds in different mediums. Light travels the fastest through the vacuum.

When light passes from one transparent medium to another, it changes its speed and direction (or bends). This bending of light is called **refraction**. But, when light falls perpendicular to the surface of the medium, it does not change its direction.

Fig. 9.1: The pencil in the glass of water looks as it has been broken at the water line. It is because of refraction of light.

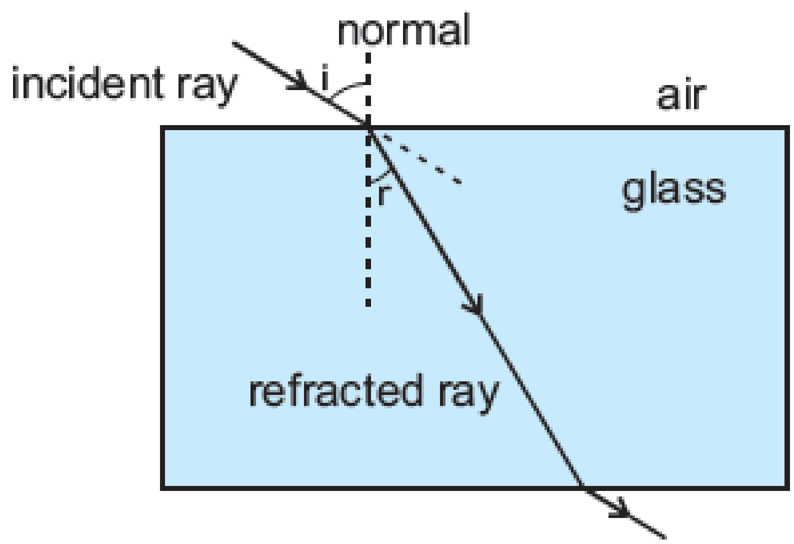


Fig. 9.2: A light beam bends as it travels from air into glass and also from glass into air.

Important Terms

We can understand the term refraction with the help of the following terms:

Incident Ray: The ray of light that travels in one medium and falls on the surface of the second medium.

Refracted Ray: The ray of light that changes its direction in the second medium.

Normal: An imaginary line, drawn perpendicularly on the surface of the medium at the point where incident ray falls (point of incidence).

Angle of Incidence: The angle between the normal and the incident ray. It is denoted by '*i*'.

Angle of Refraction: The angle between the normal and the refracted ray. It is denoted by '*r*'.

Animation 9.3: Total Internal Refraction
Source and Credit: The University of Sydney

Activity 9.1 Effect of Refraction

You will need:

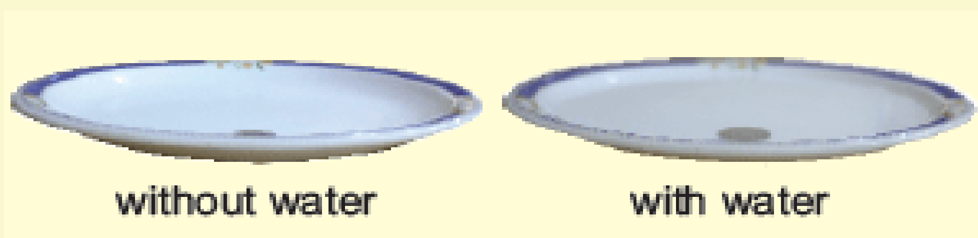
- a plate
- water
- a coin

Procedure

1. Take a short, opaque plate and place a coin at its bottom.
2. Position yourself in such a way that the coin is just not visible to you.
3. Ask your partner to pour water into the plate until you can see the coin clearly.

What happens?

When the coin is not visible to you, the rays of light travelling from the coin in a straight line are not able to enter your eyes. These rays are blocked by the edge of the plate. As soon as water is poured in the plate, the change of medium occurs. Now light has to travel from water into air. Due to refraction of light it bends to enter your eyes. The coin is now visible to you due to refraction.



9.2: Refraction in Different Mediums (Glass and Water)

When light passes from air to water or glass, it bends towards the normal. The angle of incidence is greater than the angle of refraction (Fig:9.3a).

$$\angle i > \angle r$$

When light passes from water or glass to air, it bends away from the normal. The angle of refraction is greater than the angle of incidence (Fig:9.3b).

$$\angle r > \angle i$$

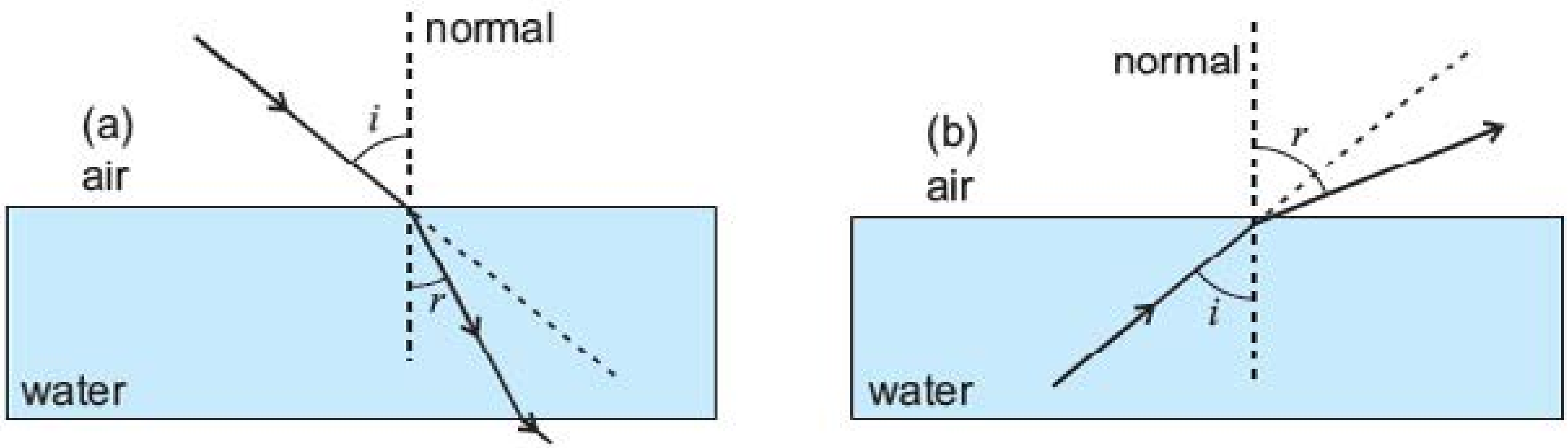


Fig. 9.3: (a) Light bends towards the normal when passes from air into water or glass. (b) It bends away from the normal when passes from water or glass into air.

Extend Your Thinking
A light wave is bent more as it travels from air to glass than in traveling from air to water. Is the speed of light greater in water or glass?

9.3: Laws of Refraction

There are two laws of refraction.

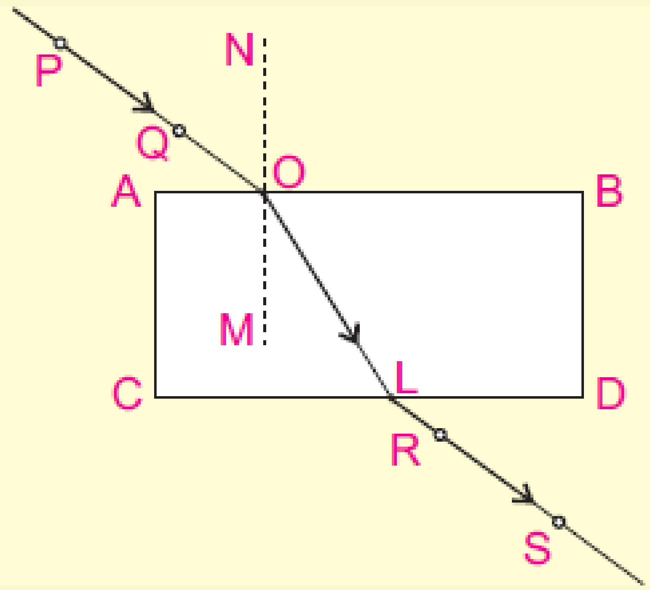
1. The incident ray, the refracted ray and the normal at the point of incidence, all lie in the same plane.
2. The ratio of the speed of light in vacuum to its speed in another medium is always constant.

Activity 9.2

You will need

- A glass slab
- Adrawing board
- Drawing pins
- White sheet of paper
- Common pins
- Geometry box

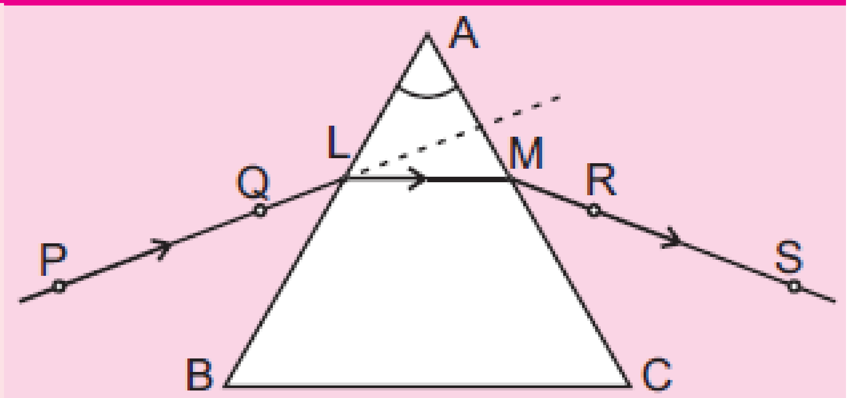
Procedure



1. Fix a white sheet of paper on a drawing board.
2. Put a glass slab in the centre of the paper. Draw the boundary of the slab as ABCD.
3. Fix two pins P and Q on the paper in such a way that they make an angle with the slab.
4. Look for the image of the pins from the other side through the slab. Fix two more pins R and S in line with the images of P and Q.
5. Remove the slab and the pins. Mark the position of the pins.
6. Join P and Q as the incident ray to AB at point O.
7. Join R and S as the refracted ray to CD at point L.
8. Join O and L.
9. Draw a normal NOM at point O.
10. Fix P and Q pins at different positions and place R and S pins on the other side of the slab accordingly.

You can see that the incident ray, the refracted ray and normal at the point of incidence, all lie in the plane of paper.

Using the knowledge from the above activity study the refraction of light through a prism.



9.3.1: Refractive Index

The speed of light varies in different mediums. Some mediums cause light to bend more than others when it passes through them. The degree to which a medium can bend light is given by its refractive index.

In terms of speed of light, we can define refractive index as, "refractive index is the ratio of the speed of light in vacuum to its speed in the medium".

$$\text{Refractive Index of the medium} = \frac{\text{Speed of light in vacuum}}{\text{Speed of light in the medium}}$$

9.4: Real and Apparent Depth

Sometimes refraction of light gives us a false impression of the depth and position of objects in water or glass. For example, we have noticed that clear swimming pools look shallower than their actual depth. It is because of refraction of light.

Light travels faster in air than in water. When light passes from a denser medium (water) to a rare medium (air), it bends away from the normal. When this refracted light enters our eyes, the bottom of the pool and objects lying on the bottom appear close to us than they really are (Fig.9.5).

Fig.9.4: Willebrord Snell (1580–1626) was a Dutch astronomer and mathematician. In 1621, he presented the law of refraction.

9.5: Critical Angle

When light rays pass from a denser medium (water or glass) to a rare medium (air), they bend away from the normal.The angle of refraction is greater than the angle of incidence. If the angle of incidence is gradually increased, a stage will come when maximum refraction occurs and the angle of refraction becomes **90°**(Fig.9.6). Here the refracted ray becomes parallel to the surface of the refracting medium. The angle of incidence for which the angle of refraction is 90° is called the **critical angle**. It is denoted by 'C'. Critical angle for water is about 49° while for glass is 42°.

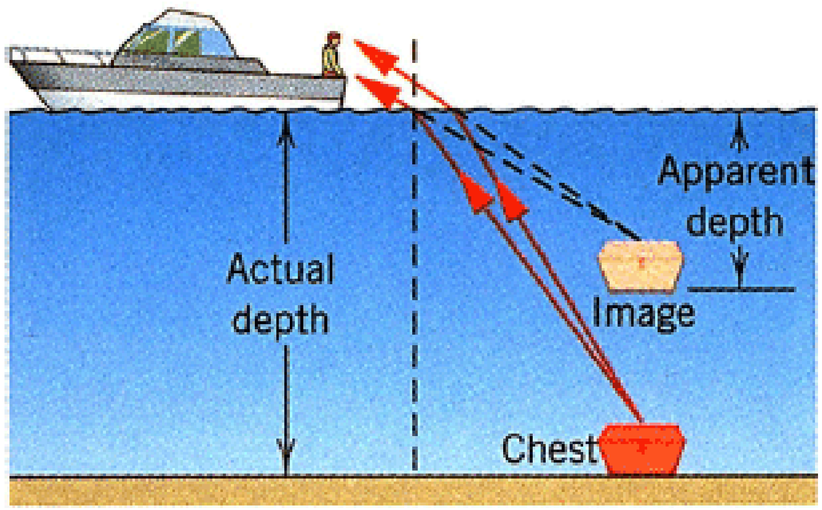


Fig.9.5. It is because of the refraction of light that the chest (box) appears higher in the water than actually is.

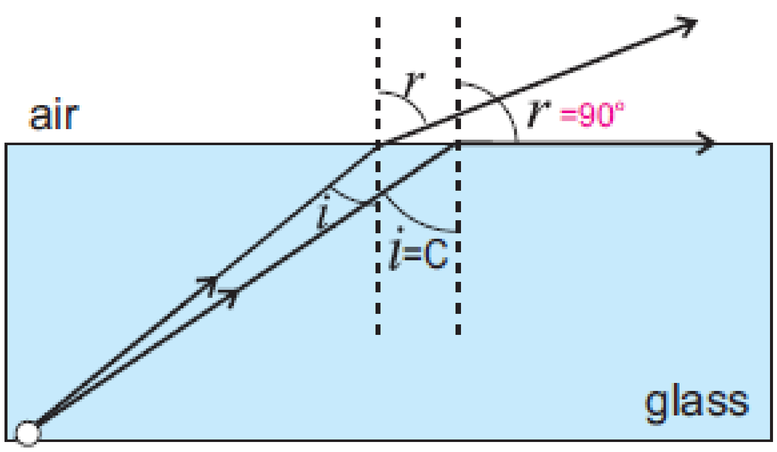


Fig. 9.6: C is the critical angle of glass.

9.6: Total Internal Reflection

When light passes from glass or water to air (denser to rarer medium), it bends away from the normal. But when angle of incidence (i) is greater than the critical angle 'C', the light rays reflect in the same denser medium. This phenomenon is called **total internal reflection** (Fig.9.7).

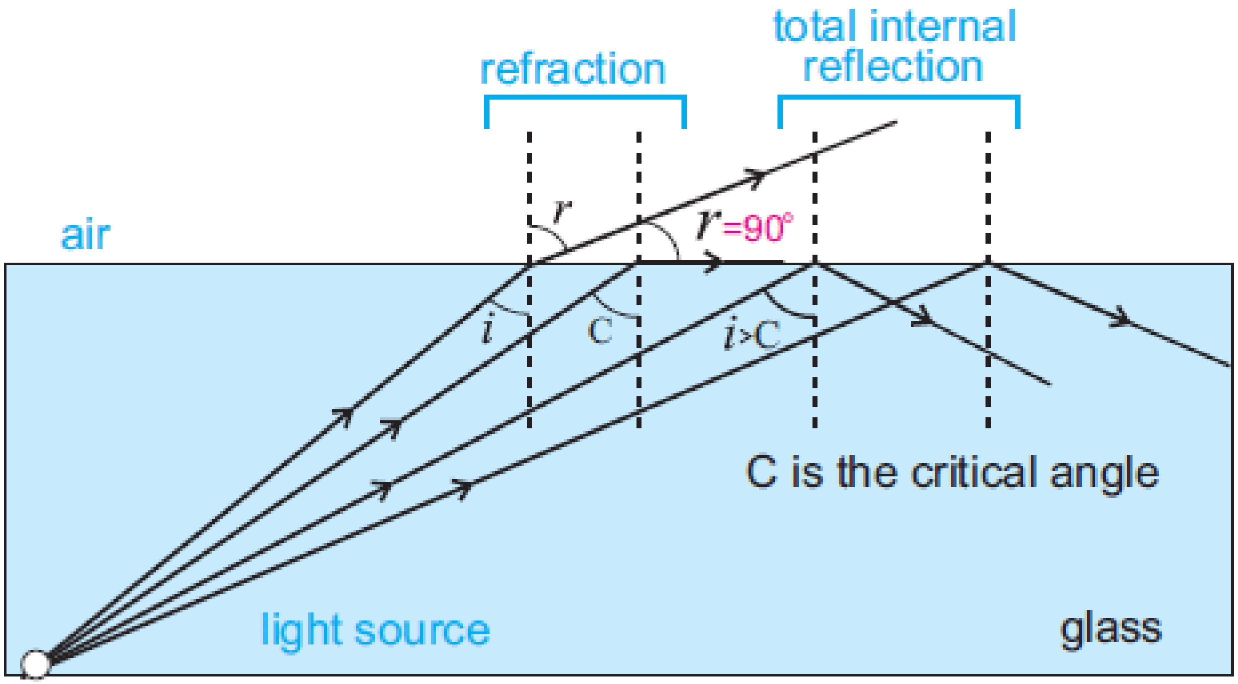


Fig. 9.7: Total internal reflection

Total internal reflection takes place only when:

1. Light passes from a denser medium (water or glass) to a rare medium (air).
2. The angle of incidence of all rays must be greater than the critical angle of that denser medium.

$$\angle i > \angle C$$

Fig. 9.8: The underwater reflection of the turtle is the result of total internal reflection.

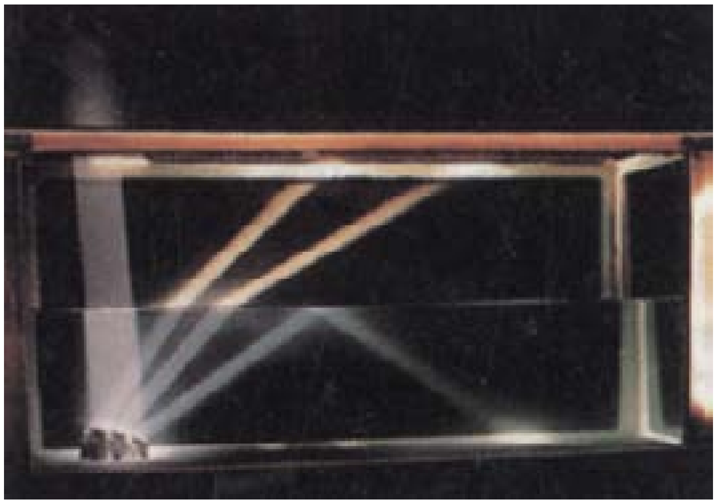


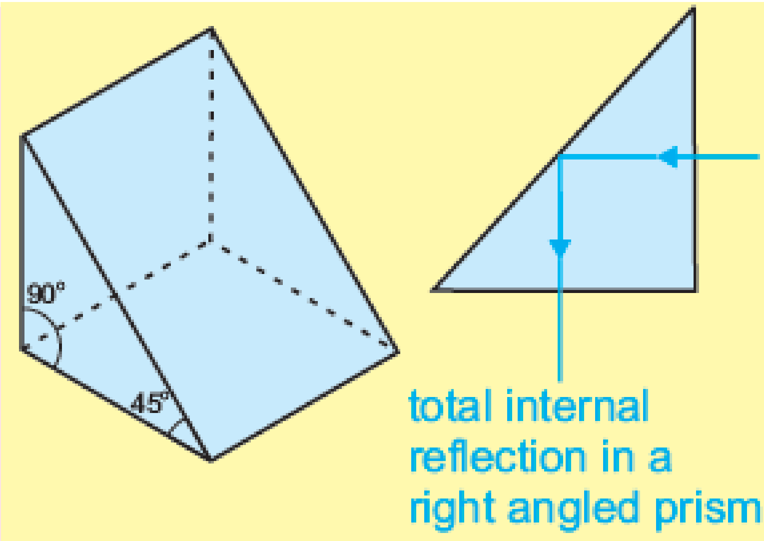
Fig. 9.9: Once the angle of light beam becomes greater than the critical angle, it is totally reflected at the surface of the water.

9.7: Applications of Total Internal Reflection

Many optical instruments use the principle of total internal reflection for their working.

Prisms

A **prism** is a block of glass with three rectangular and two triangular surfaces. A **right angled prism** has one 90° and two 45° angles. The critical angle for glass is about 42°. When light enters the prism, it will undergo total internal reflection.



Binocular

The critical angle for glass is around 42°. When light enters a right-angled prism, it makes an angle greater than the critical angle. It causes total internal reflection to take place. A binocular uses reflecting prisms to see distant objects (Fig.9.10).

Animation 9.4: Total internal Refraction with critical view Source and Credit: Science Joy Wagon

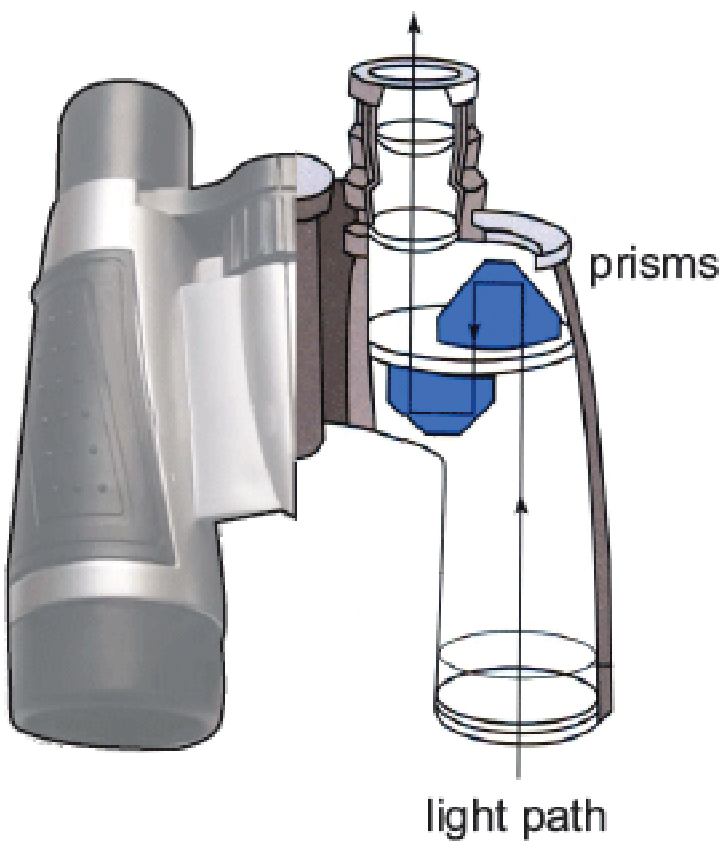


Fig: 9.10: A binocular uses reflecting prisms to see distant objects.

Periscope

We can see objects which are higher than our eyes with the help of a periscope. A simple periscope consists of a tube, at the ends of which are fitted two right angled prisms. The first prism turns light coming from the object towards the second. The second prism turns it to our eyes. The prisms use the principle of total internal reflection (Fig.9.11). Periscopes are used in submarines, tanks, etc.

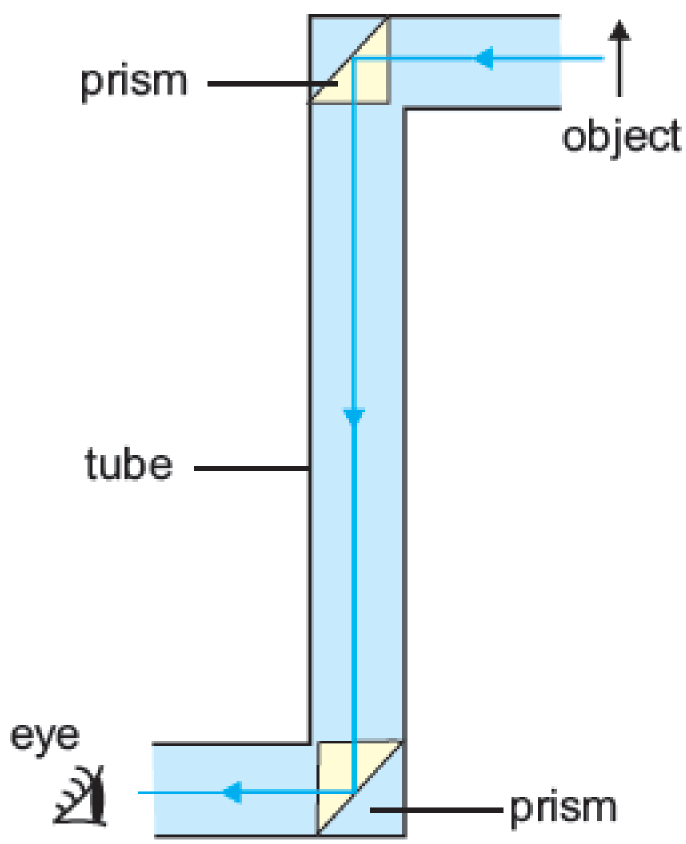


Fig:9.11: Prisms in a periscope help to see objects which are higher than eyes.

Mirages

Have you ever seen water on the road ahead while travelling on a hot, sunny afternoon ? But when you get there the road is perfectly dry (Fig.9.12). The water was never there. What you saw was a mirage.

A **Mirage** is an image of some distant object which appears to us due to the refraction and total internal reflection of light.

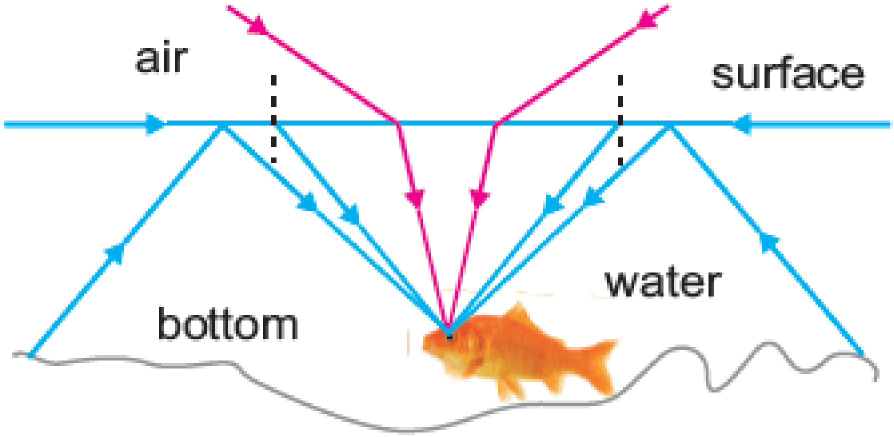
The air higher up is cooler than the air near the road. Light travels faster when it reaches the warmer air. The light rays bend as they travel downward due to refraction. Near the ground where air is even more warm, the light rays travel almost parallel to the ground but continue to bend in other direction (total internal reflection). When we see these bending light rays, our brain assumes that the rays have travelled in a straight line. These rays seem to us as reflecting from water. As a result, we see a mirage. Desert travelers often observe mirages.

Fig. 9.12: We see a mirage due to the refraction and total internal reflection of light.

Fish Eye View

We have studied that when light travels from one medium into another, its speed changes, which causes the light to refract at the boundary. As light travels from water to air, it will bend away from the perpendicular to the surface. When the angle of incidence is greater than 49 degrees, all the light is reflected back into the water (total internal reflection). When fish looks up, it will see reflected view of the sides and bottom of the pond, while directly above, it sees a compressed view of outside world due to refraction.

Animation 9.5: Prism
Source and Credit: info@physics.nad.ru



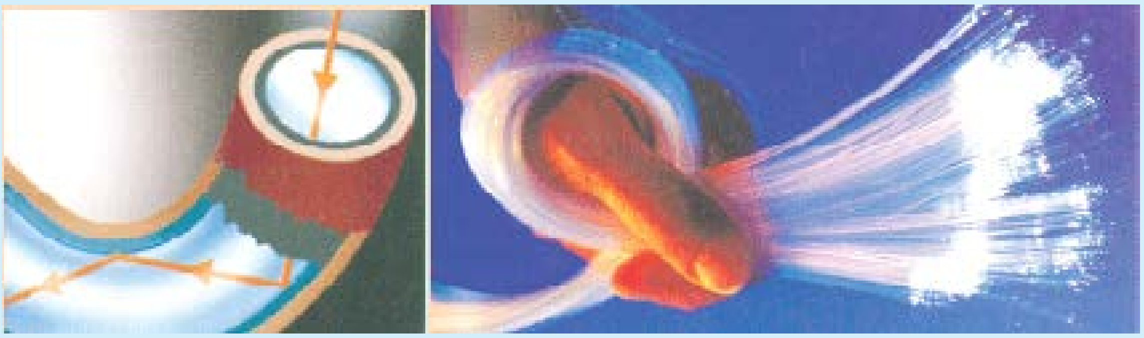
Animation 9.6: Total internal refflaction of light
Source and Credit: info@physics.nad.ru

Animation 9.7: Total internal refflaction of light
Source and Credit: info@physics.nad.ru

Fig. 9.13: A fish looks the water above as a mirror due to total internal reflection.

Science, Technology and Society

The critical angle of glass is 42°. Total internal reflection makes light transmission over long distances possible in optical fibres. Optical fibres are thin transparent glass fibres in which light travels due to total internal reflection. These fibres are commonly used in communication, e.g. in telephone transmissions, TV programs and computers. An optical fibre can carry thousands of phone calls at the same time. Find other uses of optical fibres in medicines and industries.



9.8: Dispersion of Light

Sunlight is often called white light, although it is a combination of different colours. We can see these colours in a rainbow. These colours are red, orange, yellow, green, blue, indigo and violet. We can also spilt white light into its colours by passing it through the prism. The band of seven colours obtained is called spectrum of white light. The splitting of white light into its component colours is called dispersion of light (Fig.9.14).

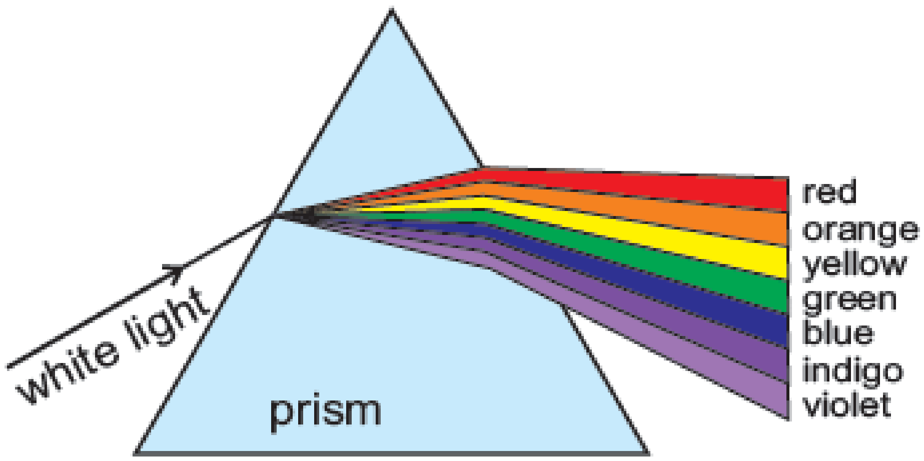


Fig. 9.14: Spectrum of light

Animation 9.8: Critical angle
Source and Credit: Science Joy Wagon

Activity 9.3 **Obtaining a Spectrum of Colours**

You will need:

- A prism
- A white cardboard

Procedure

Shine a narrow beam of sunlight on one rectangular surface of a prism in such a way that a spectrum of colours forms on a white cardboard screen on the other side of the prism. **Identify** the colours of light, seen by you. Which colour is at the top and which one is at the bottom?

9.8.1: Why does White Light get Dispersed?

When a beam of light enters a prism, all the colours of white light refract at different angles– it causes the white light to split into its component colours. Red light bends the least. Violet light bends the most and refracts by the largest angle. In this way, white light disperses into its component colours {Fig.9.15(a)}. When this spectrum is again passed through another prism as shown in the Fig. 9.15(b), a beam of white light is obtained.

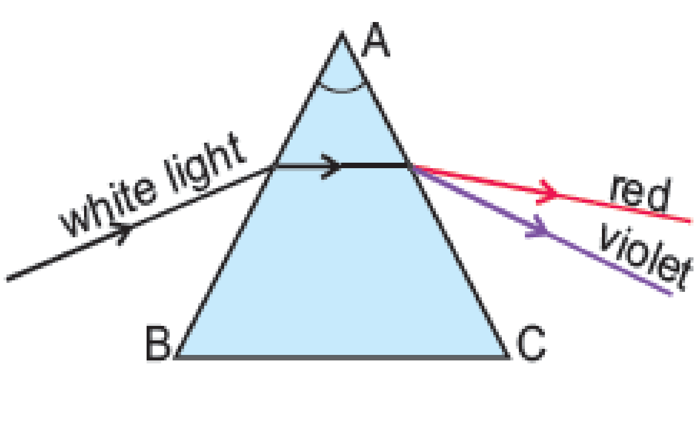


Fig. 9.15(a)

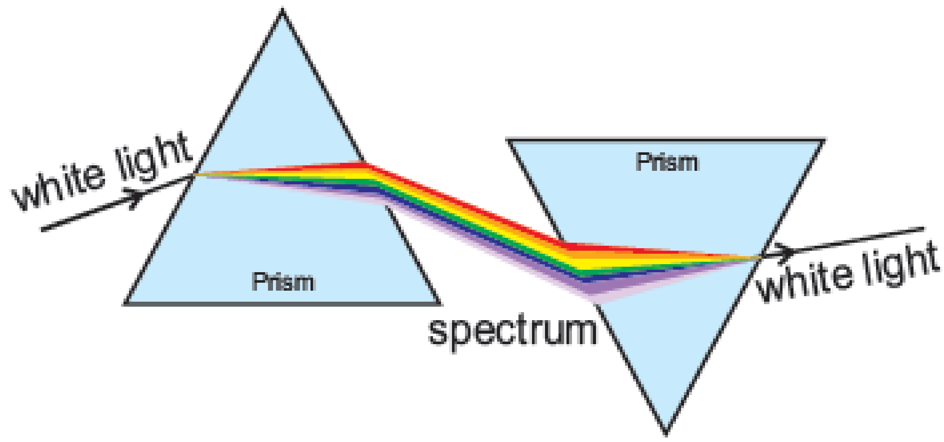


Fig. 9.15(b)

Activity 8.5	White light is a combination of seven colours.

You will need:

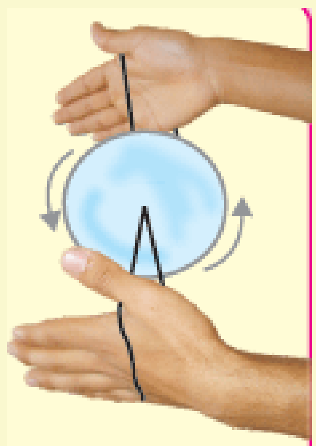
- a cardboard
- a string
- glazed papers of different colours

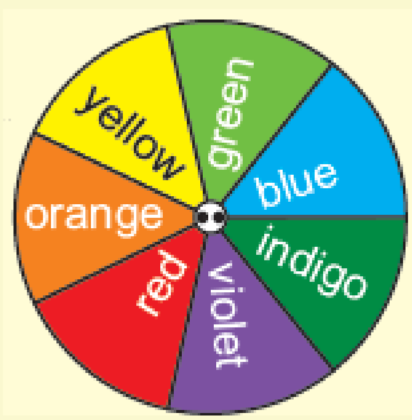
Procedure

1. Take a round cardboard. Paste equal-sized pieces of glazed papers of seven colours of light.
2. Make two holes near the centre of the cardboard. Make a loop of a string through these holes. Hold the two ends of the loop into your hands and also twist the string strongly.
3. Let loose the string and stretch your hands in and out alternately. Repeat this again and again. The cardboard will start revolving as shown in figure. Watch carefully the revolving cardboard.

Things to think

i. Can you still see the different colours on the cardboard?
ii. Which colour can you see in the revolving cardboard?





Rainbow Formation

A rainbow is a natural demonstration of refraction, dispersion and total internal reflection of light. When white light of the Sun passes through tiny rain drops suspended after rainfall, a rainbow may appear. Raindrops in the air act like tiny prisms. They refract and reflect the sunlight and then separate it into different colours. The colour scheme of rainbow is the same as in the spectrum made by the prism. Since red colour bends the least and violet colour bends the most from its original path, so in the rainbow, the red colour appears at the top and the violet colour appears at the bottom. The other colours appear in between these two colours (Fig.9.16).

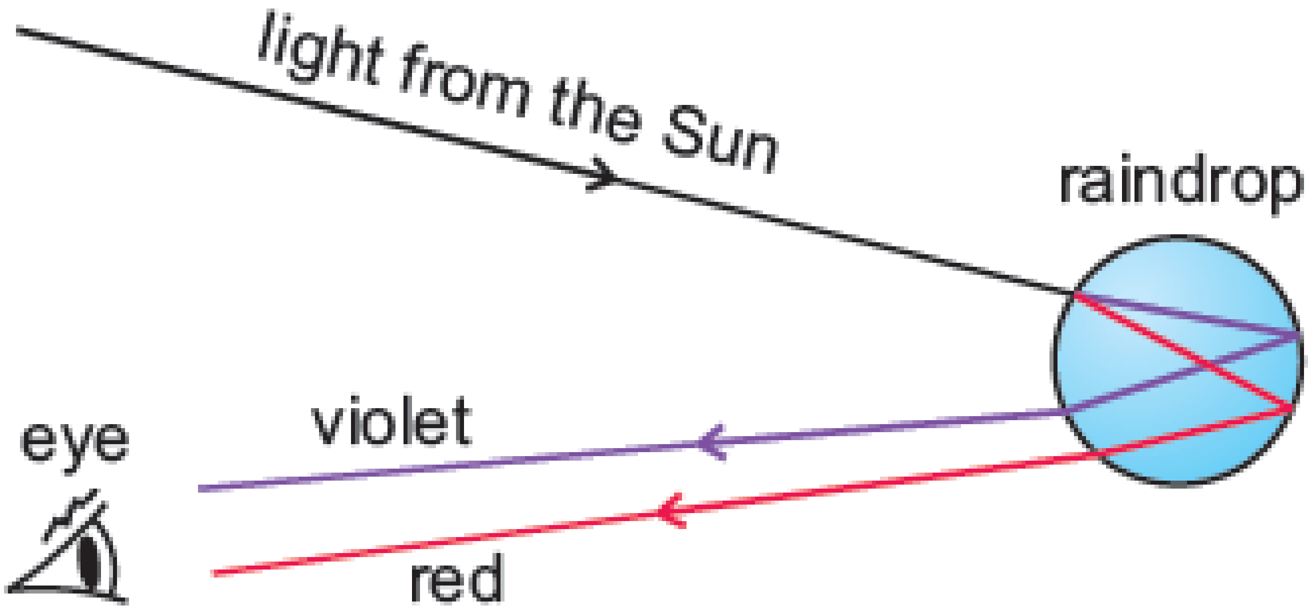


Fig. 9.16: A rainbow forms when sunlight is refracted and totally reflected by tiny water droplets.

Do You Know?

- We can only see a rainbow in front of us when the Sun is shining behind us.
- A rainbow usually shows all the seven colours of white light.

Extend Your Thinking

Why don't we see a rainbow during most rainstorms?

Activity 9.5	Seeing a Rainbow

You will need:

- a sunny day
- a running hose pipe

Procedure

1. Stand with your back to the Sun.
2. Spray water from the hose pipe. (Place your thumb over the hole at the end of the hose to get a spraying effect.)
3. Watch the spray against a dark background (grass or wall).

- Can you see a rainbow in the water droplets of the sprinkling water?
- What is the order of these colours from bottom to the top?

9.9: Colours of Light

An understanding of colours is very useful in photography and theater lightings. People who work with lights of different colours must know how to produce lights of various colours from a few basic colours. The colours that can be used to make any other colour are called primary colours. These are red, blue and green. We can mix the light of three primary colours to produce white light.

Animation 9.9: Color mixing
Source and Credit: info@physics.nad.ru

Red + Blue + Green = White

When two primary colours mix, they produce a secondary colour. Cyan, yellow and magenta are secondary colours. A colour television uses different combinations of colours.

Red + Green = Yellow

Red + Blue = Cyan

Blue + Green = Magenta

We can obtain other colours of light by mixing lights of primary and secondary colours.

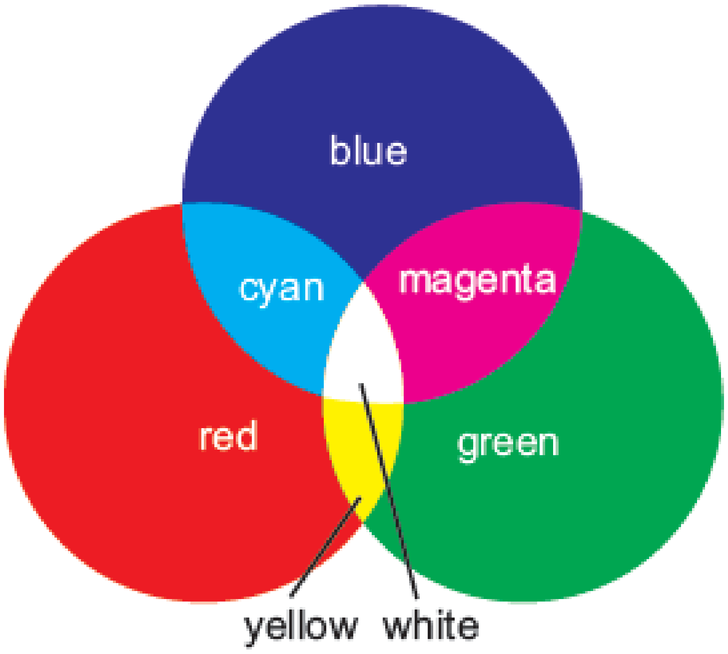


Fig. 9.17: Red, blue and green are primary colours of light.

Activity 9.6 | **Mixing the Colours of Light**

You will need:
- Three torches
- Red, blue and green cellophane papers

Procedure:
1. Take three torches. Paste a green cellophane paper on the glass of one of the torch, red cellophane filter on the second and a blue cellophane paper on the third torch.
2. Throw lights of different colours on a white screen in such a way that light of one colour falls on the light of the other colour.

Observe mixing of colours and fill the table.

Colours of the light thrown on the screen	Colour which appears on the screen
Red + Blue	
Blue + Green	
Red + Green	
Red + Green + Blue	

9.10: Colours of Objects

Fig. 9.18: The petals of this rose appear red because they reflect red light. The leaves appear green because they reflect green light.

When white light shines on non-luminous objects they reflect some colours and absorb all the others. The colour of an object is the colour of light it reflects.

A red object appears red because it reflects red colour of light and absorbs all the other colours (Fig. 9.18). The grass of our lawn appears green as it reflects green light into our eyes. Why does a blue car appear blue?

When all the colours of light are reflected into our eyes, the object appears white. And, when all the colours of light are absorbed by the object, it appears black. Black objects do not reflect any light. Objects of colours other than primary colours reflect mixture of colours.

Animation 9.10: Rainbow
Source and Credit: University of Utah

Extend Your Thinking
What colours are reflected by an object that appears black?

Key Points

- When light passes from a transparent medium to another, it changes speed and bends. This bending of light is called refraction.
- Refraction causes images to form in our eyes, a rainbow to take place, etc.
- When light passes through a prism, it refracts and bends at an angle. A prism can split white light into its component colours.
- Red, orange, yellow, green, blue, indigo and violet are the component colours of white light.
- The band of seven colours of light is called the spectrum of light.
- A rainbow disc has all the seven colours of light. When it is spinned, white disc is seen.
- Red, blue and green are three primary colours of light. Primary colours combine to make secondary colours of light.
- The colour of an objects is the colour of light it reflects. A red flower reflects red colour and appears red. A white surface reflects all the colours of light and appears white. A black surface reflects no colour.

Questions

1. Complete each of the following sentences by writing the correct term.

i. They can carry thousands of phone conversations at the same time ______
ii. The bending of light, when it enters from one medium to another ______
iii. The angle of incidence at which maximum refraction occurs ______
iv. The ratio of the speed of light in vacuum to its speed in another medium ______
v . The splitting of white light into its component colours