مدرستنا العليا الخاصة، الورقاء
OUR OWN HIGH SCHOOL, AL WARQA'A

EDUCATION

HUMAN EYE AND COLOURFUL WORLD

Notes

Physics - Grade 10

Human Eye

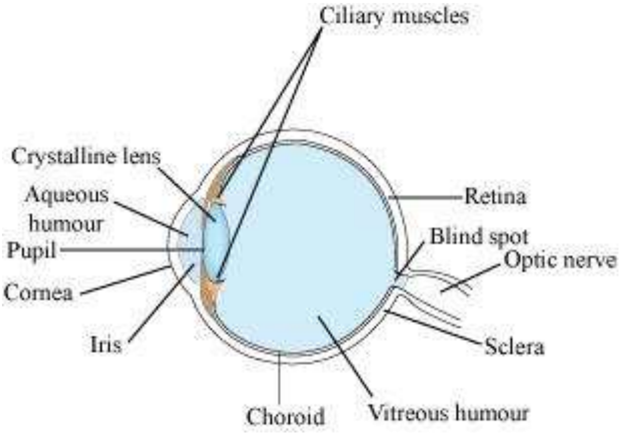
Eye is one of the most sensitive sense organs in the human body. Our eye enables us to see this beautiful world. It consists of a lens, which is made up of living tissues.

How does our eye work?

What are the nature, position and relative sizes of the images formed by the lens in the eye?

In this section, we will learn about the structure and functioning of human eye.

Structure of human eye

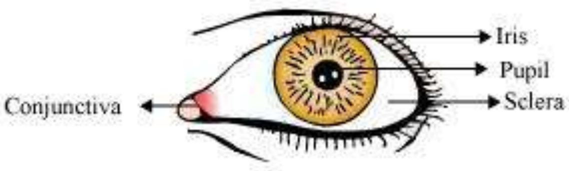


The given figure shows the structure of the human eye.

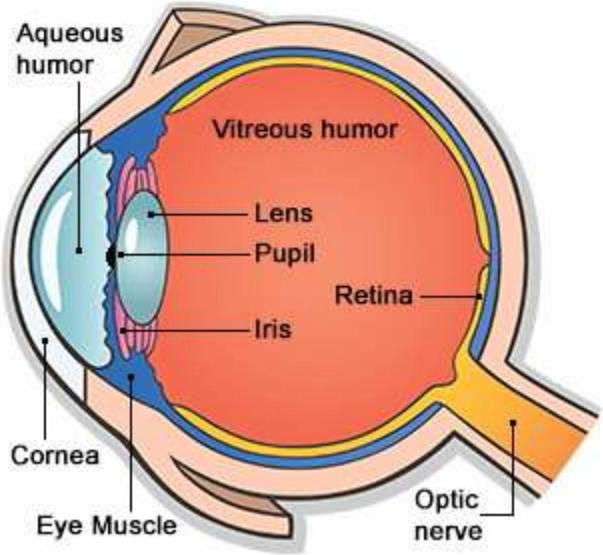
The human eye is roughly spherical in shape with diameter of about 2.3 cm. It consists of a convex lens made up of living tissues. Hence, human lenses are living organs contrary to the simple optical lenses. The following table lists the main parts of the human eye and their respective functions.

S. No.	**Human eye part**	**Function**
1.	Pupil	Opens and closes in order to regulate and control the amount of light
2.	Iris	Controls light level similar to the aperture of a camera
3.	Sclera	Protects the outer coat
4.	Cornea	Thin membrane which provides 67% of the eye’s focusing power
5.	Crystalline lens	Helps to focus light into the retina
6.	Conjunctiva	Covers the outer surface (visible part) of the eye
7.	Aqueous humour	Provides power to the cornea
8.	Vitreous humour	Provides the eye its form and shape
9.	Retina	Captures the light rays focussed by the lens and sends impulses to the brain via optic nerve
10.	Optic nerve	Transmits electrical signals to the brain
11.	Ciliary muscles	Contracts and extends in order to change the lens shape for focusing.

The **white of the eye** is known as the **sclera**. It is the tough, opaque tissue that protects the outer layer of the eye. **Iris** is the coloured part of the eye, and the **pupil** is the black,



Circular hole that is located at the centre of the iris. The thin, transparent tissue that covers the outer surface of the eye is known as the **conjunctiva**. It consists of tiny blood vessels that nourish it.



The cornea is located at the front portion of the eye. It is the transparent window that bulges outwards. The lens consists of layers of tissues enclosed in a tough capsule. The focus of the lens is adjusted by the ciliary muscles that suspend and hold it.

Functioning of the human eye

Light rays enter the eye through the cornea. The rays are bent, refracted, and focused by the cornea, lens, and the vitreous humour. The main function of the lens is to focus the light rays sharply on the retina. It is the outer surface of the cornea where most of the refraction of light occurs.

Iris and pupil control the size of the pupil and the amount of light respectively. Since the eye lens is convex in nature, the resulting image is real, small, and inverted. This image is formed on the retina. The retina converts these light rays into electrical signals with the help of light sensitive cells. These signals are sent to the brain via translated and perceived objects in an erect or upright position.

The head of the optic nerve is devoid of photosensitive cells. Hence, no image is formed at that point called the **blind spot** of the eye

On sunny days, when you enter a dimly lit room, you are unable to see clearly for a moment. Why does this happen?

In bright light, the iris expands, thereby contracting the pupil. This happens so that only a small quantity of light enters the eye. As a result, the retina is protected from exposure to excessive light.

On entering a dimly lit room after having been in the sun for some time, the iris contracts slowly to expand the pupil. Gradually, more light is able to enter the eye. Hence, it takes a few seconds before we are able to see the objects present in the dimly lit room.

Colour perception

Have you wondered how do we see colour?

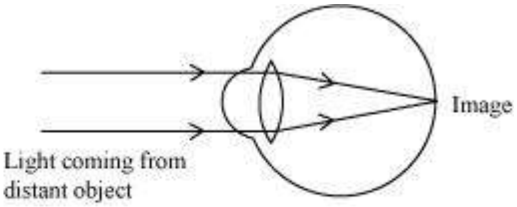
Retina consists of two types of light sensitive cells – rod cells and cone cells. The rod shaped cells respond to the intensity or brightness of the focussed light whereas the cone shaped cells of the retina respond to the colours. Thus, the cone cells of the retina make colour perception possible.

A person having defective cone cells is not able to distinguish between the different colours. This defect is known as **Colour Blindness**.

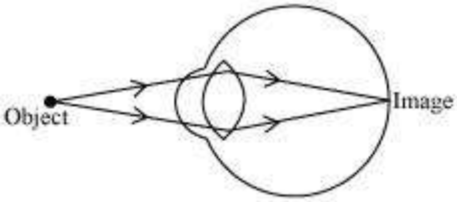
Power of Accommodation And Defects of Vision of Human Eye

Have you wondered why the eye is able to focus the images of objects lying at various distances?

It is made possible because the focal length of the human lens can change i.e., increase or decrease, depending on the distance of objects. It is the ciliary muscles that can modify the curvature of the lens to change its focal length.



To see a distant object clearly, the focal length of the lens should be larger. For this, the ciliary muscles relax to decrease the curvature and thereby increase the focal length of the lens. Hence, the lens becomes thin. This enables you to see the distant object clearly.



To see the nearby objects clearly, the focal length of the lens should be shorter. For this, the ciliary muscles contract to increase the curvature and thereby decrease the focal length of the lens. Hence, the lens becomes thick. This enables you to see the nearby objects clearly.

The ability of the eye lens to adjust its focal length accordingly as the object distances is called **power of accommodation**.

- The minimum distance of the object by which clear distinct image can be obtained on the retina is called **least distance of distinct vision**. It is equal to 25 cm for a normal eye. The focal length of the eye lens cannot be decreased below this minimum limit of object distance.

Let us see what happens when an object is at a distance less than 25 cm from the eye lens

The **far point** of a normal eye is infinity. It is the farthest point up to which the eye can see objects clearly.

The range of vision of a normal eye is from 25 cm to infinity.

Have you ever thought why animals' eyes are positioned on their heads?

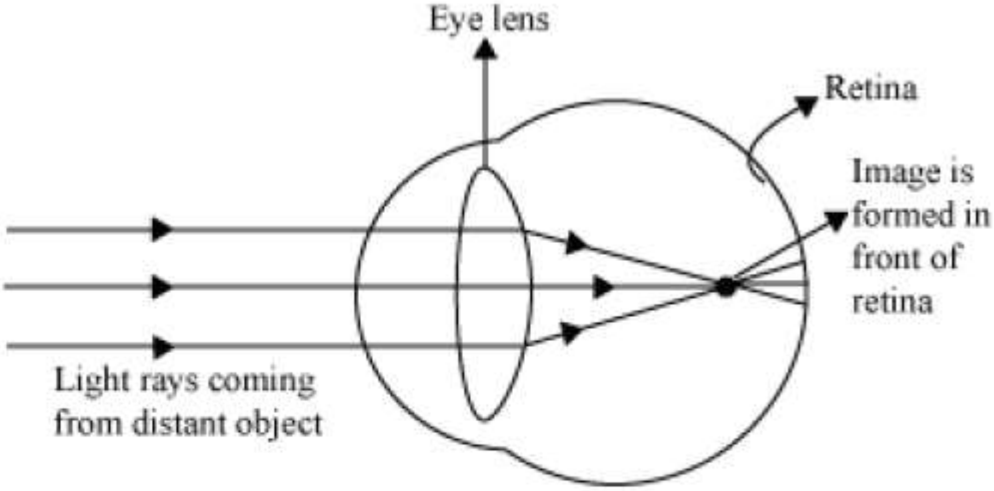
This is because it provides them with the widest possible field of view. Our eyes are located in front of our face. One eye provides 150° wide field of view while both eyes simultaneously provide 180° wide field of view. It is the importance of the presence of two eyes as both eyes together provide the three-dimensional depth in the image.

The loss of power of accommodation of an eye results in the defects of vision.

There are three defects of vision called **refractive defects**. They are myopia, hypermetropia, and presbyopia. In this section, we will learn about these defects of vision in detail.

1. Myopia (short sightedness)

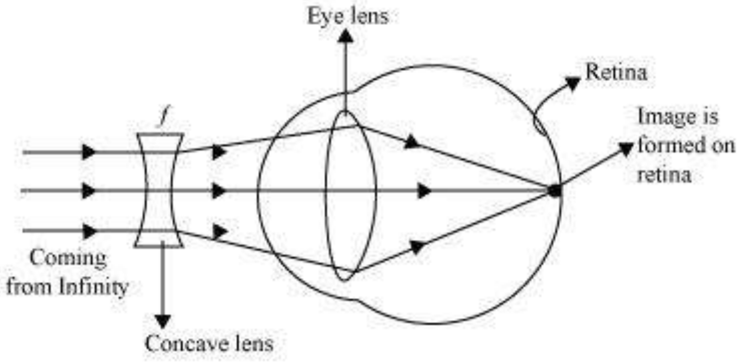
Myopia is a defect of vision in which a person clearly sees all the nearby objects, but is unable to see the distant objects comfortably and his eye is known as a myopic eye. **A myopic eye has its far point nearer than infinity. It forms the image of a distant object in front of its retina** as shown in the figure.



Myopia is caused by

1. increase in curvature of the lens
2. increase in length of the eyeball

Since **a concave lens has an ability to diverge incoming rays**, it is used to correct this defect of vision. The image is allowed to form at the retina by using a concave lens of suitable power as shown in the given figure.



Power of the correcting concave lens

The lens formula $\frac{1}{v}-\frac{1}{u}=\frac{1}{f}$ can be used to calculate the focal length and hence the power of the myopia correcting lens.

In this case,

Object distance, $u = \infty$
Image distance, v = person's far point

Focal length, f =?

Hence, lens formula becomes

$$\frac{1}{\text{far point}}-\frac{1}{\infty}=\frac{1}{\text{focal length}}$$

$$\frac{1}{\text{far point}}-0=\frac{1}{\text{focal length}}$$

In case of a concave lens, the image is formed in front of the lens i.e., on the same side of the object.

$\therefore$ Focal length $= -$ Far point

Now, Power of the required lens (P) = $-\frac{1}{f(\text{in m})}$

Example: A person can clearly see up to a maximum distance of 100 cm only. Calculate the power of the required lens that can correct his defect?

Solution:

Since the person is not able to see farther than 100 cm, he is suffering from myopia. Hence, a concave lens of suitable power is required to correct his defect. The focal length of the lens is given by his far point i.e.,

Focal length = $-$ Far point

= $-$ 100 cm

$\therefore$ Power of the lens = $-\frac{1}{f(\text{in m})} = -\frac{1}{\frac{100\text{ m}}{100}}$

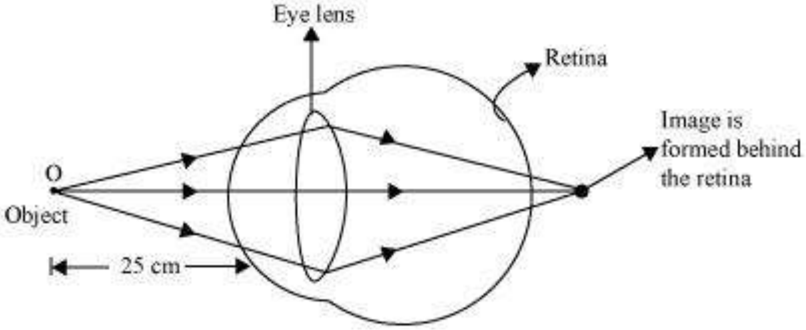
$= \frac{-100}{100\text{ m}} = -1\text{ D}$

Hence, a concave lens of power $-$ 1 D is required to correct the given defect of vision.

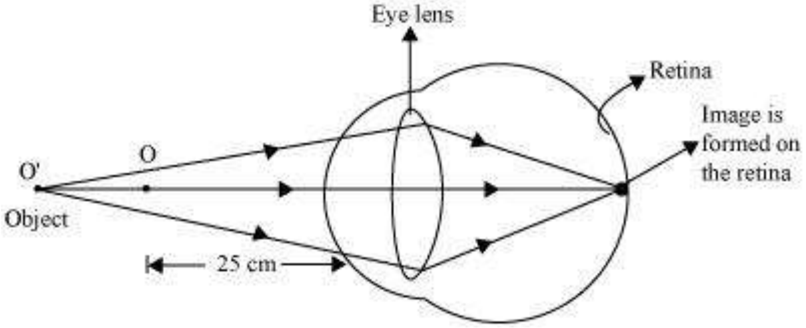
2. Hypermetropia (Long sightedness)

Hypermetropia is a defect of vision in which a person can see distant objects clearly and distinctively, but is not able to see nearby objects comfortably and clearly

The problem with a hypermetropic eye can be solved with the help of a diagram. It is shown in the given figure.



A hypermetropic eye has its least distance of distinct vision greater than 25 cm.



Hypermetropia is caused due to

1. reduction in the curvature of the lens
2. decrease in the length of the eyeball

Since **a convex lens has the ability to converge incoming rays**, it can be used to correct this defect of vision, as you already have seen in the animation. The ray diagram for the corrective measure for a hypermetropic eye is shown in the given figure.

Power of the correcting convex lens

Lens formula, $\frac{1}{v}-\frac{1}{u}=\frac{1}{f}$ can be used to calculate focal length f and hence power P of the correcting convex lens, where

Object distance, u = –25 cm, normal near point

Image distance, v = defective near point

Hence, the lens formula is reduced to

$$\boxed{\frac{1}{v}+\frac{1}{25}=\frac{1}{f}}$$

Example: The defective near point of an eye is 150 cm. Calculate the power of the correcting convex lens that would correct this defect of vision.

Solution:

Given that, hypermetropic near point = 150 cm

Hence, image distance, *v* = – 150 cm

We have the correction formula,

$$\frac{1}{f}=\frac{1}{v}+\frac{1}{25}$$

$$\frac{1}{f}=\frac{1}{-150}+\frac{1}{25}$$

$$\frac{1}{f}=\frac{-1+6}{150}=\frac{5}{150}$$

$$f=\frac{150}{5}\text{ cm}$$

$$f=0.3\text{ m}$$

∴ Power of the correcting convex lens,

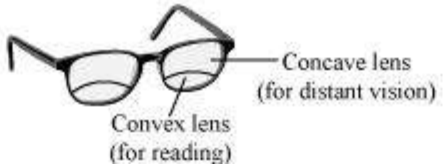
$$P = \frac{1}{f\ (\text{in m})} = \frac{1}{0.3} = 3.3\ \text{D}$$

Hence, a convex lens of power 3.3 D is required to correct the given defect of vision.

3. Presbyopia (Ageing vision defect)

Presbyopia is a common defect of vision, which generally occurs at old age. A person suffering from this type of defect of vision cannot see nearby objects clearly and distinctively. A presbyopic eye has its near point greater than 25 cm and it gradually increases as the eye becomes older.

Presbyopia is caused by the

i. weakening of the ciliary muscles
ii. reduction in the flexibility of the eye lens
iii. 

iv. **A person with presbyopia cannot read letters without spectacles**. It may also happen that a person suffers from both myopia and hypermetropia. This type of defect can be corrected by using bi-focal lenses. A bifocal lens consists of both convex lens (to correct hypermetropia) and concave lens (to correct myopia).
v. It is a common misconception among people that the use of spectacles “cures” the defects of vision. However, this is not true as spectacles only “restore” the defects of vision to the normal value.
vi. **Cataract**
vii. It is also one of the eye defects found commonly in people of older ages. In this defect, the crystalline lens becomes milky and cloudy. This condition is also known as **cataract**. This causes partial or complete loss of vision. This loss of vision can be restored by removing the cataract by means of a cataract surgery. The use of any kind of spectacle lenses does not provide any help against this defect of vision.

Refraction Of Light Through A Glass Prism And Dispersion Of White Light

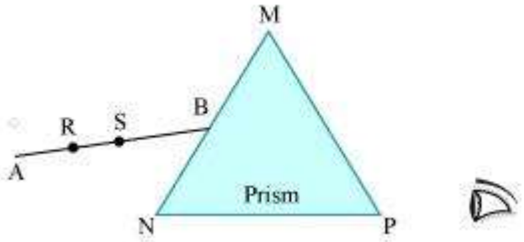
When a ray of light is incident on a rectangular glass slab, after refracting through the slab, it gets displaced laterally. As a result, the emergent ray comes out parallel to the incident ray. **Does the same happen if a ray of light passes through a glass prism?**

Unlike a rectangular slab, the sides of a glass prism are inclined at an angle called the angle of prism. Therefore, a ray of light incident on its surface, after refraction, will not emerge parallel to the incident light ray (as seen in the case of a rectangular slab).

Refraction of light through a glass prism

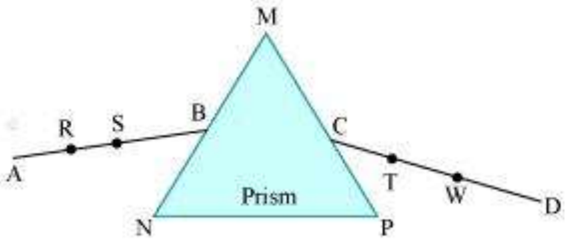
To observe the refraction of light through a glass prism, we can perform the following activity.

Take a triangular glass prism, paper sheet, and a few drawing pins. Fix the sheet on a drawing board with the help of drawing pins. Now, place the glass prism on the sheet and draw the outline **MNP** of the prism on the sheet (as shown in the figure). Draw a straight line **AB** on the sheet in such a way that it makes some angle with the face **MN** of the prism. Now, fix two pins on this line and mark them as **R** and **S** respectively.

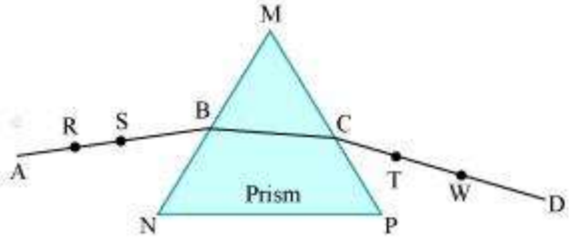


Now, observe the pins **R** and **S** through the other side of the prism. Move your head laterally to see the two pins **R** and **S** in a straight line. Fix a pin on the sheet near the prism on your side and mark it as **T**.

Repeat the same step and try to observe the three pins **R, S**, and **T** in a straight line. Fix another pin on the sheet so that all four pins appear to be in a straight line when looked through the prism. Draw a straight line **CD** that passes through the third and the fourth pin i.e., **T** and **W** respectively (see figure).



Now, remove the prism and join points **B** and **C**. The straight line **AB**, **BC**, and **CD**shows the path of the light ray. It is clear that the path of light is not a straight line since light bends towards the base **NP**.



What causes the light to bend when passed through a prism?

Light bends because of refraction that takes place at points **B** and **C** respectively, when it tries to enter and emerge from the prism.

Now, draw a straight line HH' normal to side **MN** and let it pass through point **B**. Similarly, draw a straight line GG' normal to side **MP** and let it pass through point **C**.

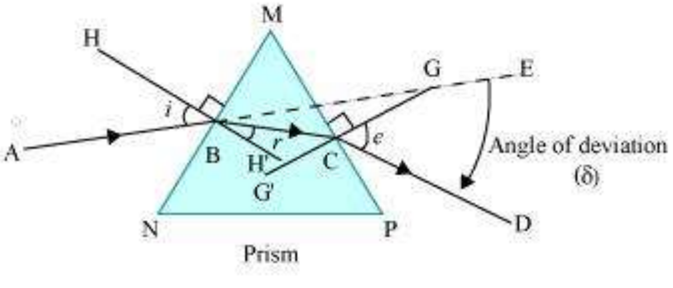
Here, line AB = Incident ray
Line BC = Refracted ray
Line CD = Emergent ray

Angle *i* = Angle of incidence

Angle *r* = Angle of refraction

Angle *e* = Angle of emergence

Angle δ = Angle of deviation



Hence, you will get the path of light ray **AB** when it travels through a glass prism. The ray **AB** will bend towards the normal HH' at point **B** and follow the path **BC**. Again, it bends away from the normal

GG' at **C**, when it tries to emerge from the prism. This is because the refractive index of air is less than that of glass. Thus, the incident ray **AB** will not follow a straight line **BE.**

The extent of deviation of the light ray from its path BE to path CD is known as the angle of deviation (δ).

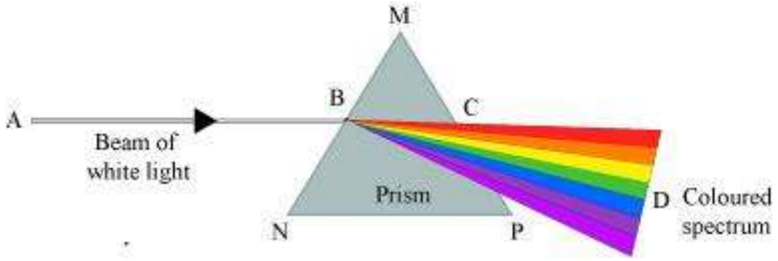
Do you know what happens when you take white light as incident ray instead of single ray?

A beam of white light will split into a band of seven colours. The splitting of a beam of white light into its seven constituent colours, when it passes through a glass prism, is called the **dispersion of light.**

Dispersion of white light by a prism

Isaac Newton was one of the greatest mathematicians and physicists the world ever saw. In 1665, with the help of an experiment he showed that white sunlight is actually a mixture of seven different colours. These constituent colours of white light can be separated with the help of a glass prism.

Take a glass prism and allow a narrow beam of sunlight to fall on one of its rectangular surfaces. You will obtain a coloured spectrum with red and violet colour at its extreme. Try to obtain a sharp coloured band on the screen by slightly rotating the prism. Count the colours of the band and write the sequence of the colours.



Do you know why white light gets dispersed into seven colours?

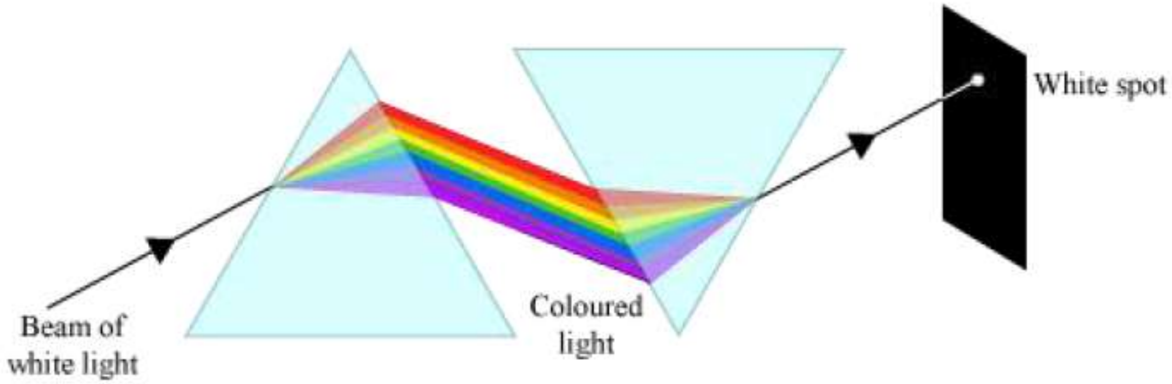
When a beam of white light AB enters a prism, it gets refracted at point B and splits into its seven constituent colours, viz. violet, indigo, blue, green, yellow, orange, and red. The acronym for the seven constituent colours of white light is VIBGYOR. **This splitting of the light rays occurs because of the different angles of bending for each colour.** Hence, each colour while passing through the prism bends at different angles with respect to the incident beam. This gives rise to the formation of the colour spectrum.

Can you say which colour undergoes maximum deviation?

Violet light bends the most whereas red colour deviates least.

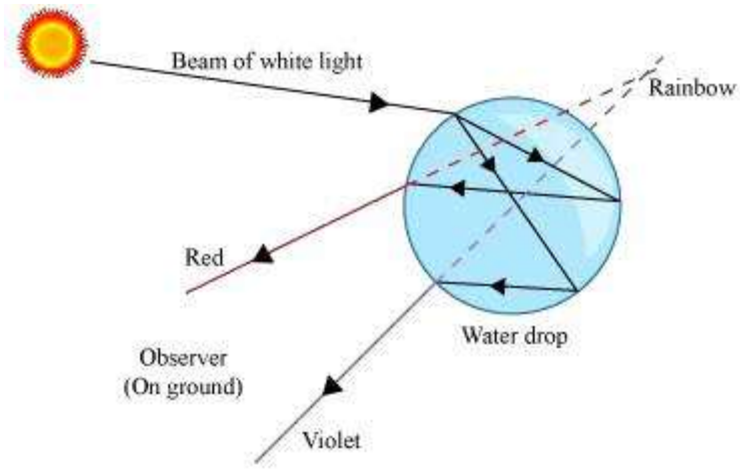
However, Newton did not stop at this point. He thought that if seven colours can be obtained from a white light beam, **is it possible to obtain white light back from the seven colours?**

For this, he placed an inverted prism in the path of a colour band. He was amazed to see that only a beam of white light comes out from the second prism. It was at this point that Newton concluded that white light comprises of seven component colours.



Formation of a rainbow

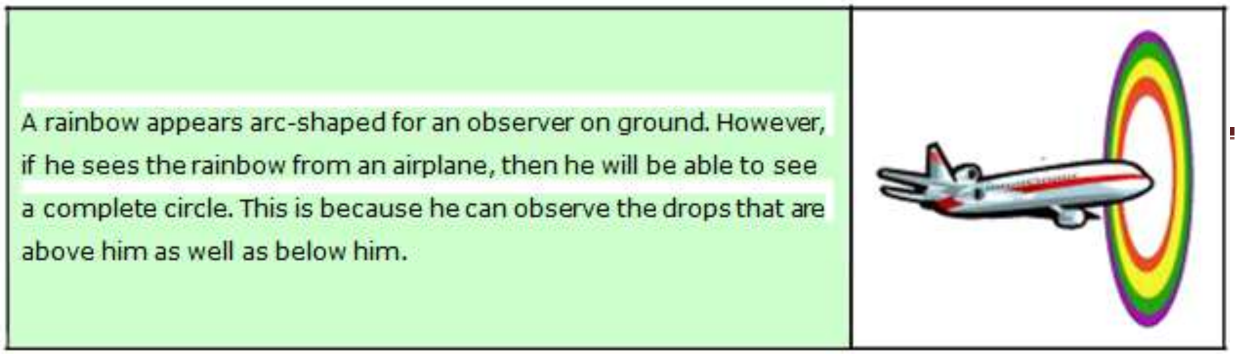
The rainbow is a natural phenomenon in which white sunlight splits into beautiful colours by water droplets, which remain suspended in air after the rain.



If we stand with our back towards the sun, then we can see the spectrum of these seven colours.

Do you know why a rainbow is shaped similar to an arc?

This is because the rainbow is formed by the dispersion of white light by spherical water droplets. It is the shape of the water droplets that gives the rainbow an arc shape.



A rainbow appears arc-shaped for an observer on ground. However, if he sees the rainbow from an airplane, then he will be able to see a complete circle. This is because he can observe the drops that are above him as well as below him.

Atmospheric Refraction

Raj has read in his science book that like the sun, stars are composed mainly of gases. He has also read that most of the stars are bigger than the sun. This makes him wonder how stars appear to twinkle at night.

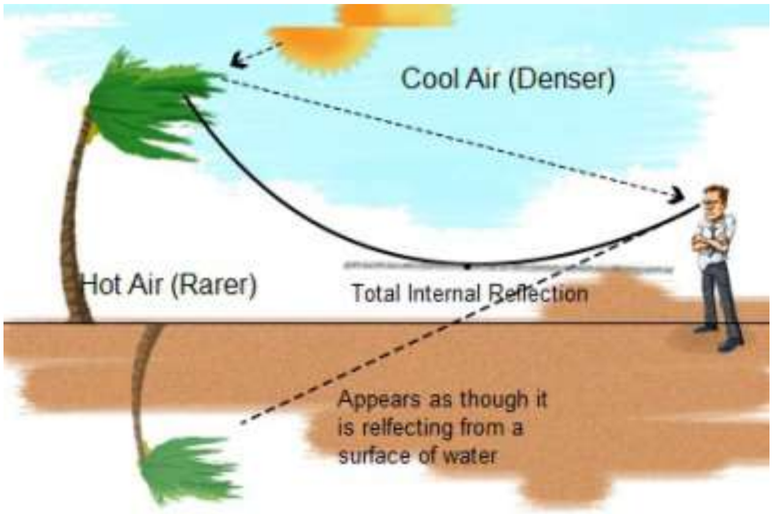
Do you know what causes the stars to twinkle? Why does not the sun twinkle?

A Star appears to twinkle because of uneven heating of atmospheric air that results in a variation in the refractive index of air.

In this section, we will discuss about some natural phenomenon that occur as a consequence of atmospheric refraction.

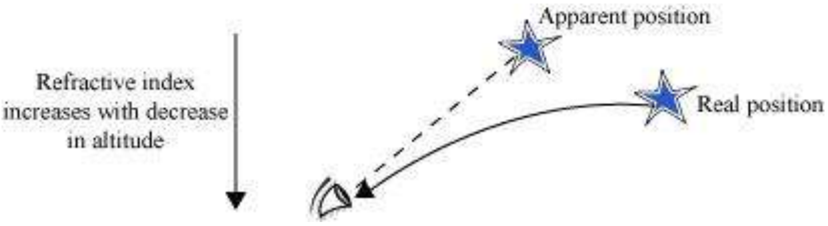
- **Flickering of objects**

Observe an object that is placed near a rising flame or fire. It will appear to be flickering. This is because the air above the fire is relatively hotter than the air further up in the atmosphere. Hence, hot air rises up and cold air moves in to fill the space. This process results in the variation of refractive index of air, present in the vicinity of fire. The refractive index of hot air, which is rarer than cool air, is less than that of cool air. The physical condition of the atmosphere changes continuously, thereby bringing a continuous change in the refracting index of air. Hence, the apparent position of the object seems to fluctuate when seen through hot air (see figure B).

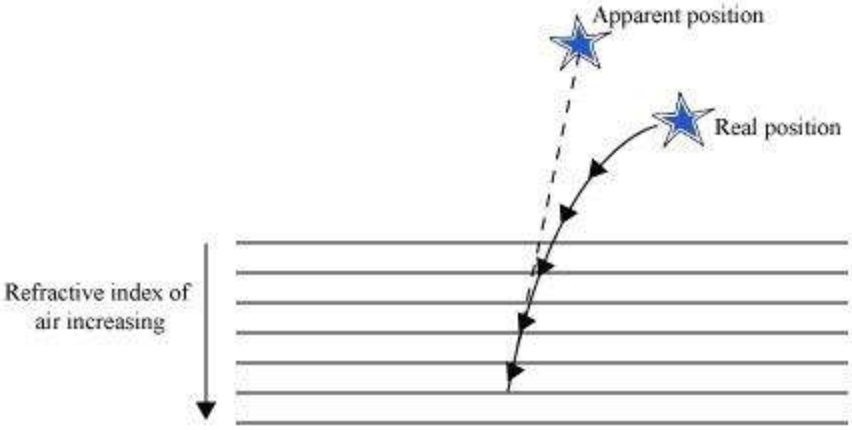


Twinkling of stars

Light coming from the stars undergoes refraction on entering the Earth's atmosphere. This refraction continues until it reaches the Earth's surface. This happens because of uneven heating of atmospheric air. Hence, the atmospheric air has changing refractive index at various altitudes. In this case, starlight continuously travels from a rarer medium to a denser medium. Hence, it continuously bends towards the normal.



The refractive index of air medium gradually increases with a decrease in altitude. The continuous bending of starlight towards the normal results in a slight rise of the apparent position of the star.



Since the physical conditions of the Earth’s atmosphere keeps changing, the apparent position of the star is not stationary. The star changes its position continuously, which makes it twinkle. This happens because starlight travels a very large distance before reaching the observer. However, the path varies continuously because of uneven atmospheric conditions. Hence, the stars seem to be fluctuating, sometimes appearing brighter and sometimes fainter. All this together, gives rise to the twinkling effect of stars.

The sun and the other planets of the solar system are relatively closer to the Earth. Thus, these are not seen as point sources like stars, but are considered as extended sources. Any variation or fluctuation of light coming from any part cancels out with each other. This results in zero fluctuation. Hence, the sun and the planets do not twinkle.

There is no twinkling effect of the sun as seen from the Earth’s surface.

What happens to its apparent position as observed from the Earth?

- **Early sunrise and delayed sunset**

As viewed from the Earth, the sun rises 2 minutes before the actual sunrise and sets 2 minutes after the actual sunset.

So, you see how we get to see sunrise 2 minutes before the actual sunrise. Similarly, after two minutes of sunset, we can still see the sun. Hence, atmospheric refraction lengthens a day by 2 + 2 = 4 minutes every day.

We define the phenomenon of sunrise as the rise of the sun above the horizon. Similarly, sunset is defined as the phenomenon of setting of the sun below the horizon.

Scattering Of Light

Do you know why the sky appears blue in colour? What causes the water, which is colourless, to appear blue in the ocean? What do you think about the red colour of the sun at sunrise and sunset?

These natural phenomena are governed by the scattering of sunlight through suspended air particles present in it from random directions. Scattered sunlight may be white or of any component of the seven colours, depending on the size of the particles that cause the scattering. This phenomenon is governed by the **Tyndall effect.**

Tyndall effect

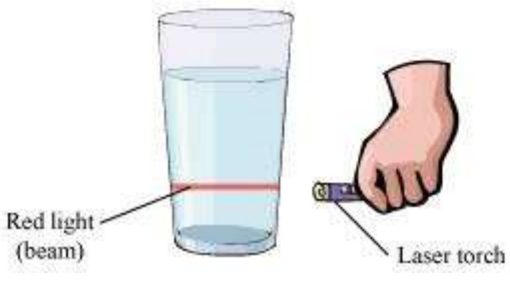
The Tyndall effect is caused by the scattering of light by very small air particles, which are suspended in the Earth's atmosphere. To observe the Tyndall effect, the particles diameter should be less than $\frac{1}{20}$ th of the wavelength of the light used.

This effect can be seen when light enters through a hole in a dark room filled with dust particles.

Have you looked at light rays coming through clouds, holes, or headlight beams during a foggy night?

These are some well known examples of the Tyndall effect.

John Tyndall (1820-1893) was one of the most distinguishing physicists of the 19^{th} century. He was the first person to explain the reason behind the appearance of sky as blue. The Tyndall effect, named after him, shows that light is scattered by the particles of the medium. His other contributions are in the field of geology and physics.



Take few mL of milk in a transparent glass and dilute it with water to make it clear. Now, take a laser torch and point the beam through the solution. Observe the solution.

Does the path of laser beam become visible in the solution? Why?

You are able to see the path of laser light because of the scattering of laser beam by the suspended particles of milk in the solution. This is another example of the Tyndall effect.

The colour of the scattered light depends on the particle size.

- Fine particles mainly scatter blue light.
- Large particles scatter red light.

- It is observed that blue colour light scatters more easily than red colour light. This is because red colour light is of a longer wave length.

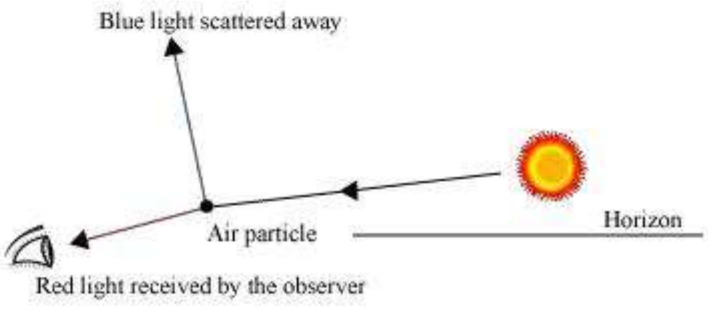
Some natural phenomena related to the Tyndall effect

If there was no atmosphere on the Earth, there would no scattering of light. Hence, in deep space, the sky will appear to be dark.

The least scattering red colour light finds its application in various fields. For example, in marking red light, danger signals etc. red colour is preferred because it is scattered least by fog, smoke, and dust particles present in air.

2. Sunrise and sunset

At sunrise or sunset, the sun is located near the horizon of the Earth. Hence, light has to travel a long distance through the Earth’s atmosphere. At the time of sunrise or sunset, when white sunlight falls on suspended atmospheric particles, blue colour light scatters out in deep space, while red colour light scatters less, and reaches the observer on the surface of the Earth. Hence, when this less scattered red light reaches our eyes, the sun and its surroundings appear to be reddish.



When located overhead, why does not the sun appear reddish in colour?

This is because light travels a relatively shorter distance when located overhead. Because of this reason, scattering of blue as well as red light is much less when the sun is near the horizon.

When there is no impurity present in air, the colour of the sun at sunrise and sunset appears to be yellowish. Due to the presence of salt particles in air over seas and oceans, the colour of the sun at sunrise or sunset appears to be orange.

- Due to the presence of red iron-rich dust, the sky appears red from the Martian surface. All these natural phenomena take place due to the scattering of sunlight