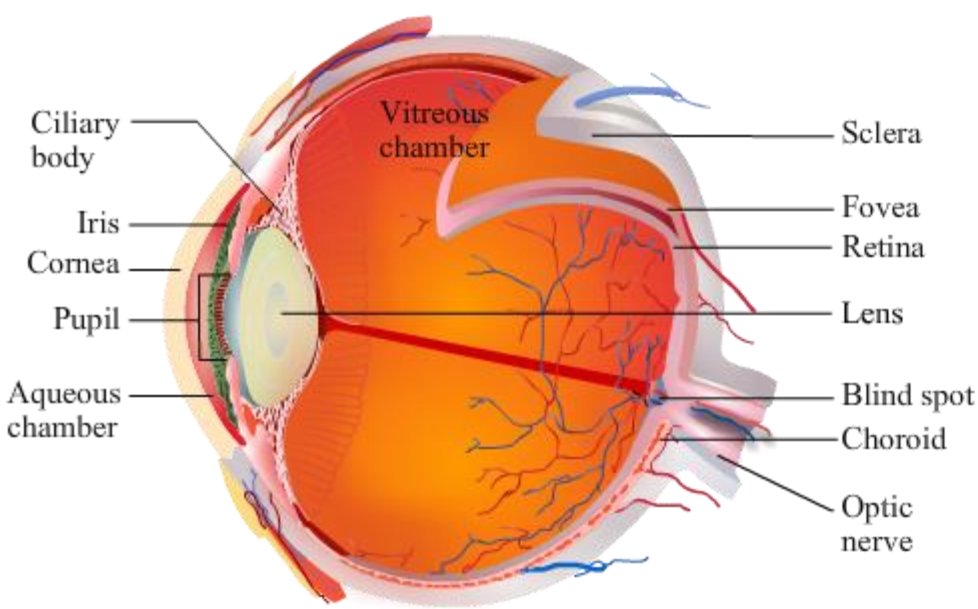
The Human Eye and the Colourful World

Human Eye

We are able to see things with the help of our eyes. The Eye is one of the most important sense organs. Let us see the structure of our eye.

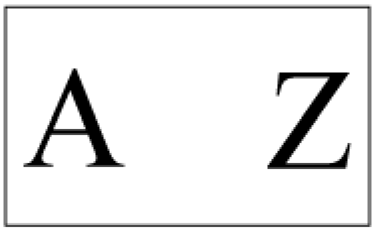
The Shape of the eye is roughly spherical with an average diameter of around 2.3 cm. The outer part of the eye is quite tough and white in colour. This white part of the eye is known as **sclera.** The transparent, front outer covering of the eye is known as the **cornea**. Behind the cornea, there is a colored membrane known as the **iris**. It regulates the amount of light entering the eye. It also gives colour to the eye. In the iris, there is a variable sized, black circular opening known as the **pupil**. Its size is controlled by the iris. It appears to be black in colour because most of the light entering it is absorbed by the tissues, which are present in the pupil.

The size of the pupil depends on the brightness of light. It opens and closes in order to regulate and control the amount of light entering the eye. When we enter a dimly lit room, it takes the iris some time to expand the pupil to allow more light to enter the eye. For this reason, it takes us a few seconds to clearly see objects in a dimly lit room



Behind the pupil there is a lens which is thicker at the centre. It is made up of **living cells**. Two **Ciliary muscles** hold the lens within the eye-ball. The eye lens being convex in nature converges the light rays' incident on it. Hence, it focuses the light falling on it on a thin layer of nerve cells called the **retina.** The retina is made up of a large number of nerve cells. Light falling on these nerve cells stimulate two kinds of sensitive cells known as **cones** and **rods**. Rods are sensitive to low light levels. Cones are sensitive to bright light, but they sense colours. Sensation felt by them is transmitted to the brain in the form of electrical signals through the optic nerve. This allows us to see.

The point where the retina and the optical nerve meet each other is devoid of any sensory cells. Hence, vision is not possible from this point. This point is known as the blind spot.



Take a white sheet of paper and write the alphabets **'A'** and **'Z'** on it (as shown in the give figure). Make sure that both alphabets are separated by atleast 8 cm. Now, close your right eye and look continuously at **'Z'**. Simultaneously, move the paper sheet slowly towards your eye. You will observe that the letter **'A'** disappears at some point. **What does this indicate?**

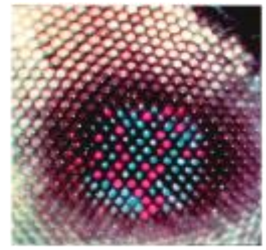
It indicates that there exists a spot on the retina where no images are formed. Perform the same activity by closing your left eye and looking at letter **'A'**. This time the alphabet **'Z'** would disappear. This implies that the blind spot is situated rightward in the right eye and leftward in the left eye.

The natural tendency of the iris and the pupil to contract and expand respectively, when exposed to bright light is used to check an unconscious person. Paramedics use this by shining a torch light in the eyes of an unconscious person to observe whether his/her iris or pupil is showing any change or not.

Persistence of an image

The image formed on the retina persists for about $\frac{1}{16}$th of a second. This means that if you are shown still pictures of a moving object at a rate faster than 16 pictures per second, then the object will appear to be moving. This is because, the image of a picture stays on your retina for $\frac{1}{16}$th of a second and you will not be able to recognize the time taken to change these pictures. This method is used in motion pictures where a large number of pictures are flashed at a rate of 24 images per second! Hence, they appear to be moving.

Do You Know:

Animals use their eyes in a special way. Crabs have very small eyes, which are located on the head. This helps a crab to look behind. Butterflies have a large number of eyes. An Owl's eye is composed of a large numbers of rod cells and a very few number of cones on the retina. Hence, it is not able to see in daylight.	 Butterfly eye

Do you know what happens if the image of an object does not form on the retina of an eye?

One will not be able to see clearly. The retina consists of photosensitive cells, which sends electrical pulses to the brain via the optic nerve. This enables us to see and sense objects.

Eye defects

We can see distant objects as well as the objects near us. The minimum distance up to which an eye can see clearly and distinctly without any stress is called the **least distance of distinct vision.**

The least distance of distinct vision for a normal eye is 25 cm.

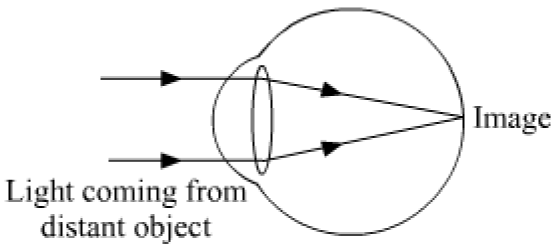
The least distance of distinct vision varies as we grow older or because of some disease. This leads to many eye defects. For example, some people are able to see distant objects clearly; however they face problems in looking at objects close to them. On the other hand, some people can clearly see objects close to them, but face problems in looking at distant objects. These eye defects can be corrected by using suitable lenses (convex lens for the first defect, and concave lens for the second defect).

Sometimes with the passing of age, the eye lens can become cloudy and opaque. Due to this, the person's eyesight becomes foggy. This defect is known as **cataract**. In this defect, a white spot can be seen in the eye lens. This type of a defect is corrected by surgery, by removing the opaque lens and installing an artificial lens.

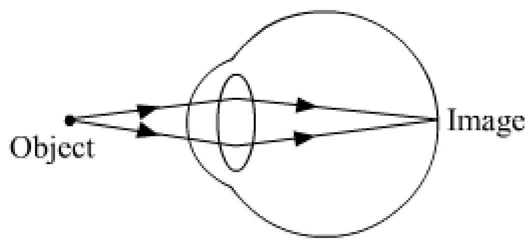
Defects of Vision

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?

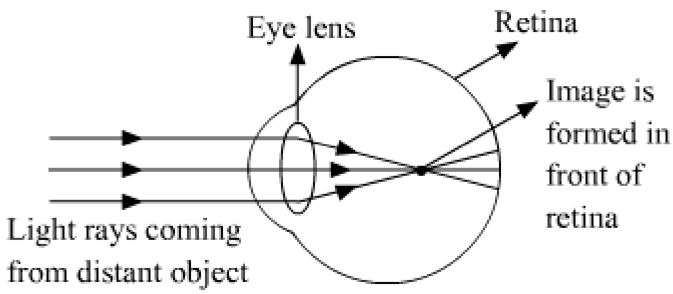
This is because it provides them with the widest possible field of view. Our eyes are located in front of our face. One eye provides 150° wide field of view while both eyes simultaneously provide 180° wide field of view. It is the importance of the presence of two eyes as both eyes together provide the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

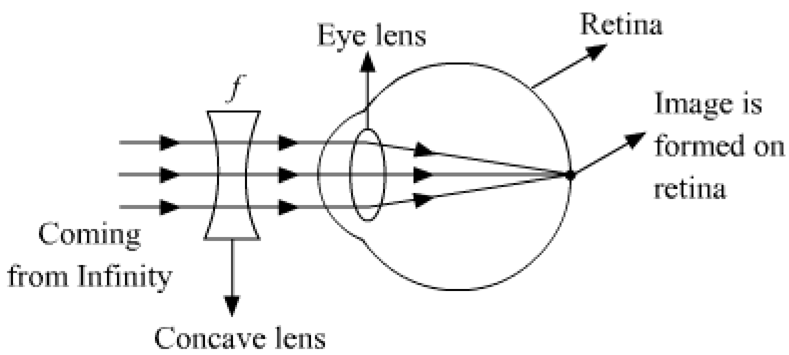
Myopia is a defect of vision in which a person clearly sees all the nearby objects, but is unable to see the distant objects comfortably and his eye is known as a myopic eye. **A myopic eye has its far point nearer than infinity. It forms the image of a distant object in front of its retina** as shown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

∴ Focal length, f = –- 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

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

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

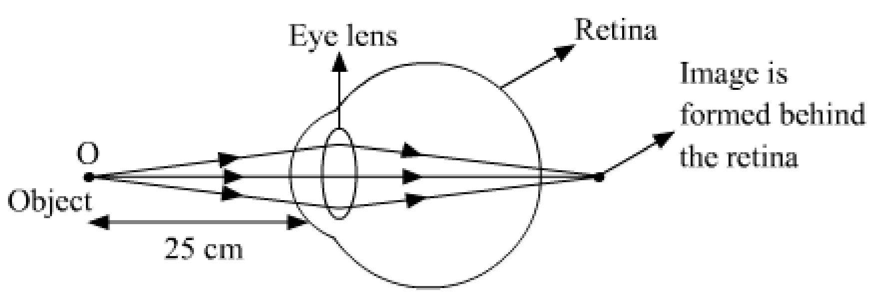
Hence, a concave lens of power −1 D is required to correct the given defect of vision.

2. Hypermetropia (Long sightedness)

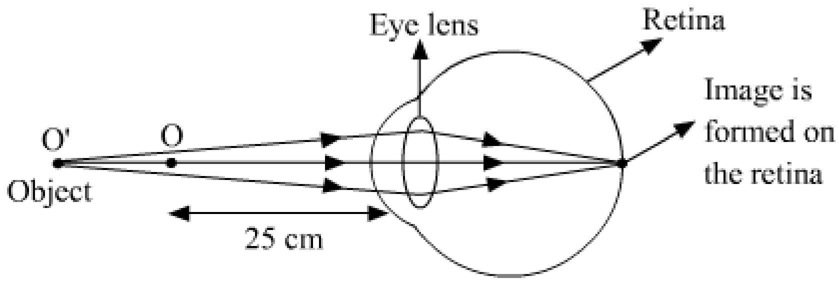
Hypermetropia is a defect of vision in which a person can see distant objects clearly and distinctively, but is not able to see nearby objects comfortably and clearly.

You know the definition; now let us see what actually happens in case of a hypermetropic eye and its corrective measure.

So, now you can easily represent the problem with a hypermetropic eye 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.

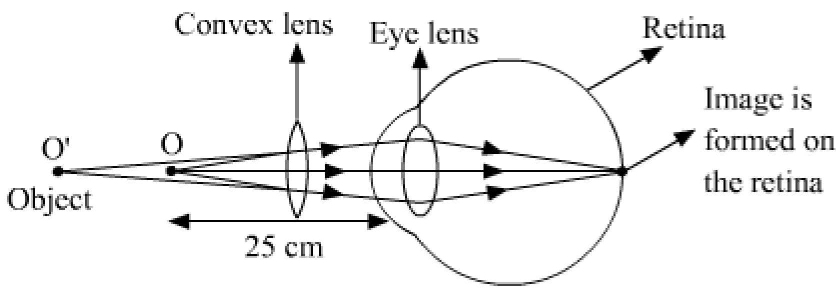


Hypermetropia is caused due to

1. reduction in the curvature of the lens

2. decrease in the size 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

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

Now, $-\dfrac{1}{f(\text{in m})}$

Power of the required lens (P) =

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)

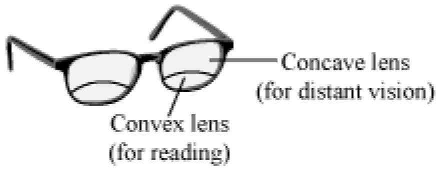
Presbyopia is a common defect of vision, which generally occurs at old age. A person suffering from this type of defect of vision cannot see nearby objects clearly and distinctively. A presbyopic eye has its near point greater than 25 cm and it gradually increases as the eye becomes older.

Presbyopia is caused by the

1. weakening of the ciliary muscles

2. reduction in the flexibility of the eye lens

Let us see how a presbyopic eye is actually different from a normal eye.



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).

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.

Cataract

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.

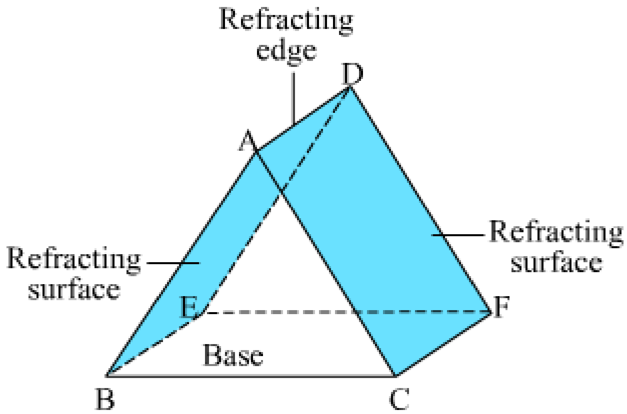
Dispersion of White Light in Prism

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).

Prism

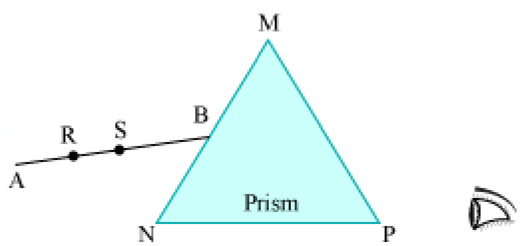
A transparent refracting medium which is bounded by five plane surfaces and having a triangular cross section is known as prism.



Refraction of light through a glass prism

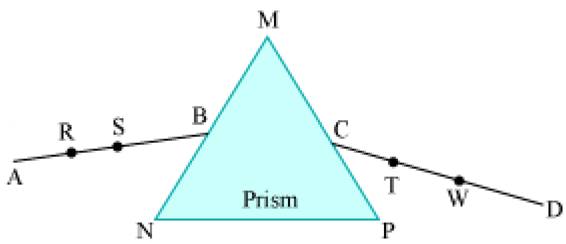
To observe the refraction of light through a glass prism, we can perform the following activity.

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.

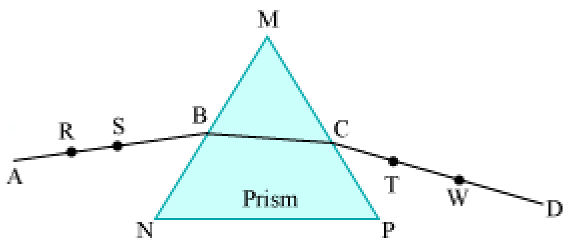


Now, observe the pins **R** and **S** through the other side of the prism. Move your head laterally to see the two pins **R** and **S** in a straight line. Fix a pin on the sheet near the prism on your side and mark it as **T**.

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

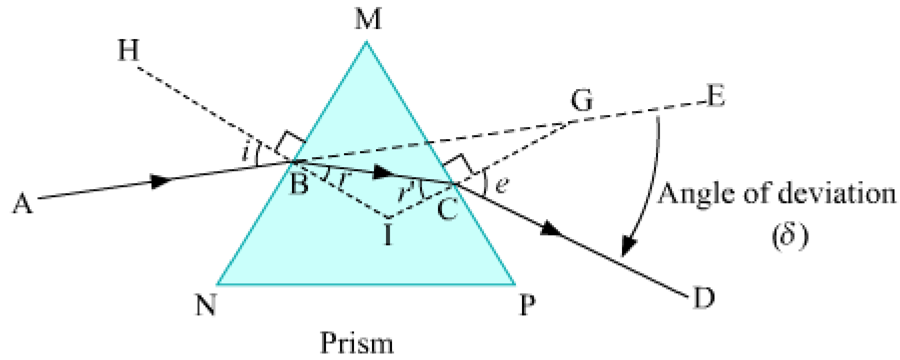
Line CD = Emergent ray

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 **HI** at point **B** and follow the path **BC**. Again, it bends away from the normal **GI** 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).

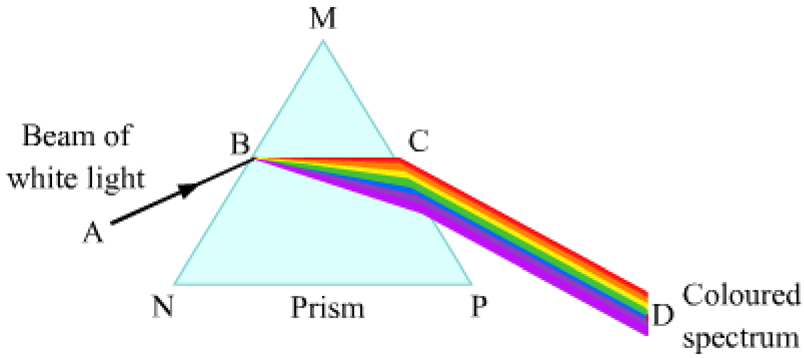
Do you know what happens when you take white light as incident ray instead of single ray?

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?

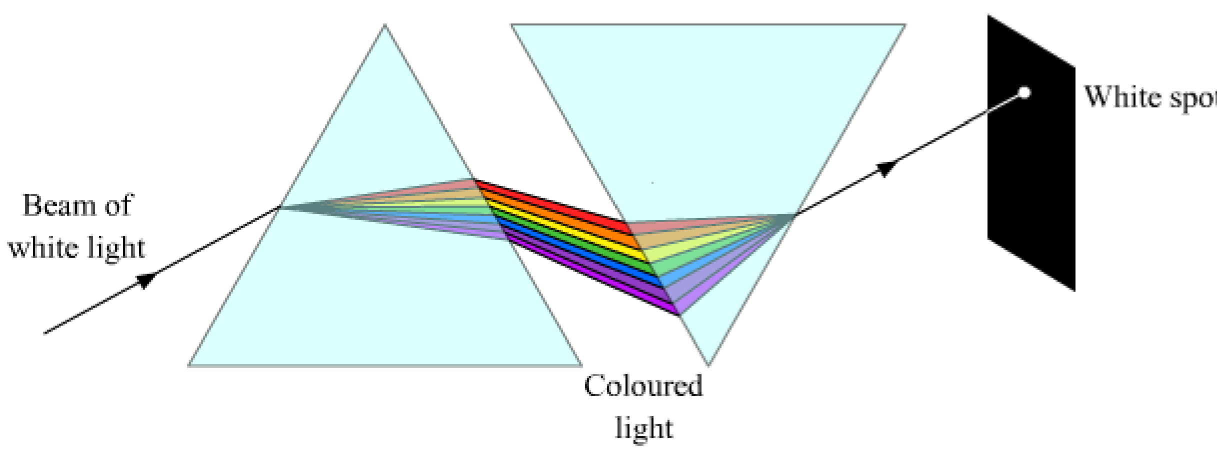
When a beam of white light AB enters a prism, it gets refracted at point B and splits into its seven constituent colours, viz. violet, indigo, blue, green, yellow, orange, and red. The acronym for the seven constituent colours of white light is VIBGYOR. **This splitting of the light rays occurs because 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.

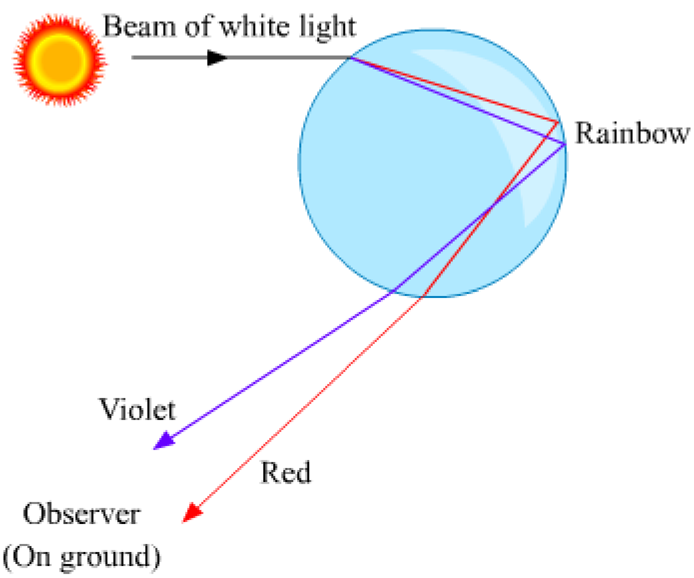
However, Newton did not stop at this point. He thought that if seven colours can be obtained from a white light beam, **is it possible to obtain white light back from the seven colours?**

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.



Let us see how a rainbow is actually formed.

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 temperature variation 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

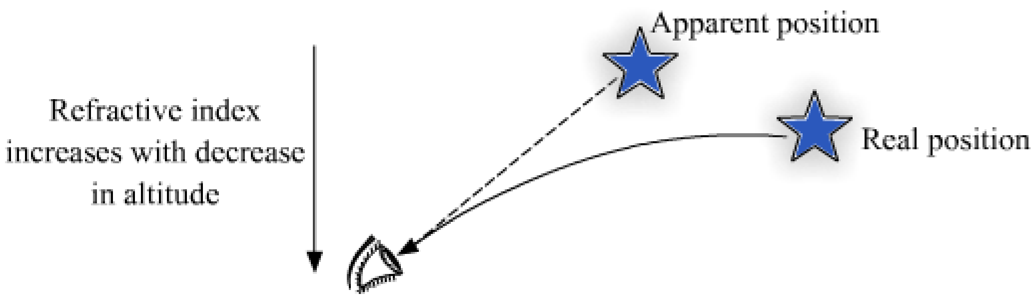
Observe an object that is placed near a rising flame or fire. It will appear to be flickering. This is because the air above the fire is relatively hotter than the air further up in the atmosphere. Hence, hot air rises up and cold air moves in to fill the space. This process results in the variation of refractive index of air, present in the vicinity of fire. The refractive index of hot air 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).

Figure A Figure B

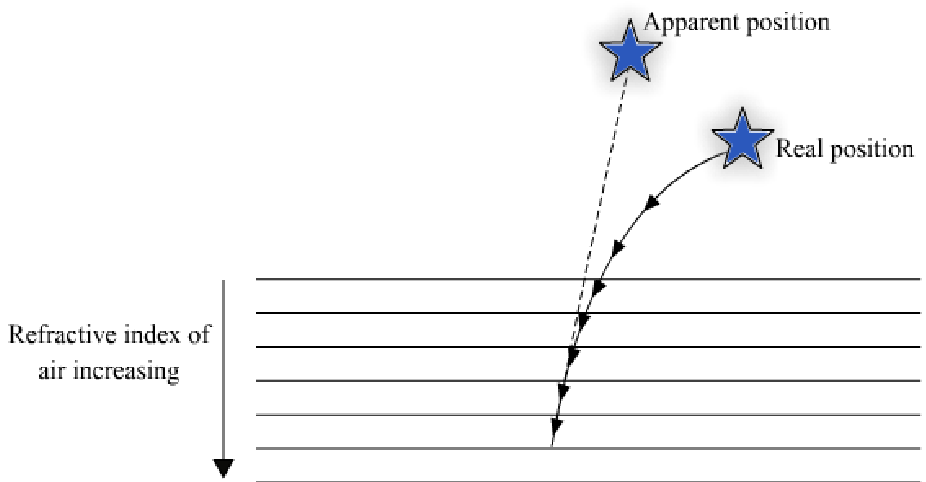
Original object Object as seen through hot air

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 temperature variation 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

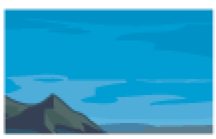
As viewed from the Earth, the sun rises 2 minutes before the actual sunrise and sets 2 minutes after the actual sunset.

So, you see how we get to see sunrise 2 minutes before the actual sunrise. Similarly, after 2 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**.

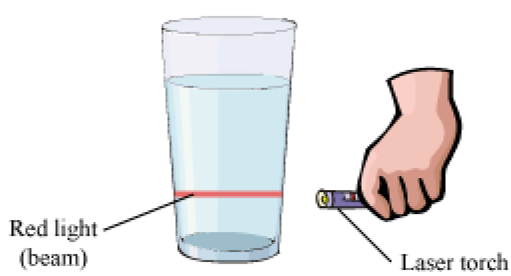
Tyndall effect

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.

Do You Know:

John Tyndall (1820-1893) was one of the most distinguishing physicists of the 19th 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 appear cloudy. 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?**

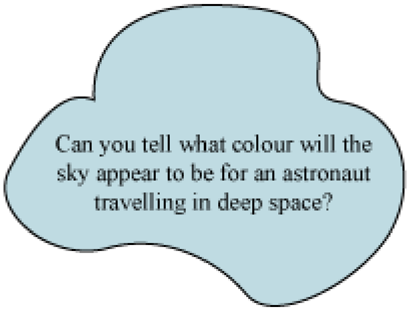
You are able to see the path of laser light because of the scattering of laser beam by the suspended particles of milk in the solution. This is another example of the Tyndall effect.

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

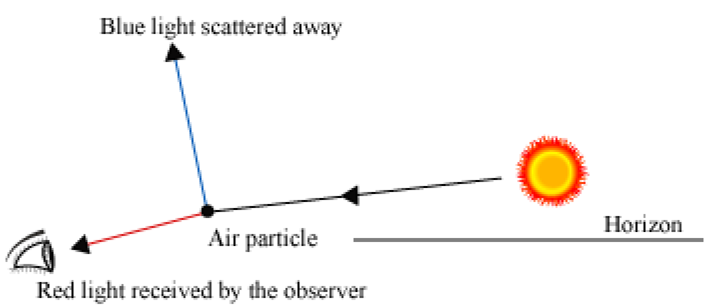


If there was no atmosphere on the Earth, there would no scattering of light. Hence, in deep space, the sky will appear to be dark.

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 located overhead.

Do You Know:

- 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