# 9 REFRACTION OF LIGHT

You know that any plane mirror will form a single reflected image. In your previous class you have made kaleidoscope. Take two plane mirrors, set them at right angles to each other with their edges touching. Place an object like a candle between them. Guess, how many images would be seen? Do this activity yourself or with your friends.

Now place the mirrors at different angles as $45^o$, $60^o$, $120^o$, $180^o$ and place a candle or any object between the mirrors. Note the number of images formed in each situation. Finally, place the mirrors parallel to each other. Now see how many images are formed. Placing the mirrors at different angles makes the formation of many images (multiple image formation) which is used to make different patterns. This is used in textile industry in making designs.

You know that when the rays of light fall on any shiny surface, they are reflected. According to the laws of reflection, the angle of incidence is always equal to the angle of reflection and the ray of incidence, the ray of reflection and the normal at the point of incidence all lie in the same plane. Can you tell what happens when light rays pass through water?

## 9.1

We can see through transparent materials as air, water, glass etc. because light rays can easily pass through them. Such transparent material are called optical media. These media can be as dense as glass and water and thin or rare as air.

Let us see what happens when a light ray passes from one optical medium to another optical medium.

### Activity 1

**Materials required:** One cardboard, glass, water, pin and a spoon of milk, torch.

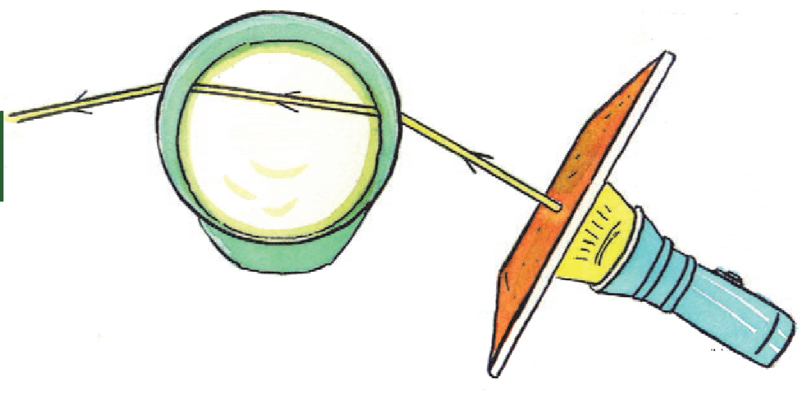


Fig 9.1 Bending of light rays in change of medium

Fill the glass half with water and mix milk in it. Water becomes milky. With the help of a pin pierce a hole in the cardboard. Now place the cardboard over a lighting apparatus (torch) such that the light passes through the hole and touches the water in the glass. On seeing from above the glass, you will find that the light is passing through the milky water in the glass. Observe clearly the line of light ray which passes through the glass. Do you find any change in the rays (fig 9.1)?

When light passes from one optical medium (air) to another optical medium (milky water) we find the ray bend at the contact point of the two media. Bending of light rays due to change of media is called refraction of light.

## Activity - 2

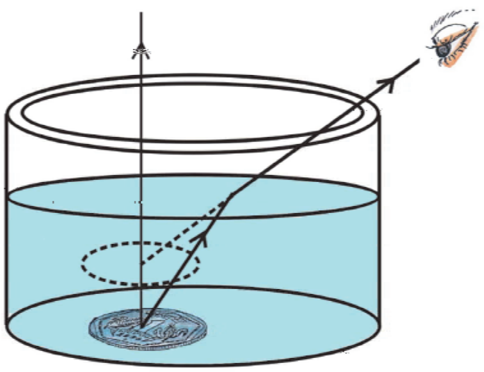


Fig 9.2 Coin appears to be raised from the bottom

**Materials required:** A bowl, a coin, a glass of water.

Place the coin in a bowl. Stand a little away from the bowl and try to observe the coin with one eye. Now adjust yourself such that the coin disappears.That is the light rays coming from the coin is stopped by the walls of the bowl and doesnot reach you (fig 9.2).

Now stay in the same position and ask your friend to fill the bowl with water slowly so that the coin is not disturbed. You must also not move and keep your neck and eyes as it is.

Do you now see the coin? Till now the light rays from the coin was stopped by the walls of the bowl. Now what happens is that when the bowl is filled with water you could see the coin. How?

Of course, it is due to refraction. On filling the bowl with water the light rays from the coin, on reaching the surface of the water get refracted (bend) and could reach your eyes and you could see the coin. The assumed path of light rays are shown in fig 9.2.

## 9.1.1 Refraction of light through a glass slab

## Activity - 3

**Materials required:** Glass slab, a plain mirror, black sheet of paper, a white paper, blade or scissors, scale, protractor, rubber band.

Cover the mirror with black paper and make a small hole on it. Now place the white paper on a table or flat surface in such a way that the sun rays reflected by the mirror passes through the hole in the black paper & falls on it. If you shade the white paper you could see the ray more clearly.

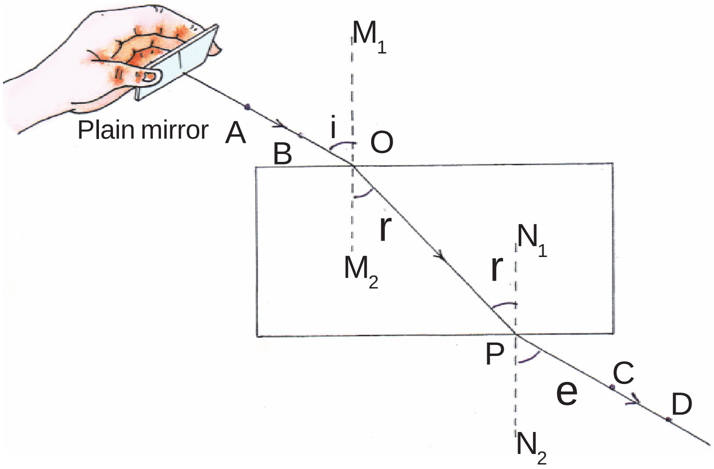



Fig 9.3 Refraction through a glass slab.

Now place the glass slab on the white sheet in such a way that the light rays fall on its length. Draw the outline of the glass slab on the paper and mark the point of the incidence. According to fig 9.3 mark the incident ray as AB and the point of incidence as O and draw a perpendicualr normal $M_1$, $M_2$ at O to the glass slab.

Now place the glass slab back at its place and with the help of plain mirror point the rays at O through line AB. On placing the plane mirror at the correct place, you will find the ray of light passes through the glass slab in a straight line to the point P and from there it gets refracted to air again and forms the path CD. Keeping the incident ray stable, ask your friend to mark point P and the outgoing rays at C and D. Now remove the slab and join point O and P. Join P and C also. Also draw a perpendicular $N_1N_2$ at P point to the glass slab. Your figure will be similar to fig 9.3.

This figure tells us that the incident ray AB when it enters the glass from air at O bends towards the perpendicualr normal $M_1M_2$ and goes further as the refracted ray OP. This ray OP goes into the air medium again or comes out as CD from the glass slab. Second time at point P the line OP becomes incident ray and CD the outcoming refracted ray which moves away from the perpendicualr normal $N_1N_2$. So by this activity we see the light rays refrects twice from air to glass and from glass to air. And it also shows the effect and direction change. In this condition air is a rarer medium and glass is a denser medium.

## Observe the figure of the experiment and answer these

1. When light travels from a rarer medium (air) to a denser medium (glass) the refracted ray bends in which direction - towards the perpendicular normal or away from it?
2. When light travels from a denser medium glass to a rarer medium (air) the ray bends towards the perpendicular normal or away from it?

In fig 9.3 the angle $\angle AOM_1$ formed between ray AB and the perpendicular $M_1M_2$ is called the angle of incidence and is denoted by $\angle i$. In the same way the refracted ray OP and the perpendicular $M_1M_2$ makes the angle $\angle M_2OP$ is the angle of refraction and is denoted by $\angle r$.

From figure 9.3 you can understand that both perpendiculars $M_1M_2$ and $N_1N_2$ are parallel and so $\angle M_2OP$ and $\angle N_2PO$ is similar. You can confirm it by measuring the angles in the figure.

So at point P on second refraction the angle $\angle N_1PO$ will be the angle of incidence and is equal to $\angle r$ and the outgoing ray PCD form the angle $\angle N_2PD$ at point P is the refracted angle which we will denote by $\angle e$. This angle formed on the second refraction is also angle of refraction. With the help of the protractor measure $\angle i$, $\angle r$ and $\angle e$ and note them in your copy and check the conclusions given above in 1 and 2.

In this activity you can change the angle of incidence $\angle i$ and find out if the same conclusions are true or not.

## Activity - 4

You can do activity 3 in such a way that the incident ray is in the same direction with $M_1OM_2$. Does the incident ray deviate from its line after refraction?

From activity 3 and 4 you can form the definition in your own words. With the help of your teacher and your friends you can make the definition of refraction.

## 9.1.2 Refractive Index

Moving from one medium to another medium, the deviation of the incidence ray is how much and to which direction is calculated by refractive index. Refractive index is a unit to express the optical density of a medium.

$$\text{Refractive Index of any medium} = \frac{\text{Velocity of light in vacuum/air}}{\text{Velocity of light in the particular medium}}$$

Let us see a method to know refractive index.

## Activity - 5

Take the figure of activity 3. In it make a circle with point O as the centre and which cuts the incident ray at A and the refracted ray at F.

Now we have to find the distance of point A and F from the perpendicular $M_1M_2$. For this draw a line from A & F to $M_1M_2$ and name them AX and FY. You have learnt this method in mathematics in class 6. Your figure will be similar to figure 9.4.

Measure AX and FY with the help of a scale and find its ratio as AX/FY. The number got by you is the refractive index. This number is denoted by the greek word μ and is pronounced as 'miu' so ratio is μ = AX/FY (refractive index of air to glass).

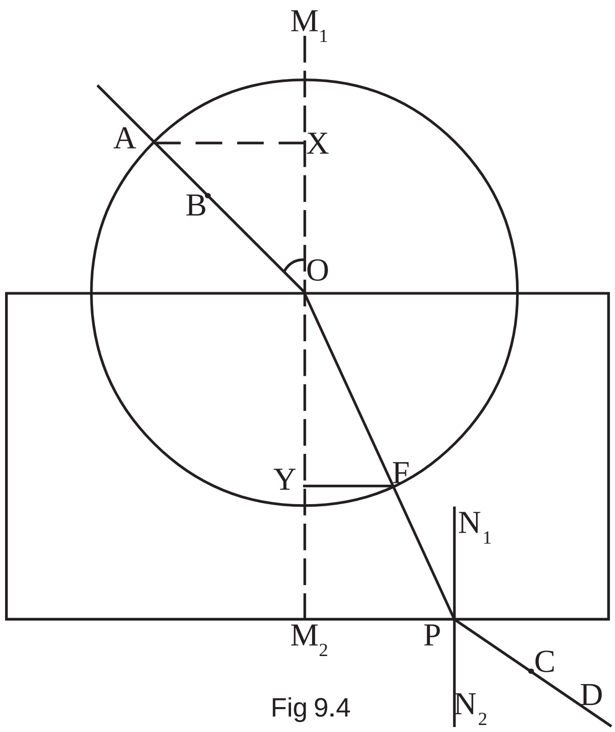



Fig 9.4

This depends on the type of glass. The refractive index is about 1.5 when light passes from air to glass. What ratio did you get from your experiment with the glass slab? Now, calculate refraction using different angle of ∠i by the same method.

You will find that refraction will be same for both the values of ∠i from air to glass i.e. refraction does not depend on ∠i (angle of incidence) but depends on the nature of both the mediums.

Using the same method you can measure the ratio of refractive index at point P and taking PD as a radius of circle. Is the number you got less or more?

On comparing the refractive indices of air to glass and glass to air you can conclude that if the refractive index is more than 1, then the light ray is moving from rarer medium to a denser medium ,it shifts towards the normal. And if the refractive index is less than 1 and the light ray is moving from a denser to rarer medium, it deviates away from normal.

## NOW ANSWER THESE

1. What changes happen to the path of light ray when it moves from denser to rarer medium?
2. If the light ray deviate towards the normal when passing from medium 1 to medium 2. What can you say about the medium being denser or rarer?
3. A light falling perpendicular to a optical medium moves in which direction?
4. Glass is denser than water. So will the refractive index of air to glass and air to water be more or less?

## 9.2 Refraction through lens

Optical medium with two surfaces with one side circular or rounded and the other side rounded or plane is called lens. These are two types of lens :-

(1) Convex lens (2) Concave lens.

The Concave and Convex lens can be classified as follows (fig 9.5).

| Convex lens | Concave lens |
|---|---|
| 1. These lenses are thick at centre and tapers to the ends. | 1. These lenses are thin at the centre and thickens at the ends. |
| 2. These lenses converge the light rays so they are also called converging lens. | 2. These lenses diverge the light rays. So they are called diverging lens. |

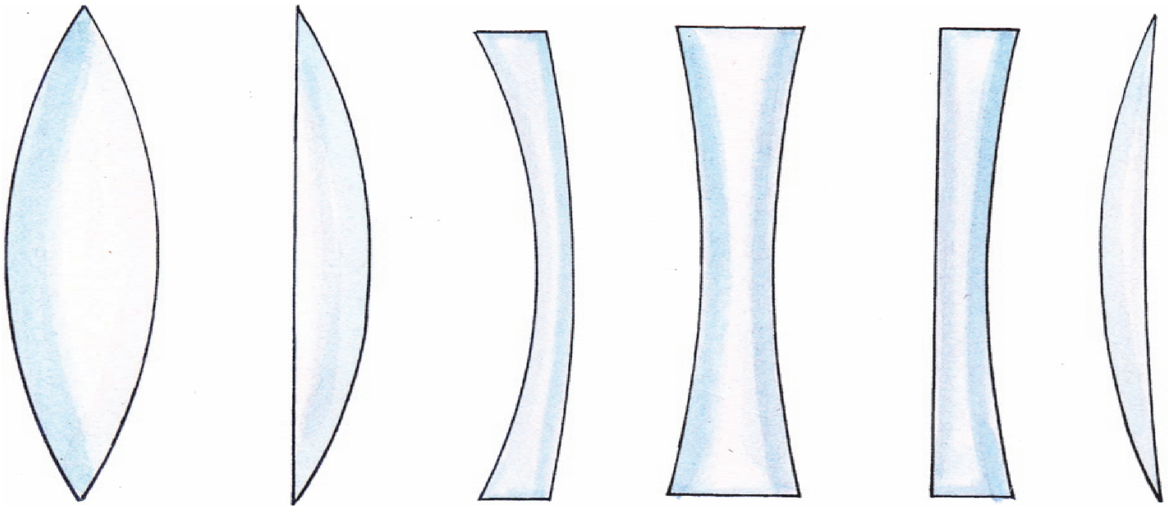


Fig 9.5 Some common shapes of lens

## 9.4.1 Some definitions used in lens

1. **Principal axis -** The line joining the centre of curvature of both the surfaces is called principal axis. ($C_1C_2$ in figure 9.6)

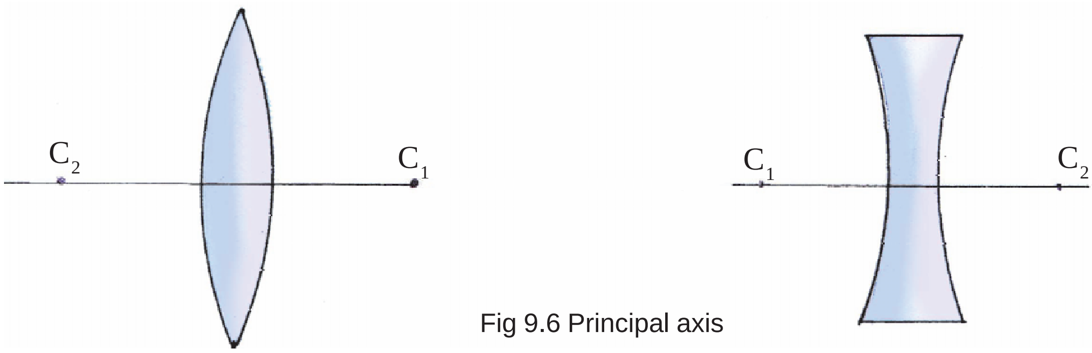



Fig 9.6 Principal axis

2. **Optical centre -** This is the centre of the lens from where rays pass (fig 9.7) without bending

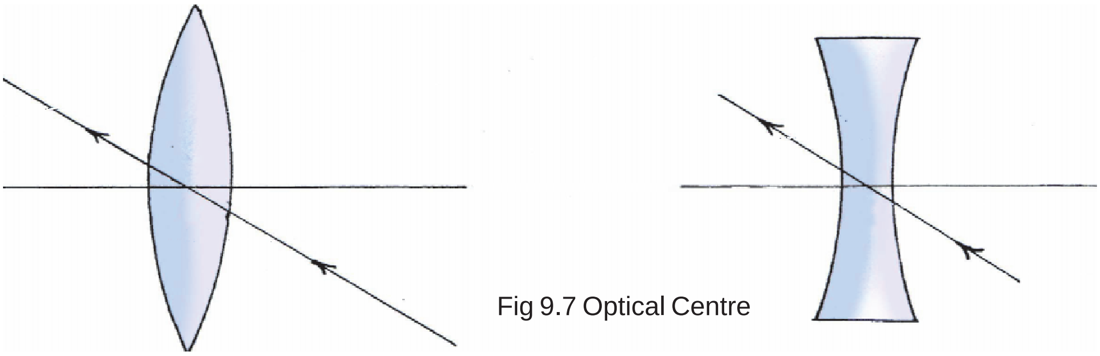


Fig 9.7 Optical Centre

3. **Principal focus -** The point at which the light rays parallel to the principal axis after passing through a lens converge (in convex lens) and appear to diverge (in concave lens) is the principal focus (fig.9.9)

4. **Focal length (f)** -It is the length between principal focus and optical centre.

## 9.2.2 Rules of formation of images by lens

1. The rays which pass through optical centre, pass without any deviation (fig 9.8).

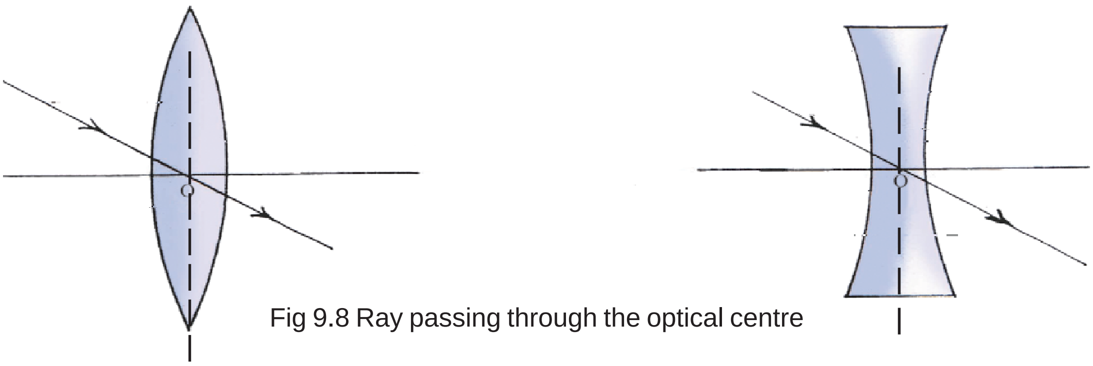



Fig 9.8 Ray passing through the optical centre

2. The rays which run parallel to the principal axis after refraction pass through the focus in convex lens and appear to pass through the focus in concave lens. (fig. 9.9)

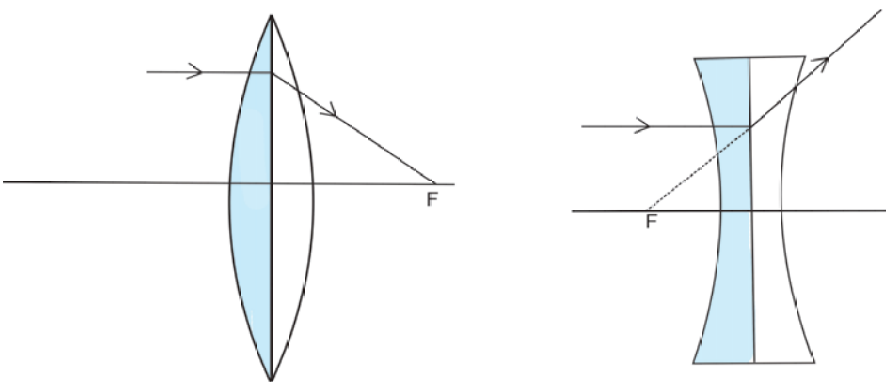



Fig 9.9 Ray coming parallel to principal axis

3. The rays which pass through the focus in convex lens or appear to come from the direction of the focus in concave lens after refraction runs parallel to the principal axis (fig 9.10).

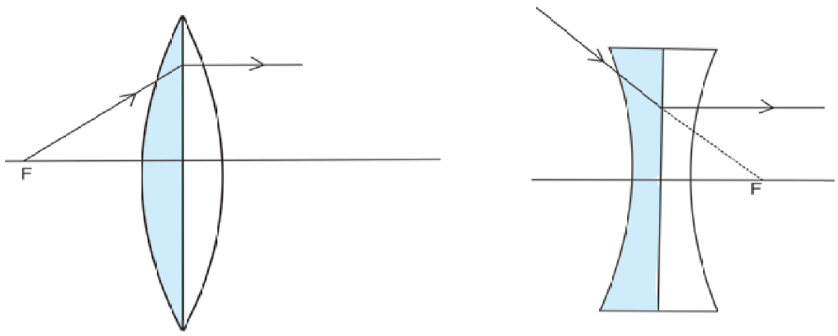



Fig 9.10 Ray coming from the focus

After knowing about lens, come let us do some activity associated with this.

## Activity - 6 (Demonstrated by teacher)

**Material required :** Convex lens, paper.

Take a convex lens and hold it perpendicular to the sun rays. With your other hand hold a paper on the other side of the lens. Adjust the position of the lens such that the rays fall as a shining dot on the paper. (fig. 9.11) If you hold the paper and lens in the same position for one or two minutes. You will find that the paper starts burning. If you use carbon paper it will burn in comparatively lesser time.

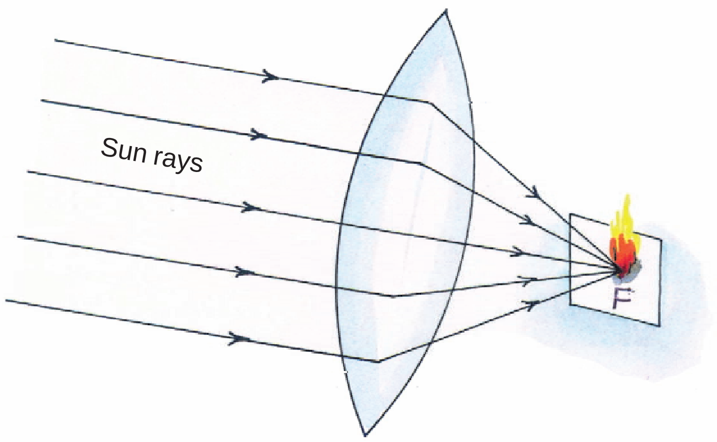



Fig 9.11

The paper placed at the focus of the convex lens burns because the sun rays are converged to that point.

## 9.2.3 Formation of images by convex lens

## Activity 7

**Materials required:** Convex lens, candle (object) Screen (Paste a white paper on a slate), three blocks of wood, match box, pins/nails.

Make a furrow on the block of wood and place the lens on it (fig 9.12) On the second block place the candle and on the third block fix the screen with pins. Arrange them according to the picture. Now adjust the screen in such a way that the candle image is brightest and most clear. You will find that changing the distance of the object as compared to the lens changes the shape, size and distance of the images.

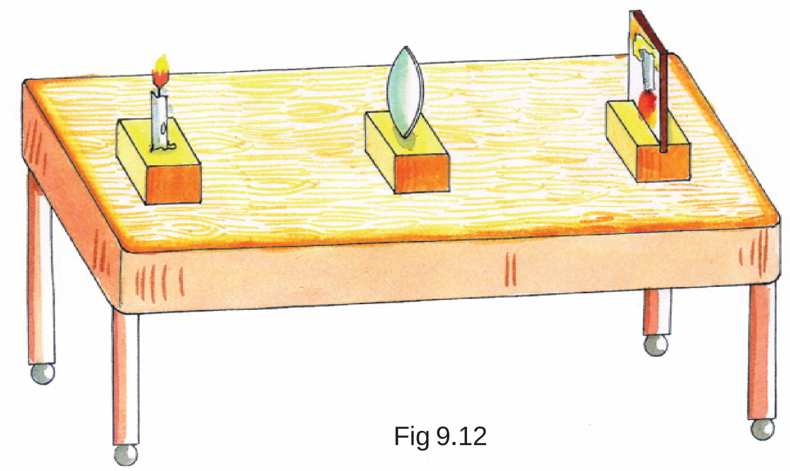
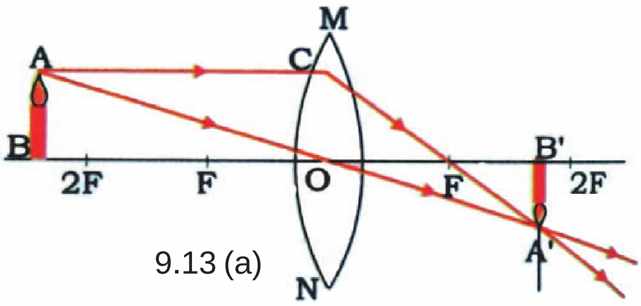
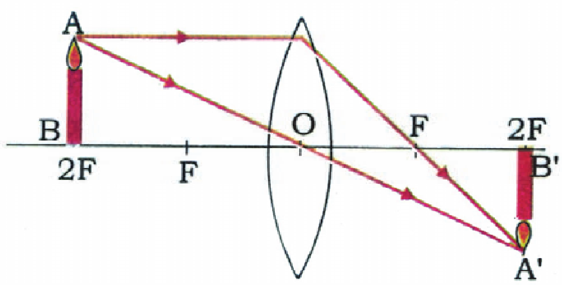


Fig 9.12

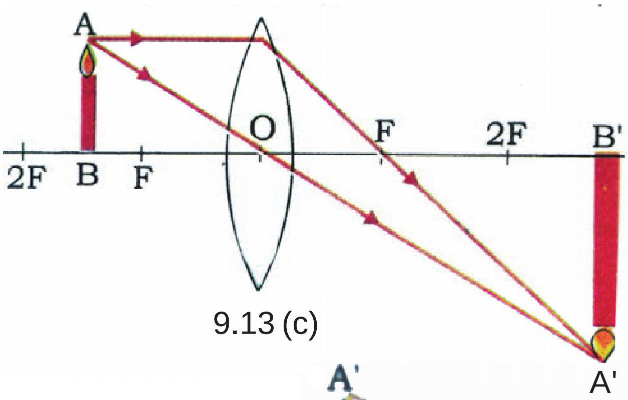
Write the different positions shape and manner of images formed at different positions in table 9.1. And compare them to the figures (9.13 a, b, c, d, e).



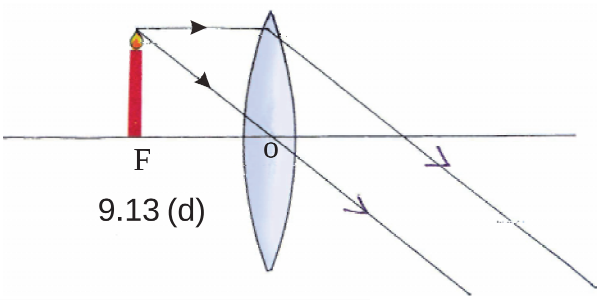

9.13 (a)



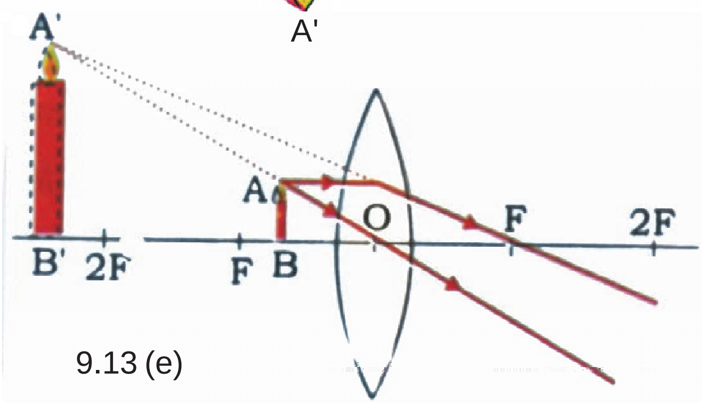

9.13 (b)




9.13 (c)




9.13 (d)




9.13 (e)

Fig 9.13 Images formed by a convex lens

## TABLE 9.1

| S.No. | Position of object | Position of image | Type of image | Size of image |
|---|---|---|---|---|
| 1. | Beyond 2F | ............... | .................. | ................. |
| 2. | At 2F | ............... | .................. | ................. |
| 3. | Between F & 2F | ............... | .................. | ................. |
| 4. | At F (focus) | at infinity ............... | real .................. | magnified (bigger than the object) ................. |
| 5. | Between F and optical centre O | ............... | .................. | ................. |

From this experiment we can obtain the following conclusions :-

1. All the real images (which forms on the screen) are inverted.
2. As the object is brought nearer to the lens, the image moves further away.
3. As the object is brought nearer to the lens the image becomes bigger.
4. When the object is too near the lens, no real image is formed.

## 9.2.4 Images formed by concave lens

In table 9.1 you have seen and learnt the different types of images formed by a convex lens. In class 7th you have learnt about the images formed by a concave mirror. You must note that mirror reflects the light rays, on the other hand, lens refracts the light rays.

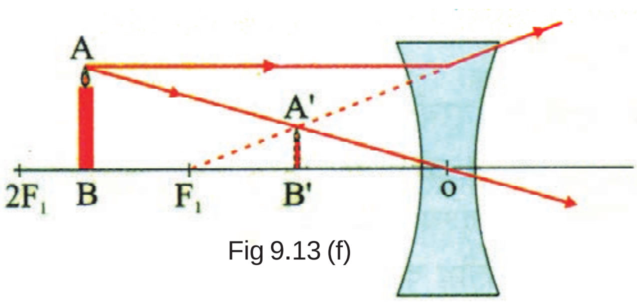


Fig 9.13 (f)

Object placed at any place/distance in front of a double concave lens makes a smaller and imaginary virtual image (fig. 9.13f)

## NOW ANSWER THESE

(1) What is a lens ? How many types of lens are there?

(2) Define - (a) Principal axis (b) Optical centre (c) Focus

(3) Write the rules about the formation of image by lens.

(4) The picture formed on the screen at the theatre hall is real or virtual?

## Activity - 8

**Material required:** Cardboard block, water, nail

With the help of a nail make a small hole on the cardboard block. Place a drop of water on this hole. If you place the cardboard in this position about 2 cm above your book and look through the hole with the water drop on it you will see the letters bigger in size.

### 9.2.3 Application of Lens

(1) **Magnifying glass -** Actually it is a convex lens. For proper handling, the lens is fixed on a frame with a handle. This is used to make small objects bigger and to get direct images. This is also called simple microscope. The eye lens used by watch repairers are also magnifying lens.

**(2) Water-lens microscope :-**

### Activity - 9

**Materials required:** Sole of old rubber slipper, saw, bolt of 2 inches, 10 cm of G.I. wire, mirror or shining plastic, fused torch bulb, candle, matches, metal pipe or metallic cap of a pen and divider of geometry box.

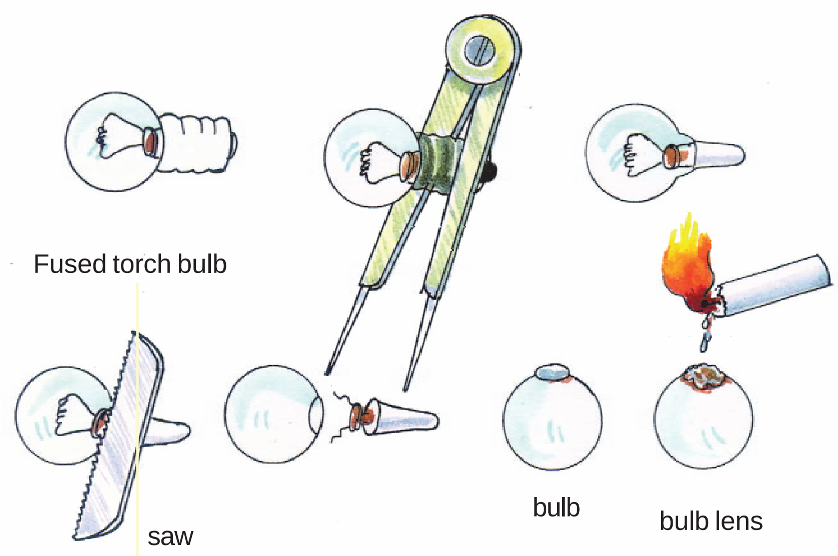



Fig 9.14 Making bulb lens

As shown in fig 9.14 remove the metallic part of the fused bulb with the help of a divider. To remove the filament cut the end of the bulb with a saw. Fill the bulb with water and seal the mouth with wax from a burning candle. See a bulb lens is ready (fig 9.14).

Now take a thick rubber sole cut a piece of 10 cm length 8-7 cm width (fig 9.15). With the help of a metallic pipe pierce 5 holes (A, B, C, D, E) As shown in the figure place the bulb lens (wax on side), mirror and bolt on the holes. Make a clip of the wire and fix as per figure 9.15. Place a millimetre graph paper or any minute thing on the stand with the clip. Now adjust the lens with the help of the bolt and enjoy observing small things in a bigger size.

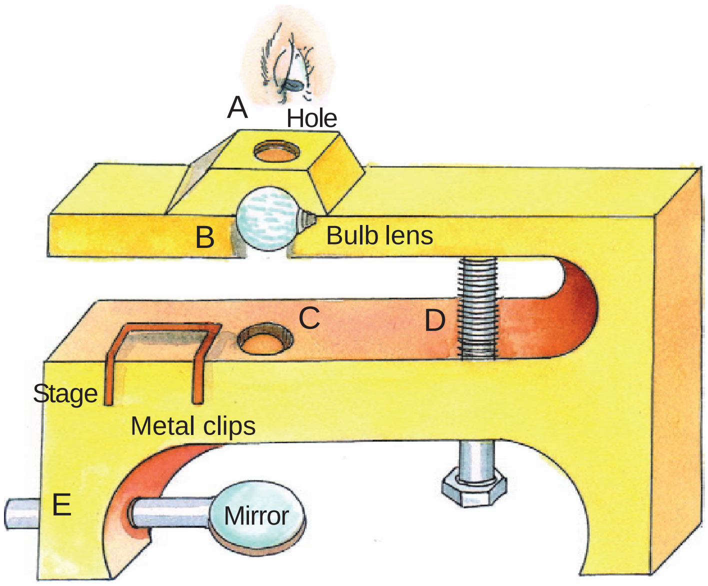



Fig 9.15 Water lens microscope

### 3. Water-lens telescope

## Activity - 10

**Materials required:** Two square or cylindrical pipes or empty boxes of incense sticks, fused torch bulb, saw, candle, matches, convex lens (about 15 cm focal length), scissors, pieces of cardsheet, pins, and divider of geometry box.

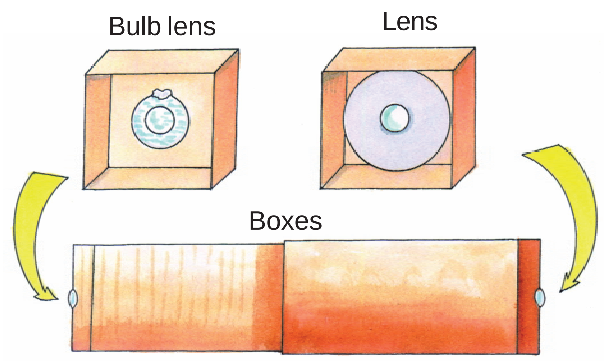



Fig 9.16 Water lens telescope

Prepare bulb lens as given in activity 9. Now take two boxes of different size or diameters. So that the smaller one can slide easily inside the bigger one (fig 9.16). Make a cardboard lid for the smaller box. Make a small hole on this lid and fix the bulb lens on it. See that the wax part is away. Now place the convex lens (about 15 cm focal length) on one side of the bigger box. Keeping 1 cm open. Paste paper on the lens and fix it on the box.

Now fix the boxes in such a way that both the lens (bulb lens and lens) are at the two ends. Keeping the bulb lens near your eyes try to observe things far away by adjusting the boxes by sliding them. The image will be inverted.

Don't forget to look at the moon through this at night and try to think of making a stand for this.

## 9.3 Human eye - A living lens

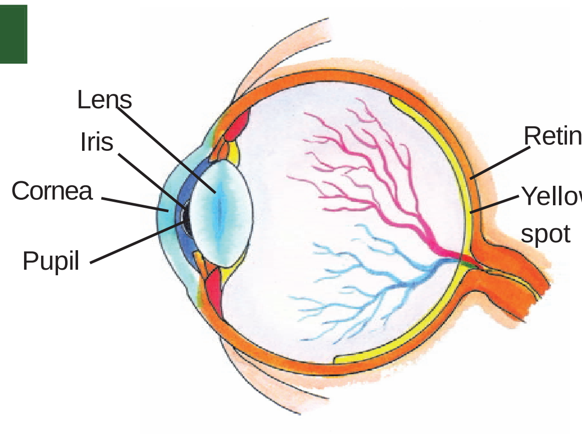



Fig 9.17 Human Eye

Human eye is spherical and the front portion is a bit bulging which is called the **cornea** (fig 9.17). Behind the cornea there is an opaque screen which is called **iris**. There is a small adjustable hole in the centre of iris, which is called the **pupil**. With the help of muscles automatically, the diameter of the pupil decreases with much light and increases when we stand in darkness. Behind this there is convex lens which is made of soft, transparent material. This is called the **lens of the eye**. In human eye the innermost part there is a transparent membrane which is called the **retina**. The real image of the object in front of person is made by the eye lens on the retina. There is spot near about in the middle of the retina which is called the yellow spot. The image formed on yellow spot is very clear.

The light rays coming from any object passes through the cornea and is refracted by the lens. After refraction the image formed on the retina is real inverted image. To get a clear image the object must be kept at minimum 25 cm distance.

## 9.4 Eye defects

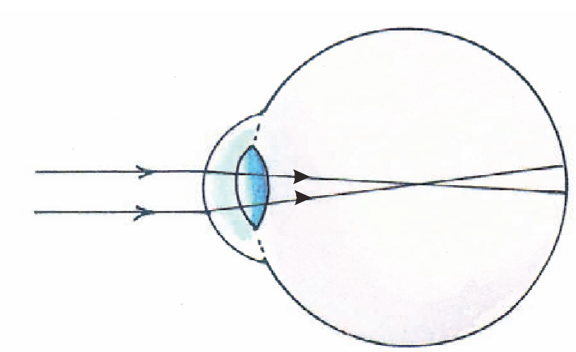


Fig 9.18 Eye with shortsightedness

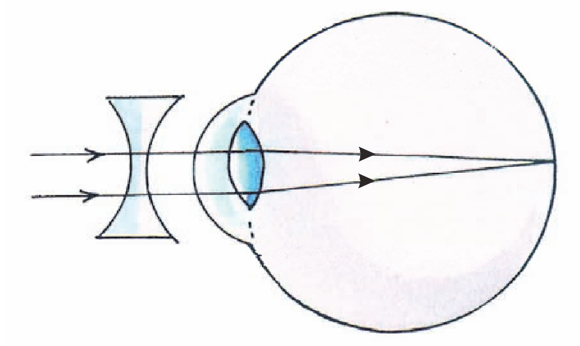


Fig 9.19 Rectification

Some persons whose eye lens are not proper cannot see things at a distance. In this the image of a far away object is not formed on the retina but at a point in front of it. This defect of eye is called **short sightedness or myopia**, (fig 9.18). This defect can be rectified by using eye lens with double concave lens . These lenses diverge the rays so that the image is formed on the retina (fig. 9.19).

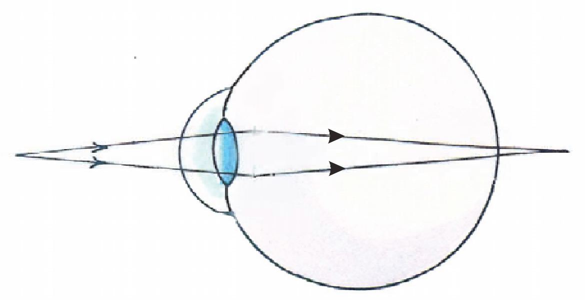


Fig 9.20 Eye with longisightedness

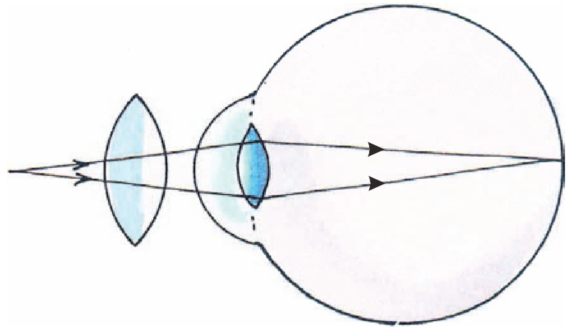


Fig 9.21 Rectification

Some person on the contrary have the opposite defect. That is, they cannot see things which are near by, because due to tension in the eye lens the focal length increases. Due to this the image of the nearby object is formed beyond the retina. This defect is known as **long sightedness or hypermetropia** (fig 9.20). This defect can be rectified by using an eye glasses with convex lens. The lens turn the rays in such a way that the rays focus properly on the retina (fig 9.21).

## NOW ANSWER THESE

1. What is the minimum distance at which a clear image can be visualized?
2. Where is the image formed in a human eye?
3. What is shortsightedness ? How can it be rectified?
4. What do you understand by longsightedness ? How can this be rectified?

## WE HAVE LEARNT

- Transparent things are called optical mediums.
- When light passes from one optical medium to another, it bends at the line of contact of the two mediums. Such bending of light rays is called refraction.
- The refraction by any medium is measured by its deviation in terms of refractive index.
- The refractive index of a medium can be more or less than 1.
- When a ray passes from a rarer medium to a denser medium it bends towards the perpendicular or normal while when moving from denser to rare medium it bends away from the normal.
- A transparent medium with two surfaces out of which one surface is spherical and the other being plain or spherical is called lens.

- Convex lens are thick at centre and thinner at the ends, where as in a concave lens it is thinner at the centre and thick at the ends.
- The line joining the centres of curvature is called principal axis.
- Optical centre - It is the centre of the lens from which the rays pass undeviated.
- The distance between optical centre and the principal focus is called the focal length.
- The rays which pass through the optical centre pass without any deviation.
- That rays which pass parallel to the principal axis after refraction pass through the focus in convex lens and appear to pass through the focus in concave lens.
- The rays which pass through the focus in convex lens or appears to comes from the direction of the focus in concave lens after refraction runs parallel to the principal axis.
- Convex lens is used in magnifying glasses, microscopes and telescopes.
- The focal length of the human eye changes automatically and the image formed by the human eye is real and inverted. To observe any object clearly the object must be at a minimum of 25 cm away.
- Short sighted person cannot see things at a distance properly. It can be rectified by using concave lens.
- A longsighted person may not be able to see nearby objects clearly. This can be rectified by using convex lens.

## QUESTIONS FOR PRACTICE

**1. Choose the correct alternative :-**

(1) The refractive index of glass is

(a) 1.5 (b) 1.3 (c) 2.4 (d) 1.0

(2) The point from which a light ray passes without any deviation is the-

(a) Focus (b) Optical centre

(c) Focal length (d) Centre of curvature.

(3) When light passes from one medium to another, it deviates from its path. This is called :-

(a) Reflection of light (b) Irregular reflection of light

(c) Refraction of light (d) None of these

(4) When the object is placed at 2F. The image formed by a convex lens will be at :-

(a) 2F (b) F

(c) Between F and 2F (d) Between F and optical centre.

**2. Match the following :-**

| **Object placed at** | | **Image formed at** | |
|---|---|---|---|
| 1. | At F | 1. | Between F and 2F |
| 2. | Between F and 2F | 2. | On the side of the object |
| 3. | Beyond 2F | 3. | at infinity |
| 4. | Between F and Optical centre | 4. | Beyond 2F |

**3. Answer the following questions -**

(1) What do you understand by refraction?

(2) When the light ray enters water medium through glass medium, where will it deflect - towards normal or away from the normal?

(3) What do you understand by refractive index of a medium?

(4) Draw a ray diagram when the object is placed between optical centre and principal focus of a convex lens.

(5) What is longsightedness ? How can it be rectified ? Explain with diagrams.

(6) Explain with the help of an activity that the incident ray the normal at the point of incidence and the reflected ray all lie in the same plane

## TRY TO DO THIS ALSO

1. Cut and remove the filament part of any fused bulb. Now fill the bulb with water. Now say what type of lens would this be. Try to find its focal length by using sunrays. Now fill this bulb with kerosene, coconut oil and glycerine in place of water. Try to find their focal length and compare all.
2. With the help of your school community organize an eye testing camp.