UNIT 6

LIGHT

Unit outcomes: After completing this unit you should be able to:

- ✓ understand concepts related to light.
- ✓ develop skill of manipulating problems related to light.
- ✓ appreciate the interrelatedness of all things.
- ✓ use a wide range of possibilities for developing knowledge of the major concepts with in physics.

6.1 What is Light?

Activity 6.1

- Describe what light is. What sense organ do you use to see light?
- Explain different sources of light.
- How does light travel from its source to your eyes?

We are sometimes afraid to walk in the dark, because we cannot see our surrounding. The greater part of what we know about the world around us is the result of our vision. Light helps us to see things around us by producing a sensation of sight through our eyes and brain. Fig 6.1 shows a boy seeing his cattle using the sun light and his eyes.

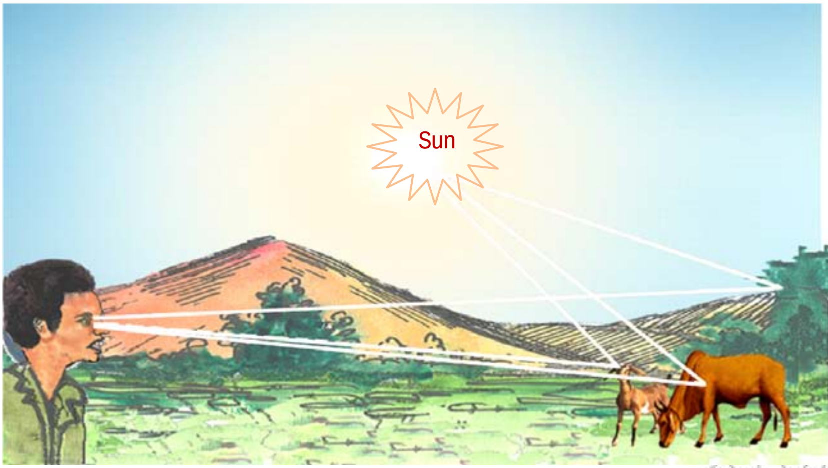


Fig. 6.1 Light helps us see things around us

The branch of physics which studies the nature, properties and all other aspects of light is called optics.

How does light also affects our life? Light helps us see things around us. It also makes plants to grow and produce the food we eat. Plants store energy which is produced from the sunlight. This stored energy is converted to fuels such as charcoal and fire woods.

Light is an electromagnetic wave which is emitted from a hot body. It produces sensation of sight on human eyes. To produce light, some other forms of energy have to be converted to light energy. For example, in an electric lamp electrical energy is changed to heat and light.

What are the sources of light?

The sources of light are bodies which generate and emit light energy of their own. These bodies are called *luminous bodies*. For example, the sun, fire, burning lamps and burning candles are luminous bodies. They are sources of light.

Most bodies do not generate light of their own. Such bodies are visible only when they receive light from some luminous body and reflect it to our eyes. Bodies on which light is falling are called **illuminous bodies**.

For example a wall, a person, a tree, a book, the moon and mountains are illuminous bodies. Why is not the moon the source of light?

Check point 6.1

1. **What is light?**
2. **Describe luminous and illuminous bodies. Give examples for each of them.**
3. **Name some local sources of light in your area.**

6.2 How Does Light Travel?

Activity 6.2 Observing how light travels.

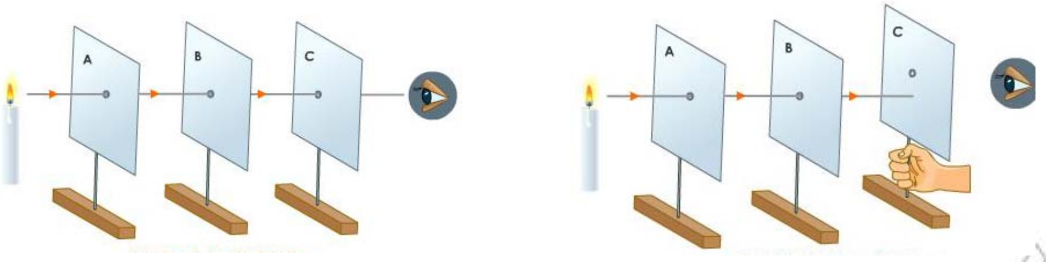
Form a group with your friends and do the following practical activity and describe how light travels. Is it in a straight line or zigzag (curved) path?

Materials required: 3 cardboards mounted on blocks (see Fig 6.2) source of light (candle or lamp).

The 3 cardboards need to have small holes at their centers exactly at the same level.

Procedure:

1. Arrange the cardboards as shown in Fig 6.2
2. Pass string through the holes and pull it tight to make sure that the holes are in a straight line.
3. Place a lighted candle at one end of the 3 cardboards. Try to look the burning candle flame through the other end as shown in the Fig.6.2. (you should be able to see the candle flame though the holes)
   i. Can you see the flame through the holes?
   ii. If any of the cards is moved slightly from their position, can you still see the flame?
   iii. What do you conclude about the motion of light? Does light travel around a corner



a) Straight holes b) Disordered holes

Fig. 6.2 Propagation of light

From Activity 6.2 you might have noticed that when the holes of each card are exactly at the same level you can see the light of the candle (Fig 6.2(a)). But if one of the cards is moved (disordered) slightly out of the line the light will not be seen, because the light from the flame is blocked by the surface of the displaced card (Fig. 6.2(b)). Light does not move around a corner. This activity shows that light travels in a straight line.

Let us take other practical examples in our life.

If you open a window facing sunlight or walk through trees at sunrise or sunset you will see light streaming through in straight lines as it passes through the window to the opposite wall or between the branches of trees to the ground.

The same effect is also observed in cinema halls as light travels from the projector to the screen. These events suggest that light travels in straight lines.

Actually, we see the light because it hits particles in its path and reflect to our eyes. The direction of the path followed by the light is called a **ray** and is represented by a straight line with an arrow. A group of rays of light is called a **beam of light**. There are different types of beams of light: parallel, diverging and converging beams as shown in Fig 6.3

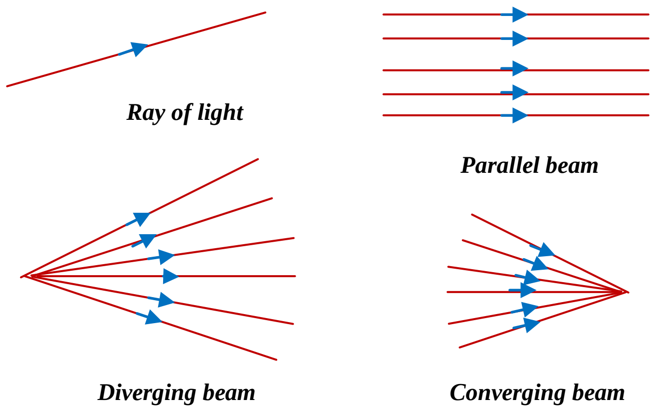


Fig 6.3 Types of rays.

Kinds of light transmission

Light travels in a straight line. It can travel through a vacuum and through some materials.

Some objects like the wall, do not allow light to pass through them at all. Such objects are called **opaque**.

Other objects allow light to pass through them partially. Such objects are said to be **translucent**. Special glasses used in toilet and bathroom windows and water are examples of such material. Materials like air and ordinary window glasses allow light to pass through them. You can see things through them clearly. Such objects are said to be **transparent**. They serve as media for the propagation of light. What is a medium?

Opaque materials reflect light falling on them completely, while translucent materials reflect light partially.

Pin-hole camera

A pinhole camera consists of a closed box with a small hole on one face and screen on the opposite side. The screen could be made from oiled paper or plastic sheet or white pieces of cloth as shown in Fig 6.4.

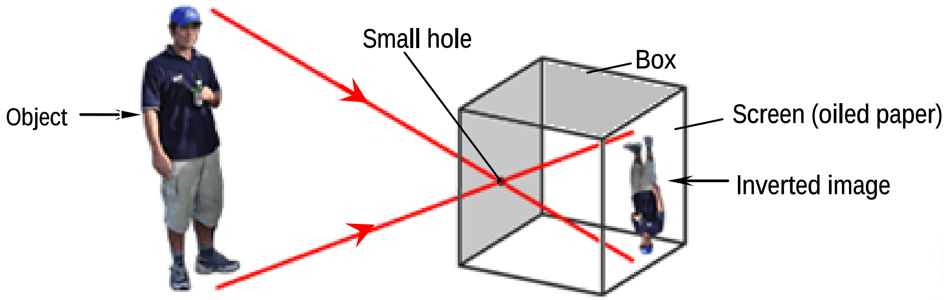


Fig 6.4 Pin-hole Camera

Activity 6.3 To Construct a pinhole camera

Materials required: A paper box, silver color plastic sheet (oiled paper), a pin and scotch tape.

Procedure: Make a hole with a pin on one side of the box.

- Remove the opposite side of the box, and replace it with the oiled paper or plastic sheet.
- Seal the sides of the box with the scotch tape, not to allow light inside the box. (Fig 6.4)
- Use the pinhole camera you prepared to observe things around you like a flag, a burning candle, or a tree placed in the sunshine.
- Explain the image formed by the pinhole camera.

The image formed on the screen will be seen more clearly if the observation is done in a darkened room.

Geometrical optics is a branch of optic which deals with the properties of light by using a light 'ray' model.

Since light travels in a straight line, each point of the image on the screen will be illuminated only by the light travelling in a straight line from a particular point source. The tiny particles of light from the object combine to form an inverted (upside down) image of the object as shown in the figure. If the hole is enlarged, the image becomes blurred. You get clear picture when the hole is very small like a pinhole.

We can think of a bigger hole as equivalent to a group of small holes close together. Each hole produces its own image and the overlap of these causes the image to appear blurred. (not clearly identified)

Shadows

When an opaque object is place between a source of light and a screen, a shadow is formed on the screen. This is because light travels in a straight line and so will not be able to go round the object. The formation of a shadow is a practical example that show light travels in a straight line. When the source is very small, i.e a point source, the shadow produced is sharp and equally dark all over. When the source is large, however, the shadow has one central dark patch the umbra surrounded by a lighter ring called penumbra. Some rays of light are able to reach the penumbra but none reaches the umbra.

Check point 6.2

1. **Explain how light propagates.**
2. **What is a pin-hole camera? Describe its uses.**
3. **Explain the nature of the image formed by the pinhole camera.**
4. **What is meant by the terms translucent, transparent and opaque materials? Give examples for each of them.**

6.3 Reflection of Light

Light travel in all directions from a source. This propagation of light is represented by rays of light.

Light travels in straight line in a given medium. When light reaches the boundary of another medium through which it does not travel, some changes may happen. These are;

i. Some amount of light is absorbed by the boundary medium.

ii. The rest is turned back into the first medium. If the surface is polished and glazed like a mirror, most of the light is turned back from the surface. This phenomenon of light is known as the **reflection of light**.

Reflection of light is the turning back or bouncing of light rays when it encounters a different medium.

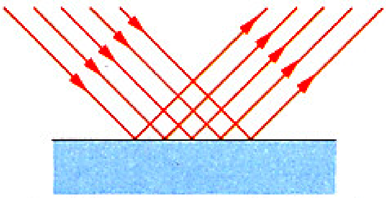
When a light ray hits an opaque material it totally reflects.

Can you see any relationship between the angle at which the light ray hits the opaque material and the angle at which it is reflected?

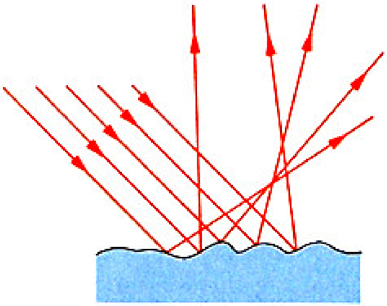
There are two kinds of reflection:

i. *Regular reflection:* is a reflection from regular, shining and smooth surface. Example a mirror. (Fig 6-5 a)

ii. *Diffuse reflection:* is a reflection from irregular and rough surfaces (Fig 6-5 b)



a) Regular reflection



b) Diffused reflection

Fig 6.5 Regular and diffuse reflections

The rays that strike the surface are called **incident** rays while the rays that are bouncing back from the surface are called **reflected** rays.

When you look at yourself in the mirror, incident rays from your face hit the mirror and return as reflected rays. As these rays enter your eyes you see the picture of yourself behind the mirrors. This picture is called an **image**.

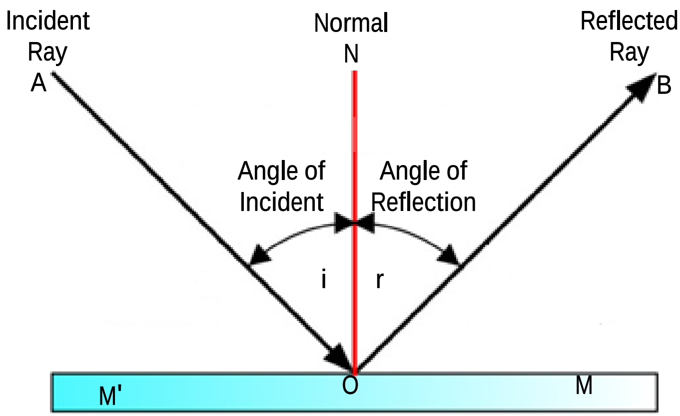


Fig 6.6 Terms used in reflection of light ray

MM' is the reflecting surface of a plane mirror.

AO is the direction in which the light from the object (or source) falls on the reflecting surface and is called the **incident ray**. The point **O** is the point of incidence and **OB** is the **reflected** ray. The line **NO** is perpendicular to **MM'** and it is called the **normal**.

The angle formed by the **incident ray** and the normal is called the **angle of incidence**. The angle formed by the reflected ray and the normal is called **the angle of reflection**. They are represented as $\hat{\imath}$ and $\hat{r}$ respectively, where

$\hat{\imath}$ = The angle of incidence.

$\hat{r}$ = The angle of reflection.

Activity 6.4 Observing the law of reflection

Obtain a white sheet of paper and draw a straight horizontal line about its center. Place the paper on a piece of soft cardboard or a horizontal table and use four pins to hold the paper to the cardboard (table).

Place a strip of plane mirror vertically so that its silvered surface (i.e. the back of the mirror) is on the line you have drawn. Label this line MM'. Stick two pins P_1 and P_2 on the paper in front of the mirror, so that the line joining p_1 and p_2 is at an angle to MM'. The pins p_1 and p_2 should be 5 or 6 cm apart.

With the eye at a convenient point, observe the images of p_1 and p_2 of the two pins (i.e P_1' and P_2'). Stick two other pins p_3 and p_4 in a straight line with these images. The set-up is shown in Fig.6.7. Now remove the mirror and the pins. Draw the line p_1p_2 and p_4 p_3 to cut MM'.

If you did the experiment carefully, you would find that the lines meet at a point on MM'; call this point O and draw a perpendicular to MM' as shown.

Measure the angel P_2ON ($\hat{i}$) and P_4ON ($\hat{r}$) and record your results. Repeat the experiment for different angles and tabulate your results as shown below.

On Table 6.1. Angles i and r are the angles of incidence and reflection respectively.

Table 6.1		
Experiment number	Angle of incidence (i)	Angle of reflection (r)
1	10^0	-
2	20^0	-
3	30^0	-
4	45^0	-
5	60^0	-

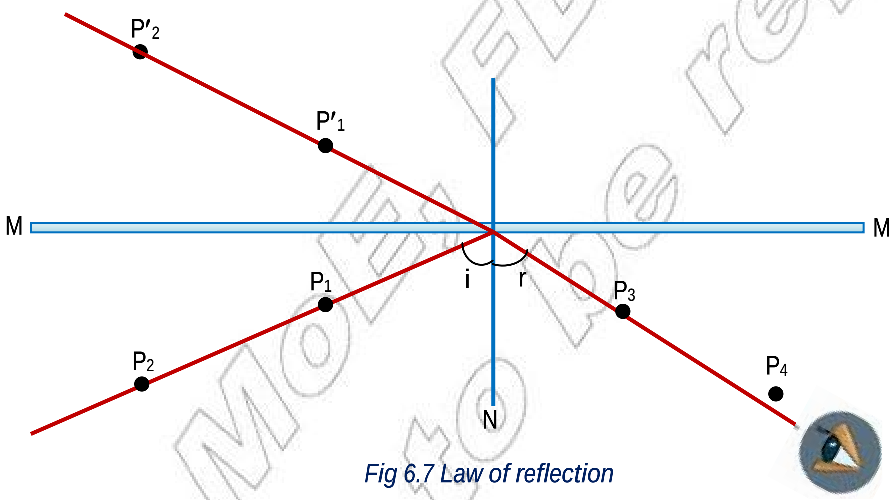


Fig 6.7 Law of reflection

The results obtained from this experiment can be summarized as laws of reflection.

Laws of reflection

The angle of incidence is equal to the angle of reflection.

The incident ray, the reflected ray and the normal to the reflecting surface at the point of incidence all lie in same plane.

Worked Example

An incident ray strikes the surface of a mirror at angle of 30°. What are

a) The angle of reflection and

b) The angle between the reflected ray and the mirror?

Solution

- Draw the normal lie at the point where the incident ray strike the mirror

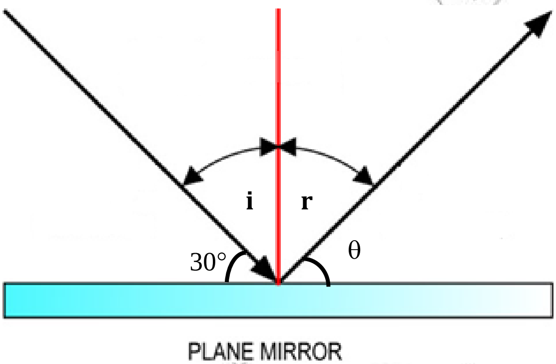


Fig 6.8

a) The angle between the incident ray and the normal
$= 90° - 30° = 60°$

Therefore, the angle of reflection = 60° since $\hat{i} = \hat{r} = 60°$.

b) The angle between the reflected ray and the mirror is
$90° = \hat{r} + \theta° \Rightarrow \theta° = 90 - \hat{r}$

If $r = 60°$ then $\theta° = 90° - 60° = 30°$

Diffuse and regular reflection can now fulfill one of the laws of reflection When a parallel beam strikes a rough surface at an angle, all the rays in the beam will be incident at different angles of incidence from the others. So the angles of reflection for the different rays will be different resulting in reflection in all direction.

Image formation by a plane mirror

A plane mirror is a glass plate whose one of its side is painted black or silver. The reflecting surface is the surface that is not painted. Rays of light falling on a mirror are reflected in a definite direction. The reflection of an object in a mirror is called an **image**.

Fig 6.9 Image in a plane mirror

Activity 6.5 Observing your image in a plane mirror

Material required: a plane mirror.

Procedure: Take a plane mirror and place it in front of your face.

- Observe the type of image you receive on the mirror.
- Is your image enlarged, inverted, and sides exchanged in the mirror and how is its position from the mirror? Fig 6.9
- Can you receive your image on a screen (paper) and touch it with your hand?
- What do you call such images?

Consider a point object **O**, such as the tip of a candle flame, placed in front of a mirror. Two rays **OA** and **OB**, strike the mirror at A and B as show in Fig 6.10 After reflection they appear to the eye as if they were originating from I. The eye sees an image at I in such a way that ON is equal to **IN** and **ONI** is perpendicular to the mirror.

As no rays actually come from I, the image is described as a virtual image. It cannot be seen on a screen placed at I.

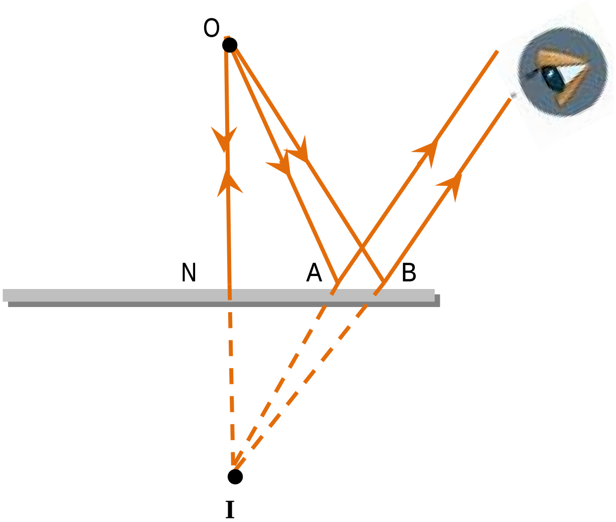
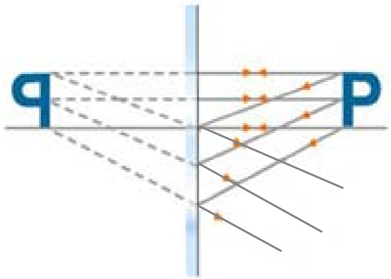


Fig 6.10 Construction of an image using a ray diagram

The image formed in a plane mirror has the following characteristics;

i. It is erect, not upside down.
ii. It is of the same size as the object
iii. It is laterally inverted. (i.e. Sideways reversed)
iv. Has the same distance behind the mirror as the object is in front i.e. the image formed in a plane mirror appears to be as far behind the mirror as It is a virtual image.

A virtual image is one through which rays of light do not pass but which is nevertheless visible to the eye. A virtual up right image is an optical illusion. A real image is one through which rays of light pass if a screen is placed at the position of a real image, the image is seen on the screen.



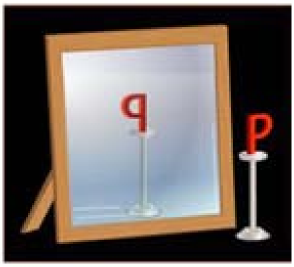


Fig 6.11 Image of a letter P in a plane mirror

A periscope

A periscope is a device that helps an observer to see over or around an opaque material. Using a periscope you can see a football game being behind a tall wall.

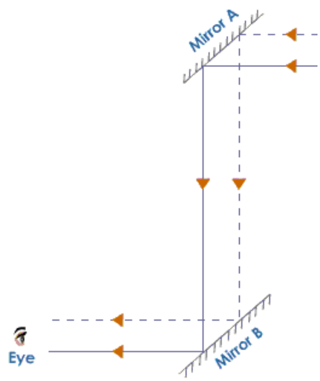


Fig 6.12 A periscope

A periscope uses two plane mirrors placed in a long tube as shown in Fig 6.12. The mirrors are placed at each end of the tube at 45° to the direction to be observed. The image formed by the top mirror is observed through the bottom mirror.

Image formed in two mirrors

When two mirrors are inclined at angle θ° (angle teta) a number of images are formed by a number of reflections.

$$\text{Number of images} = \frac{360°}{\theta} - 1$$

E.g. Images formed in two mirrors inclined at 90° are: $\frac{360°}{90°} - 1 = 3$ images.

Parallel mirrors: An infinite number of images are formed for an object placed between two parallel mirrors. These images lie on a straight line through the object perpendicular to the mirrors.

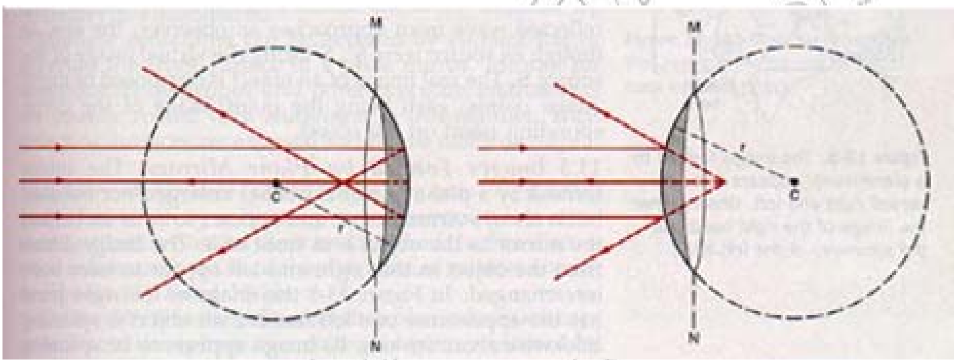
The position of the images may be found by the usual construction, remembering that each image seen in mirror will act as a virtual object and produce an image in the mirror.

Check point 6.3

1. What is reflection of light?
2. What is the difference between regular and diffuse reflection?
3. Define the terms incident ray, reflected ray, angle of reflection, angle of incidence and normal line (demonstrate pictorially.)
4. State and describe the law of reflection.
5. What is the angle between incident ray and reflected ray if the angle of incidence is 40°?
6. Describe the nature of images formed by a plane mirror.
7. Explain the difference between real and virtual images.
8. What is a periscope? Describe how to make it.

6.4 Image Formation by Curved Mirrors

Curved mirrors are made up of a spherical shaped body. Consider the cover of a hollow sphere of glass. We could produce a curved surface by cutting out the part of this spherical cover. If we reflect light from the outside of this surface, we produce a **convex mirror**. If we reflect light from the inside surface we have a **concave mirror**. Such mirrors are called **curved mirrors**.



a) Concave mirror *b) Convex mirror*

Fig. 6.13 Curved mirror

When the reflecting surface of mirrors is curved rather than plane, the law of reflection holds true. But the size and position of the image formed are quite different from those of the image formed by a plane mirror.

Because of the curved nature of these mirrors, they do not produce images in the same way as the plane mirrors discussed earlier in this unit.
Concave mirrors are used in torches and car head-lights, in reflecting telescopes and as showing mirrors.

Convex mirrors are often used as driving mirrors (i.e. as rear-view mirrors in cars) and to see round corners in Supermarket.

To study the images formed by curved mirrors we need to define some terms used in connection to these mirrors. See Fig. 6.14.

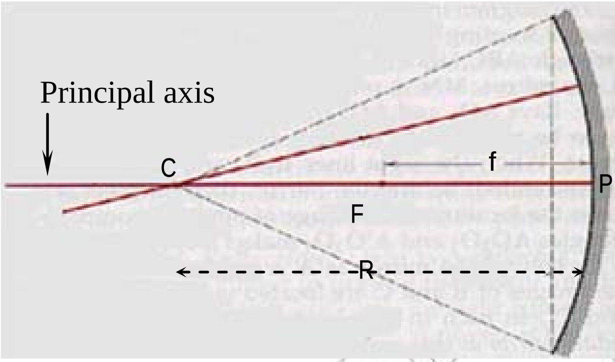


Fig. 6.14 A plane diagram for defining terms used with curved mirrors.

1. The **pole (p)** of the mirror is the midpoint of the mirror
2. The **center of curvature (C)** is the center of the sphere of which the mirror forms a part.
3. The **principal axis** is the line that passes through the pole and the center of curvature of the mirror.
4. The distance from P to C is the **radius of curvature** (R). It is the radius of the sphere from which the mirror was cut out. The action of a curved mirror depends on the radius of curvature.
5. The **principal Focus (F)** of a concave mirror is the point where rays that are parallel to the principal axis converge after reflection. Fig.6.15 (a) illustrates

that when a beam of light is incident on a concave mirror, the rays are reflected to converge or come together at a point F called a **principal focus**.

6. The **principal focus (F)** of a convex mirror is the point from which rays parallel and close to the principal axis appear to diverge after reflection. With a convex mirror, the rays appear to diverge or move out from the point F behind the mirror after reflection. See Fig.6.15 (b). With a concave mirror, the rays converge to a point which we can actually obtain on a screen placed in front of the mirror as a bright spot of light.

   The focus of a concave mirror is therefore a real focus. In the case of a convex mirror, the reflected rays do not actually pass through the focus but only appear to do so.

7. The **focal Length (f)** of curved mirrors is the distance from the principal focus F to the pole P. The focal length is found experimentally to be equal to half of the radius of curvature.

   That is $f=R/2$

   For example, if the radius of curvature is 40 cm, the focal length of the mirror $f= 40/2=20cm$.

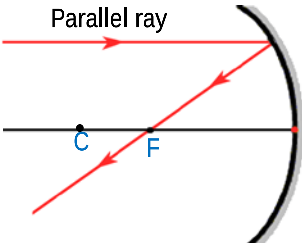
Ray diagrams for Image formation

When an object is placed in front of a mirror, we can't know where the image will be and what kind of image it is. Our general problem is that if light rays start from a point on an object, what happens to them after reflection by the mirror? We make the problem easier for ourselves by taking rays whose directions after reflection are known and can easily be drawn. The followings are rays whose direction is known.

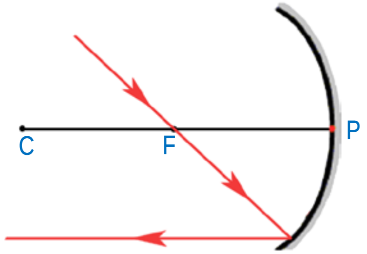
i. A ray parallel to the principal axis passes through the principal focus (F) after reflection Fig.6.15(a)
ii. A ray through the principal focus (F)is reflected parallel to the principal axis fig 6.15(b)
iii. A ray through the center of curvature (C) is reflected back along its path, fig 6.15(C)

Any intersection of the reflected rays of at least the above two rays form the image of the object placed in front of the mirrors.

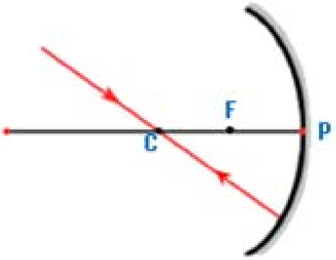
Images formed by Concave and Convex mirrors



a) Any ray parallel to the principal axis is reflected through F.



b) Any ray through F is reflected parallel to the principal axis



c) Any ray through C hits the mirror at right angles and is reflected straight back

Fig.6.15 Construction of rays for a concave mirror

Activity 6.6 Observing images in

a) Concave mirrors

b) Convex mirrors

Materials: Concave and Convex mirrors (locally available like polished metallic surfaces).

Procedure:

a) concave mirror

- Stand in front of a concave mirror at a distance. Try to observe your image in the mirror.
- Come closer to the mirror slowly, observing the type of image formed.
- And finally come very close to the mirror

Explain the types of image observed as you move closer to the mirror.

b) convex mirror

Repeat the steps you followed for a concave mirror above.

Explain the types of image (s) observed as you move from a distance to closer to the convex mirror

i. Images formed by Concave mirrors

The nature and position of the image formed by a concave mirror varies with the position of the object in front of the concave mirror. This can be observed by drawing a ray diagram to scale. Ray diagrams in Fig 6.16 illustrate the different images formed for different distant objects.

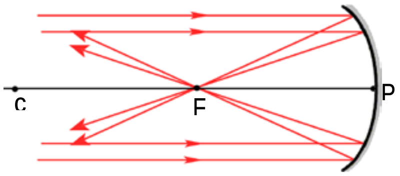
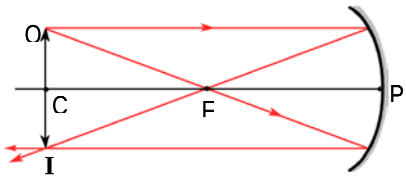
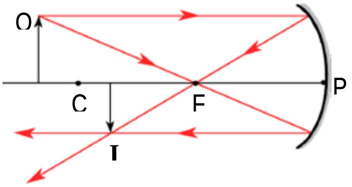
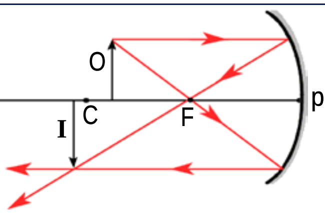
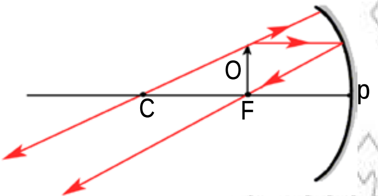
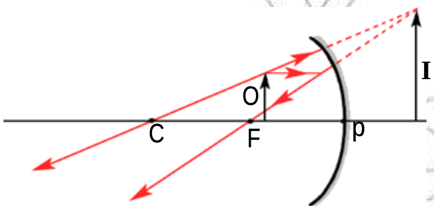
a) 	Object at infinity (Very far)	The image is 1. At F 2. Real 3. Inverted 4. Smaller than object
b) 	Object at C (S_0=2F)	The image is 1. Real 2. Inverted 3. Same size 4. At C
c) 	Object beyond C ($s_0 > 2f$)	The image is 1. Real 2. Inverted 3. Smaller than object 4. Between C and F
d) 	Object between F and C ($2f > s_0 > f$)	The image is 1. Real 2. Inverted 3. Large than object 4. Beyond C
e) 	Object at F ($s_0 = f$)	No image is observed (it is at infinity)
f) 	Object between F and P ($f > s_0$)	The image is (1) Virtual (2) Larger than object (3) Erect (4) Behind the mirror

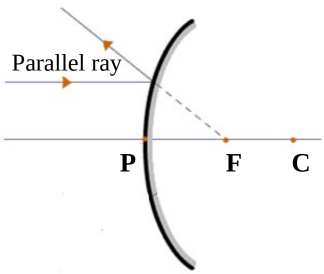
Fig. 6.16 Image formed by a concave mirror

Fig 6.16 shows the image positions for various object positions. In a concave mirror we get both a real image and a virtual image A real image is formed by the actual rays of light and can be received on a screen.

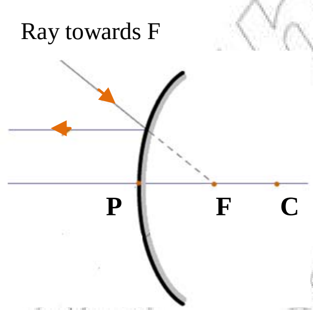
In concave mirrors

1. If an object is placed beyond focal point, the image is real and inverted. The size and position depend on the distance of the object from the mirror.
2. If an object is placed between the focal point and the mirror, the image is virtual, erect and larger than the object.

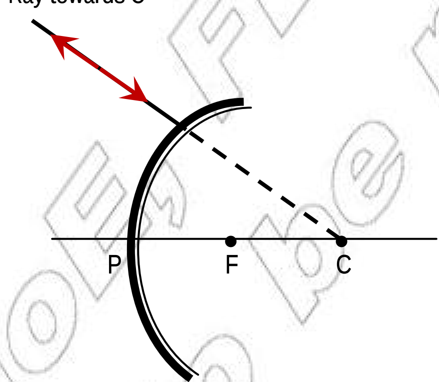
i) Images formed by a convex mirrors



a) Any ray parallel to the principal axis is reflected so that it appears to come from F.



b) Any ray going towards the principal focus is reflected parallel to the principal axis.



c) Any ray towards C is reflected straight back

Fig.6.17 Construction of rays for a convex mirror

Fig 6.17 illustrates construction of ray diagrams for a convex mirror. The image formed in a convex mirror does not depend on the distance between object and mirror.

The points to which these reflected rays appear to diverge represents the required image. In practice, however, the tracing of any two of these rays will enable us to find the position of the image.

For the convex mirror the image is always erect, diminished, virtual and behind the mirror for all object positions. (fig 6.18)

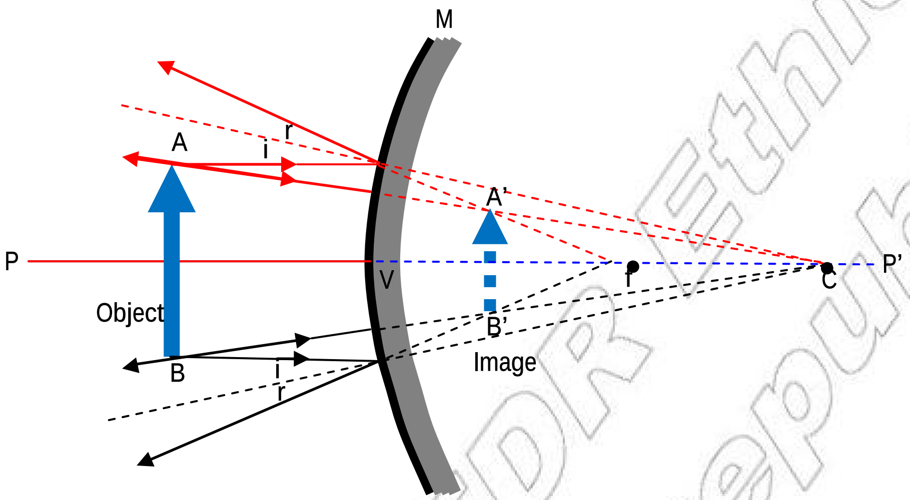


Fig.6.18 Construction of rays for a convex mirror

Most driving mirrors are convex. They gather in light from a wide area and distant objects around and direct the ray to the driver's eyes. In this way he or she can see diminished size of the objects and the whole road behind him/her.

Activity 6.7 Discuss the following questions with your friends

1. What is the difference between real and virtual images?
2. Use the images formed by a concave, convex and plane mirrors to explain the question.

Object and image are represented by O and I respectively. Fig 6.14 and Fig 6.18 show the position and nature of the image produced by curved mirrors. Where the rays diverge, do not meet, you extend them backward. The image formed where the reflected rays actually meet is called **real image**. The image formed where the extension of the reflected rays meet is called **virtual image**.

Check point 6.4

1. **Describe curved mirrors (Give examples for convex and concave mirrors).**
2. **Define the terms**
   - **Principal axis**
   - **Focal point**
   - **Focal length,**
   - **Radius of curvature**
   - **Vertex (pole) of mirror**
3. **Describe the nature and position of images formed by curved mirrors using ray diagrams, when the object is placed at different location.**

6.5 Refraction of Light

Activity 6.8 Observing refraction of light in different media.

Materials required: a torch, a card board with a pinhole, water in a plastic bag, and a glass plate.

Procedure: (Do this activity in dim or dark place)

- Arrange the torch as shown in Fig6. 16 so, a single ray could be produced.
- Direct the ray to the surface of water or glass at an angle.
- Observe what happens to the ray as it hits boundary between the air and water (or glass).
- To which direction does the light ray bends in the water medium (glass medium)?
- Follow the ray as it comes out of the glass or water. Observe how it is bending.

In the previous section you learnt that light travels in straight line in a given medium. But this is true only when light travels through a substance which has the same optical density throughout.

Optical density is a property of any transparent material, and it is the measure of the speed at which light travels through that material.

For example the speed of light through water is very nearly ¾ of the speed of light through air, so water has an optical density ¾ times that of air.

When a ray of light traveling in one transparent medium enters another different transparent medium, its direction is suddenly changed at the surface separating the two media. This happens only if the light strikes the separating surface obliquely (slantingly). Light travels in a straight line when it enters a new medium perpendicularly. The change in the direction of the light ray is known as **refraction of light**.

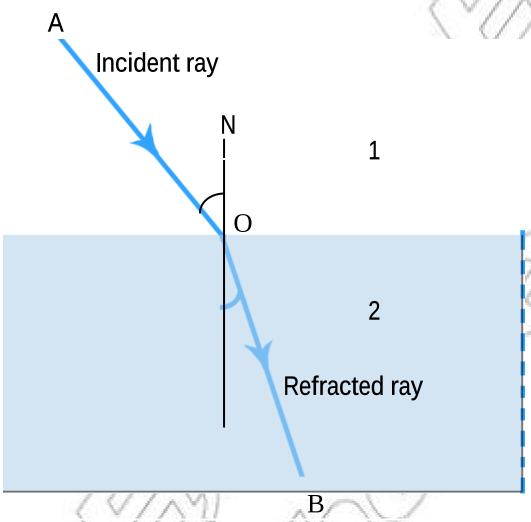


Fig.6.19 Refraction of light rays

Therefore refraction of light occurs when light travels from air to glass, from air to a liquid, from glass to air and from a liquid to air. Refraction happens due to the difference in the velocity of light in the different media.

Refraction of light is the bending of a light ray as it passes from one medium to another. It occurs because light travels at slightly different velocities in different media.

The incoming ray is called the incident ray. After bending in a new medium it becomes the refracted ray. A line perpendicular to the boundary of the two media at the point where the incident ray entries is called the normal.

The phenomenon of refraction explains why a swimming pool or water in any container appears shallower than it actually is. It also explains why a pencil appears to bend when part of it is immersed in a glass of water or any other liquid.

Fermat's least time principle

The path taken by a ray of light between any two points in a medium is always the path that takes the least time. This principle leads to the law of the rectilinear propagation of light and the laws of reflection and refraction. It was discovered by the French mathematician Pierre de Fermat (1901-1965)

Definition of terms

Consider a ray of light travelling from medium 1 to 2 using Fig 6.19 we make use of the following terms.

1. **The incident ray**: is the path along which the light travels in the first medium.
2. **The refracted ray**: is the path along which the light travels in the second medium.
3. **The angle of incidence**: is the angle between the incident ray and the normal to the surface.
4. **The angle of refraction**; is the angle between the refracted ray and the normal to the surface.

In Fig 6.19 it is shown that the refracted ray is bent towards the normal. This occurs when the ray enters a denser medium. If the same ray had started from medium 2, it would have followed the same path. That is BO would have been the incident ray and OA the refracted ray. In this case the ray entering the less denser medium would bend away from the normal. In other words a ray travelling from the denser to the less denser medium bends away from the normal as it crosses the surface of the separation of the two media;

These can be summarized as the law of refraction

Laws of Refraction

The laws of refraction are stated as follows:-

- The incident ray, the normal at the point of incidences and the refracted ray lie in the same plane.
- Light bends towards the normal in denser medium and bends away from the normal in lighter medium.

Check point 6.5

1. **What is refraction of light?**
2. **Draw and explain ray diagrams to illustrate how light travel from one medium to another.**
3. **Explain Fermat's least time principle.**

6.6 Lenses

Activity 6.8 Individual work

i) What is a lens?
ii) Describe what lenses do to parallel rays.
iii) Mention some applications of lenses.
iv) What does the hole in a pinhole camera represent

A lens is a piece of transparent medium, usually glass, bounded by two curved surfaces or by one plane and one curved surface. The word 'lens' 'lentil' was given first to convex lens because of its similarity in shape to lentil seeds.

Lenses are used in many instruments. They are used inside cameras, eye glasses projectors, microscopes, telescopes and others. (Explain the different uses of lenses indicated in (Fig 6.20)

a) Camera

b) Night vision goggles

c) Glasses

d) Over head Projector

e) Telescope

f) Microscope

Fig 6.20 Different uses of lenses

Lenses produce either real images or virtual images.

Types of Lenses

There are two types of lenses. These are:

1. Convex lens
2. Concave lens

1. Convex Lenses

These lenses are thicker at the middle and thinner at the edges. Convex lenses are also called **converging lenses**. (Fig 6.21)

A convex lens makes parallel rays of light originating from a source converge to a point called a **Focus.** It produces both real and virtual images. The virtual images are magnified but the real images can be either magnified or diminished depending on the object's distance from the lens.

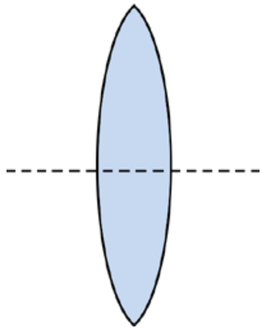


Fig 6.21 Convex lens is a converging lens.

2. Concave Lenses

These lenses are thinner at the middle and thicker at the edges. A concave lens is also called **diverging lens**. (Fig 6.22)

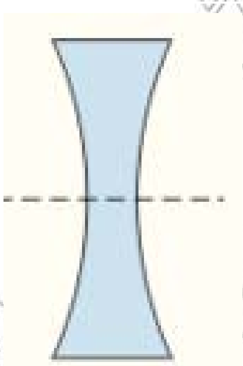


Fig 6.22 Concave lens is a diverging lens.

A concave lens makes parallel rays of light which pass through it spread out or diverge.

When you look through a concave lens, you always see a diminished and upright image.

Terms used in lenses

1. The **principal axis** of a lens is an imaginary line joining the centers of curvature of its surfaces.
2. For every lens there is a point through which rays of light pass without being bent by the lens. This point is called the **optical center** of the lens.
3. **The principal Focus (F)** of a converging lens is the point to which all rays parallel to the principal axis actually converge after refraction through the lens.

4. **The principal focus** (F) of a diverging lens is the point from which all rays parallel to the principal axis appear to diverge after refraction though the lens.
5. **The focal length** (f) is the distance between the optical center (O) and the principal focus (F) of the lens
6. **Center of curvature** (C): the center of curvature of a lens surface is the center of the sphere of which the surface forms a part.

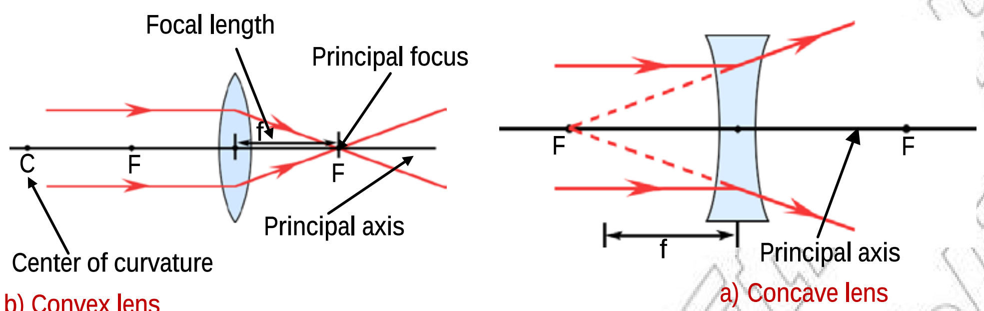


Fig. 6.23 Basic terms used in lenses

Ray diagrams used to determine nature and position of images in lenses.

As in the construction of ray diagrams for curved mirrors, three rays are used to obtain the position and nature of images formed by lenses. These rays are:

a. Rays parallel to the principal axis to it, pass through the principal focus after refraction.

b. Rays through the principal focus emerge parallel to the principal axis after refraction

c. Rays through the optical center pass through the lens unrefracted, i.e. their direction is unchanged.

Formation of images by a convex lens

Image of an object formed by lenses is located at a point where at least two of the refracted rays intersect.

When constructing ray diagrams we represent the object and the image by a perpendicular line with an arrow at the head.

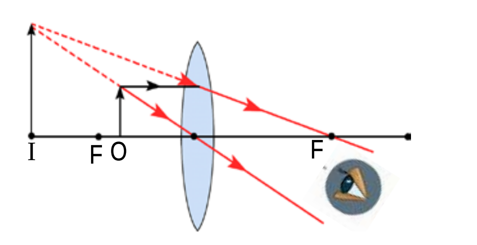
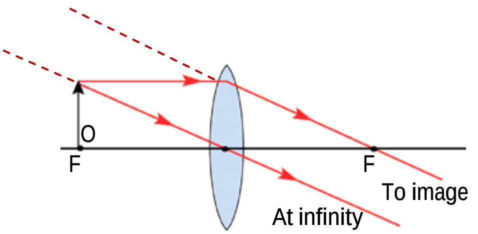
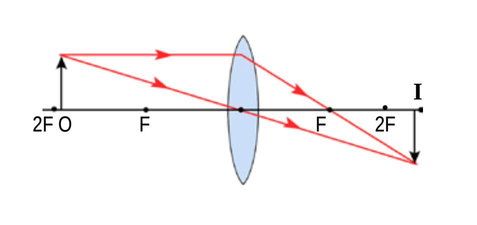
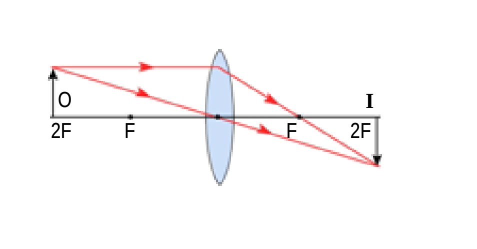
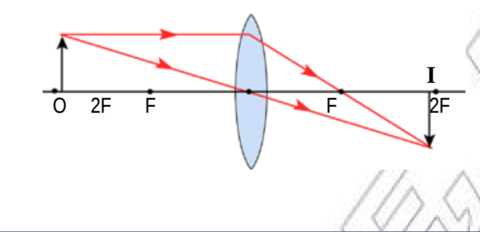
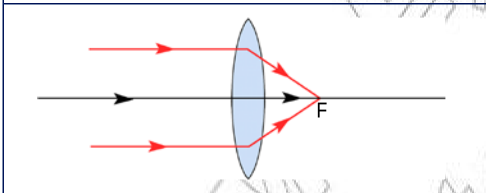
<table>
<tr>
<td>
</td>
<td>Object Between Lens and F</td>
<td>The image is
1. Behind the object
2. Virtual
3. Erect
4. Larger than the object</td>
</tr>
<tr>
<td>
</td>
<td>Object at F</td>
<td>No image is formed
the image is at infinity</td>
</tr>
<tr>
<td>
</td>
<td>Object Between F and 2 F</td>
<td>The image is
1. Behind 2F
2. Real
3. Inverted
4. Larger than the object</td>
</tr>
<tr>
<td>
</td>
<td>Object at 2F</td>
<td>The image is
1. At 2 F
2. Real
3. Inverted
4. Same size as object</td>
</tr>
<tr>
<td>
</td>
<td>Object beyond 2F</td>
<td>The image is
1. Between F and 2F
2. Real
3. Inverted
4. Smaller than the object</td>
</tr>
<tr>
<td>
</td>
<td>Object at infinity (Very Far)</td>
<td>The image is
1. At F
2. It is a point image.</td>
</tr>
</table>

Fig 6.24 Formation of images by a convex lens

Activity 6.10

How do the images in convex lens vary with the

a) Distance of the object beyond and at F?

b) Between F and the lens?

As for curved mirrors, we distinguish between real and virtual images. To repeat once again, a real image is one that can be received or projected on a screen. Actual light rays pass through it. A virtual images is one through which the light rays forming it only appear to pass, without actually doing so. A virtual image cannot therefore be projected on a screen.

Images formed by a concave Lens

For all position of the object, the image formed by a concave lens is always virtual, erect, diminished and located between the principal focus 'F' and the optical center of the lens 'O'. Fig 6.25. shows the path taken by a ray travelling parallel with the principal axis and one passing though the optical center 'O' of the lens. These rays can be used to predict the image position.

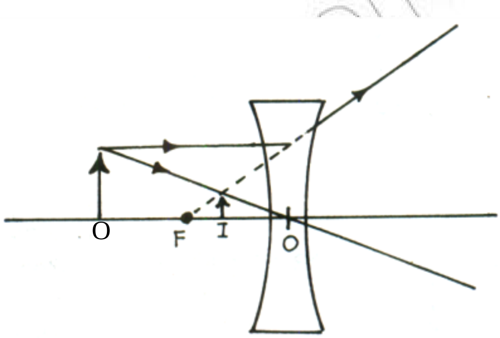


Fig. 6.25 Image formed by concave lens

Types of lens	Position of an object	Position and nature of Image formed	Uses
1. Convex lens (Converging lens)	• Object beyond 2F	- Real, - inverted, - diminished	- camera - Telescope - Projector - Magnifying glass
	Object at 2F	- Real, - inverted, - same size	
	Object between 2F and F	- Real, - inverted, - magnified	
2. Concave lens (Diverging lens)	Any position in front of the lens.	- Virtual, - erect - diminished	- spectacles (eye glasses)

A convex lens has a real focus but a concave lens has a virtual focus.

Mirage

People, who travel in a still sunny day, see inverted images of distant objects in a nonexistent pool of water. Have you ever seen a mirage? Ask your friends or parents about mirages. Mirage can be observed on asphalted road in hot days. Mirage is formed by the refraction of light traveling between hot and cold air.

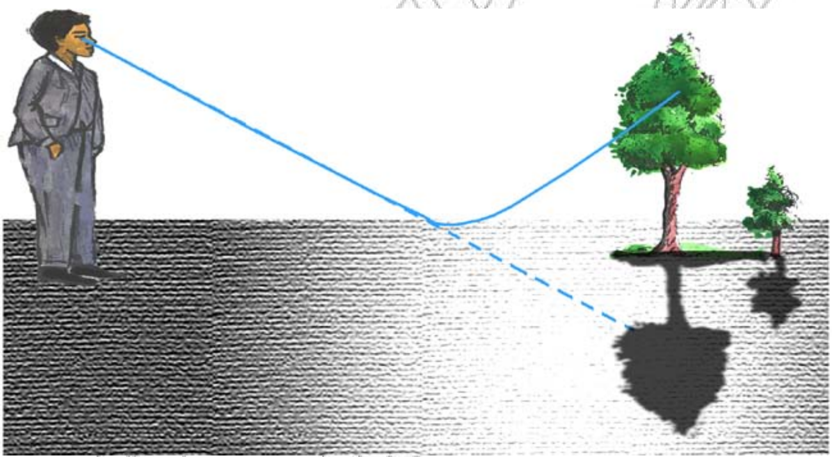


Fig. 6.26 Mirage

Dispersion of Light

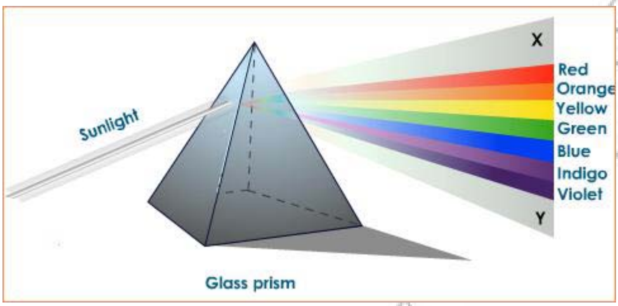
Activity 6.11

Observing white light is made up of different colors.

What is a rainbow? How is it formed? How many colors are found in a rainbow?

The band of colors you see on a screen xy is called a spectrum. The splitting of white light into different colors is called dispersion of light. It is caused by the refraction of white light at different angles to the glass prism as in Fig 6.27.

The fastest color light bends most, while the slowest color light bends least. The order of the colors of the spectrum is as follows. Red is on top followed by orange, yellow, green, blue, indigo and violet at the bottom. The violet is the most refracted while the red light is the least refracted. Thus, white light is made up of seven colors.



a) Dispersion of light in a glass prism

b) Rainbow

Fig 6.27 Dispersion of light

A rainbow is a band or spectrum of colors. It is formed by the refraction of light by drops of water in the sky.

Check point 6.6

1. What is a lens?
2. Explain the difference between convex and concave lenses.
3. Define the optical center, focal length, focal point, radius of curvature and principal axis of lenses.
4. Describe the nature of image formed by concave and convex lenses using ray diagrams.
5. What is the importance of lenses in technology?
6. Describe dispersion of light and name the spectrum of light (colors).
7. What is mirage? Describe it by comparing with refraction.

SUMMARY

In this unit you learnt that:

- light is an electromagnetic wave, that emits from a hot body
- Sources of light are the sun, burning lamp, candles and electric torch
- light travels in a straight line in a single medium.
- light travels completely through transparent materials and partially through translucent. It does not pass through opaque materials. They are either absorbed or reflected.
- reflection of light is the returning of light when it encounters an opaque or translucent material.
- the law of reflection states that the angel of incidence equals the angle of reflection.
- the image formed by a plane mirror is virtual, erect, the same size as the object and behind the mirror.
- curved mirrors are of two types; concave and convex mirrors.
- concave mirror forms real and inverted images. The size and position depends on the distance of the object from the mirror. For an object placed between the focal point and the mirror. The image is virtual, erect and larger than the object.
- the image formed by a convex mirror is always erect, diminished, virtual and behind the mirror.
- refraction of light is the bending of light as it passes from one medium to another.
- lenses are of two types: Convex and concave lenses. Convex lens converge parallel rays into a point called focal point (principal focus). While concave lens diverges parallel rays.
- the splitting of light into different colors is called dispersion. White light is made up of seven colors.

Review Questions and Problems

I. Choose the best answer among of the given alternatives

1. Which of the following is/are true about the image formed by a pinhole camera? The image is always.
   - a. diminished
   - b. inverted
   - c. magnified
   - d. a and b
2. If a pin – hole camera was made longer without changing the size of pinhole, the image would be
   - a. Smaller and less bright
   - b. Larger and less bright
   - c. Smaller and brighter
   - d. Larger and brighter
   - e. The same size and brighter
3. The image formed in a plane mirror is
   - a. Real and the same size as the object
   - b. Real and nearly the same size as the object
   - c. Virtual and the same size as the object
   - d. Virtual and nearly the same size as the object
4. A convex mirror is usually used as an out side rear-view mirror on a car because
   - a. It has a wide field of view
   - b. It has a narrow field or view
   - c. The image is always magnified
   - d. The image is always real
   - e. The image appears the same size as the object

II. Answer the following questions

1. Complete the following table with examples

Material	Examples (3 each)
Transparent	1 2 3
Translucent	1 2 3
Opaque	1 2 3

2. Write the names of the indicated types of light rays in the given space. (Fig 6.28)

   a. ______________________________

   b. ______________________________

   c. ______________________________

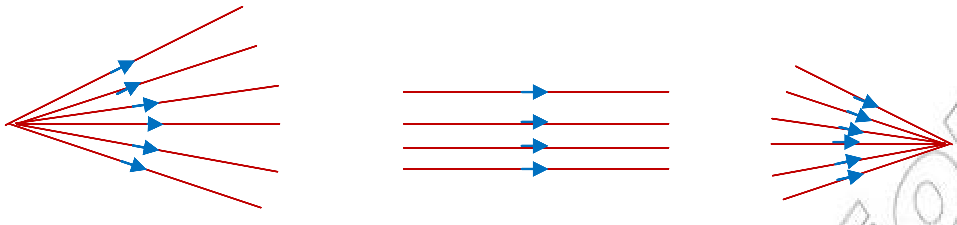


Fig 6.28 Types of light rays

3. Explain how light travels by giving practical examples.
4. The parts of the reflection of light from a mirror are labeled. on Fig 6.29 what do the letters stand for?

   A ______________________

   B ______________________

   C ______________________

   <α ______________________

   <β ______________________

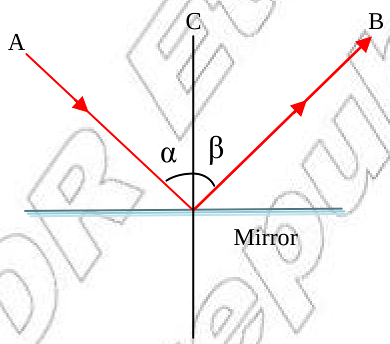


Fig 6.29 Reflection of light rays

5. Define a) Reflection of light

   b) Refraction of light

   c) Dispersion of light
6. Explain what concave and convex mirrors do to parallel rays directed to their surfaces.
7. Construct a ray diagram to find the image of a burning candle in front of a plane mirror.
8. Describe the nature of the image formed by convex and concave lenses. Fill in the Table given below.

Types of lens	Natures of Image
Convex lens	
Concave lens	

9. What is the difference between virtual and real images?
10. Draw the reflected rays for the given incident rays on

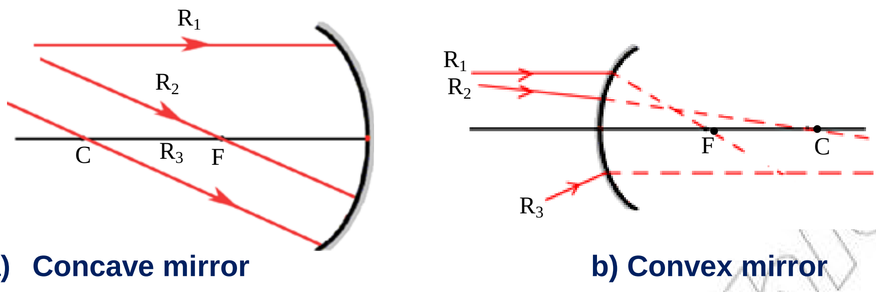


Fig 6.30 Incident rays R1,R2, & R3.

11. A convex lens has a focal length of 12 cm. what is the distance between the optical center and the center of curvature (c)?
12. The radius of curvature (R) of a concave mirror is 30cm. what is the focal length of this mirror?
13. A man is standing at a distance of 2m from a large plane mirror. He moved 1m farther away from the mirror. How far is his image now from him?
14.

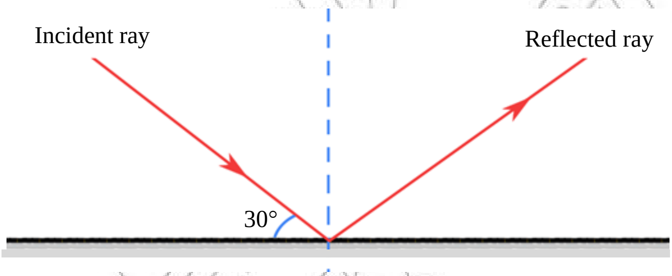


Fig 6.31 reflection on a plane mirror.

In Fig 6.31 the angle between the plane mirror and the incident ray is 30°. Find the

a. Angle of incidence
b. Angle of reflection