2 Lenses

Have you ever had such doubts?

Observe figure 2.1. Have you noticed older people using reading lens to make letters appear larger?

Where else are lenses used? Write them down.

- Toys
- Spectacles
- Door lens (lens fixed on the door to view the outside)
-

Fig. 2.1

What makes these lenses different from a sheet of glass? Let's examine.

- Allow sunlight to fall on a paper through a thin sheet of glass. What is observed?

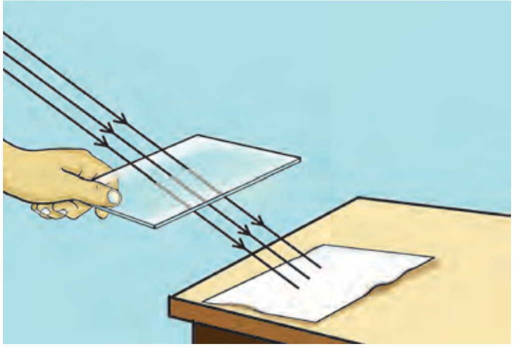


Fig. 2.2 (a)

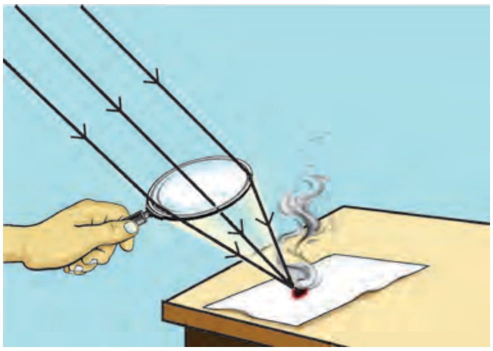


Fig. 2.2 (b)

- Vary the distance between the paper and the glass sheet. What do you observe?

It is seen that the size of the illuminated part does not change whether the glass sheet is near or far from the paper. Do the same activity using reading lens.

- What is your observation?

Note that when the lens is held at a specific distance from the paper, the size of the illuminated area is greatly reduced and the intensity of light at that area increases. Hold the lens at that point for a longer time. Can't you see the paper smouldering and catching fire?

What feature does the lens have that the glass sheet doesn't?

Convex lens and Concave lens

convex lens

Fig.2.3

Observe the lens used in the previous activity and note down its characteristics.

- Thicker in the middle
- Shows the objects magnified
-

The lens you are now familiar with is called convex lens. It is understood that such lenses can converge light rays.

Observe another type of lens (Fig 2.4). What are its features?

- Thinner in the middle
-

concave lens

Fig.2.4

Try to burn a piece of paper with such lenses. Is it possible?

It is understood that this type of lenses cannot converge light rays.

Such lenses are called concave lenses.

List the characteristics of concave lenses and convex lenses in the table.

Convex lens	Concave lens
• Thicker in the middle • •	• • Thicker at the edges •

Table 2.1

Observe the letters through each lens and move the lens to one side.

What is the observation?

- When a convex lens is used, the letters appear to move in the opposite direction.
-

This activity can be used as a method to distinguish between convex and concave lenses.

Observe figures 2.5 (a) and 2.5 (b).

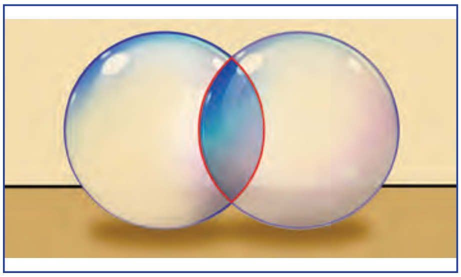


Fig. 2.5 (a)

Each lens has two surfaces. When light passes through them, refraction occurs. That means a lens has two refracting surfaces.

- Refracting surfaces of a lens are parts of (spheres / circles)

A lens is a transparent medium in which each refracting surface is part of the spheres.

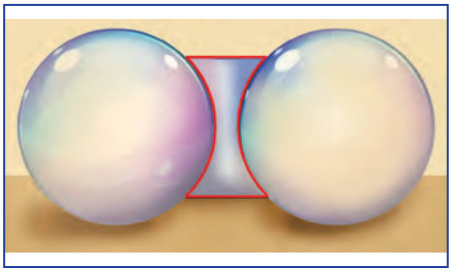


Fig. 2.5 (b)

Terms Related to Lenses

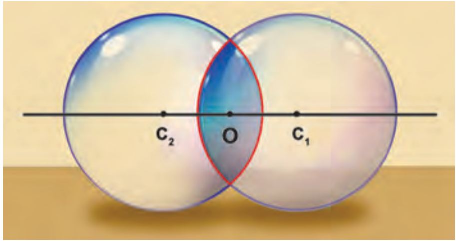


Fig. 2.6 (a)

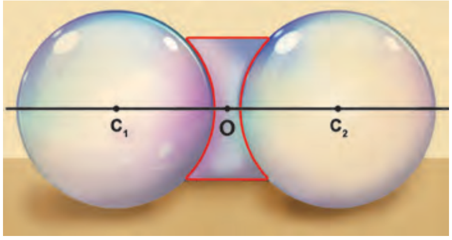


Fig. 2.6 (b)

- **Optic centre :** The midpoint of a lens is the optic centre (O).
- **Centres of curvature :** Each refracting surface of a lens is part of a sphere. The centres of such spheres are the centres of curvature.
- **Optic axis :** The optic axis is the imaginary line passing through the centres of curvature and the optic centre of a lens.
- **Aperture :** The area of the lens through which light passes is called aperture. In optical instruments such as cameras and microscopes, the aperture can be varied by using the stop.

Observe figures 2.6 (a) and 2.6 (b).

- Which figure represents convex lens? And which one represents concave lens?
- What do C_1 and C_2 indicate?
- Which refers to the optic centre? (C_1, O, C_2)
- Which represents the optic axis?

- **Principal focus**

Let's do an activity to find the principal foci of lenses.

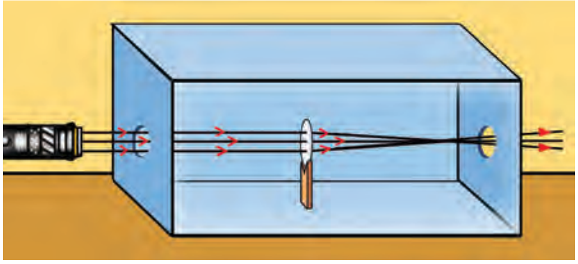


Fig 2.7

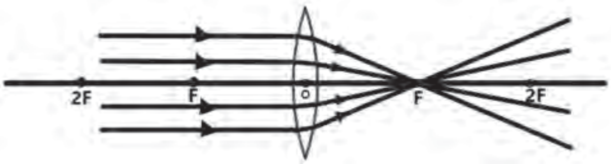


Fig 2.8

Materials : A box about 50 cm length, 30 cm width and 20 cm height, transparent on one side (a small hole should be made on the two opposite sides of the box and the holes should be sealed with a transparent sheet), laser torch (high beam type), incense stick, match box, convex lens, concave lens and lens stand.

After fixing the convex lens on the stand inside the box, fill the box with smoke. Allow light rays from the laser torch to pass through the hole and allow it to fall on the lens as shown in the figure.

- What do you observe?
- Depict the path of light

Haven't you noticed the change in the direction of light rays parallel to the optic axis of the convex lens as they pass through the lens? (It is to be noted that all light rays coming from a source or reflected from an object may not be parallel. But here we are considering only parallel rays). Haven't you seen light rays converge to a point on the other side of the lens after refraction? This point is the principal focus of the convex lens.

Light rays near and parallel to the optic axis incident on a convex lens, after refraction converge at a point on the optic axis on the other side of the lens. This point is the principal focus (F) of a convex lens.

Repeat the experiment shown in figure 2.7 by passing the light through the opposite hole. Didn't the light rays converge in this case too?

So such lenses have two principal foci, one on each side of the lens. These foci are equidistant from the optic centre.

The principal focus of a convex lens is considered real because light rays passing parallel to the optic axis of a convex lens pass through the principal focus, after refraction.

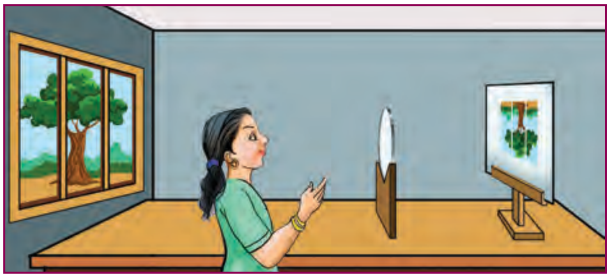


Fig 2.9

To find the approximate focal length of a convex lens, the distant object method can be used. Project the image of a distant tree or a building onto a screen using a convex lens. Measure the distance between the lens and the image using a scale. This distance is the approximate focal length of that lens.

Focal length

The focal length (f) is the distance from the optic centre of the lens to the principal focus.

Try smoke box experiment using a concave lens.

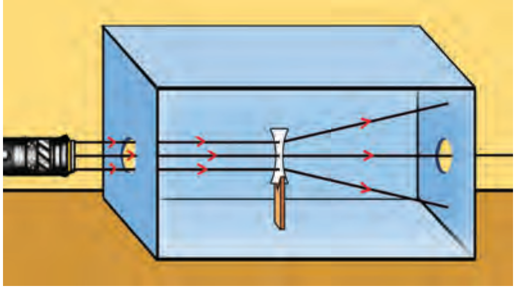


Fig. 2.10 (a)

Draw the path of the ray of light. Compare the figure drawn with figure 2.10 (a).

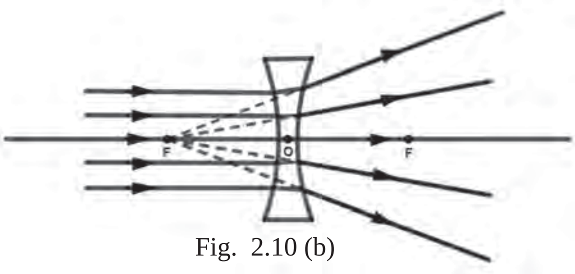


Fig. 2.10 (b)

Haven't you noticed the change in direction of the light rays passing parallel to the optic axis through the concave lens? Here the refracted rays appear to diverge from a point [Fig.2.10 (b)]. This point is the principal focus of the concave lens. A concave lens diverges the rays of light.

Light rays, near and parallel to the optic axis incident on a concave lens, after refraction appear to diverge from a point on the optic axis on the same side of the lens. This point is the principal focus of a concave lens (F).

Repeat the experiment by passing light through the other side of the concave lens. Haven't you understood that the concave lens also has two principal foci?

- Do refracted rays pass through the principal focus of a concave lens?
- If so, is the principal focus of a concave lens considered virtual or real?

Image Formation by Lenses

Project the image of a window onto a screen using a convex lens as shown in figure 2.11.

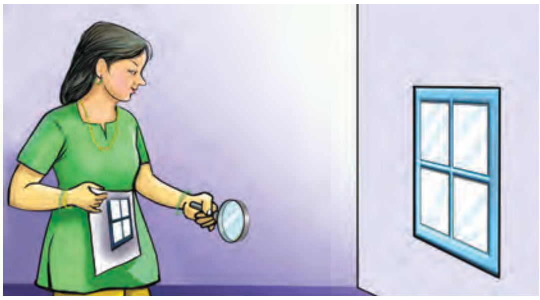


Fig. 2.11

- Try to form an image using a concave lens. Is it possible? Write down the results of the observation in the science diary.
- Which lens was used to form an image on the screen?

Images that can be projected on a screen are real images.

- Write down examples for real images.

➢ Image that is captured on a camera ➢ Image that is formed on a cinema screen

➢

Image Formation by a Convex Lens

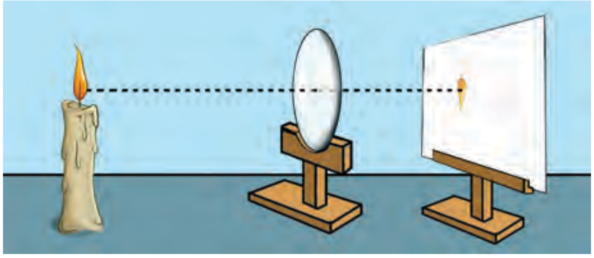


Fig. 2.12

Arrange a light source, the convex lens with pre-determined focal length, the lens stand and the screen as shown in the figure. Measure and mark F and 2F on the experiment table on both sides of the lens.

Here we have to get the image of the object on the screen. Hence the light source is used as the object in this experiment.

First place the object (light source) beyond 2F and adjust the position of the screen to get a clear image. Observe the features of the image and record them in the table given below.

Record the positions and properties of the image in the table by placing the object at various positions in table 2.2.

Position of the object	Position of the image	Characteristics of the image
Beyond 2F	Between F and 2F	Diminished, inverted, real
At 2F		
Between F and 2F		
At F	At infinity (Far away)	Magnified, inverted, real
Between F and lens		

Table 2.2

Ray Diagram of the Image Formation by a Convex Lens

Let's draw the path of light rays from an object placed in front of a convex lens as they pass through the lens.

Observe figure 2.13 (a) (b) and (c). Write down in table 2.3 the details of the path of light rays passing through the convex lens through different paths from point A.

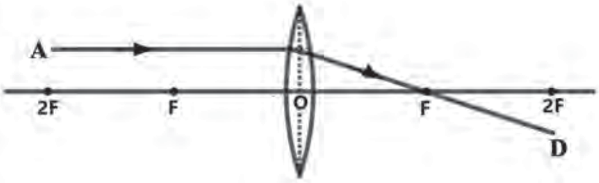


Fig. 2.13 (a)

Fig. 2.13 (b)

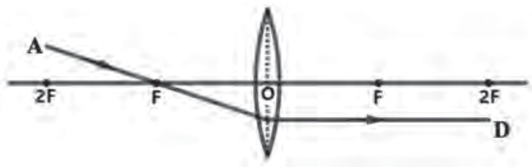


Fig. 2.13 (c)

A ray of light from a point which is parallel to the optic axis incident on a convex lens	Passes through the principal focus on the other side.
A ray of light passing through the optic centre	
A ray of light after passing through the focus on the same side of the object incident on the lens	

Table 2.3

A ray of light coming from a point on an object and passing through any point of the lens follows the laws of refraction.

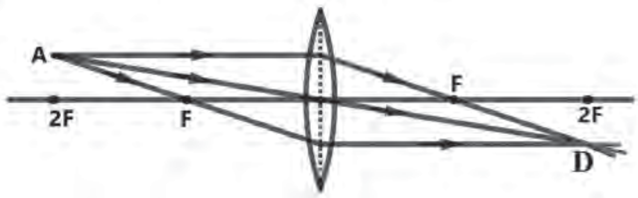


Fig. 2.14

After observing figure 2.14, haven't you seen that the light rays which have taken different paths pass through a single point?

Hence the image of A is formed at D. Similarly, the image of any point on the object is formed at the point of convergence of refracted light rays originating from the corresponding points.

If a screen is placed at the point of convergence of the refracted rays, the image is formed there.

Complete the ray diagram of the formation of image when the object is placed at different positions. Find the position and characteristics of the images.

Object beyond 2F

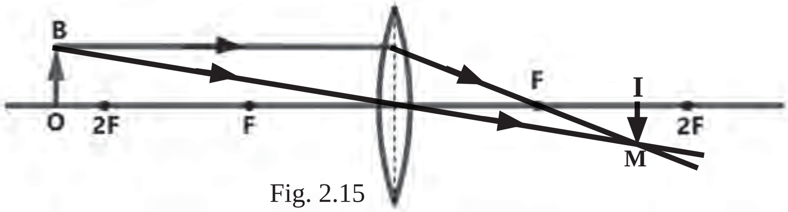


Fig. 2.15

- Position of the image : Between F and 2F on the other side
- Characteristics of the image :
  - Inverted
  - Diminished
  - Real

Object at 2F

Fig. 2.16

- Position of the image :
- Characteristics of the image :
    - ➢

PhET→ Geometric Optics-Basics

Object Between F and 2F

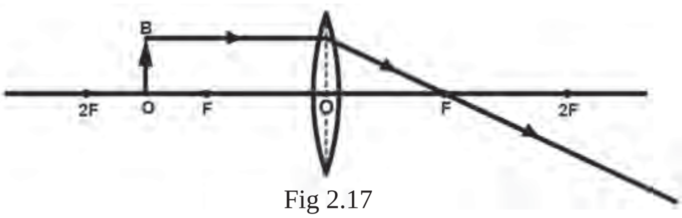


Fig 2.17

- Position of the image:
- Characteristics of the image :
    - ➢

Object at F

Draw the ray diagram of the image formation.

- Do refracted rays converge?
- What would be the characteristics of the image?

Compare it with the experiment done earlier.

Does a convex lens always form only real images?

Object between F and the Lens

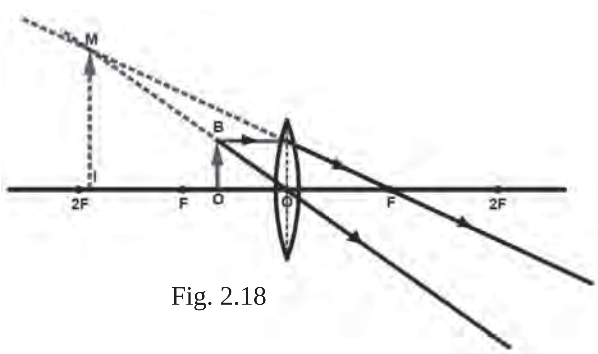


Fig. 2.18

Observe the ray diagram of the image formation when the object is placed between the focus (F) and the optic centre (O).

- Position of the image : On the same side of the object
- Characteristics of the image :
    - ➢ Erect ➢ Virtual ➢

- Here, do the light rays coming from the object and passing through the lens pass through a common point?

Aren't the light rays coming from the object diverging? When we observe this object from the other side of the lens, we can see the magnified image of the object.

Thus the image that cannot be obtained on the screen, but can only be seen, is virtual.

Images that cannot be captured on a screen, but can only be seen are virtual images.

Image Formation by a Concave Lens

We have seen how to form an image using a convex lens. Similarly try to form an image using a concave lens. What is your finding?

Ray diagram of image formation by concave lens

Complete table 2.4 by observing the change in the path of light as it passes through a concave lens.

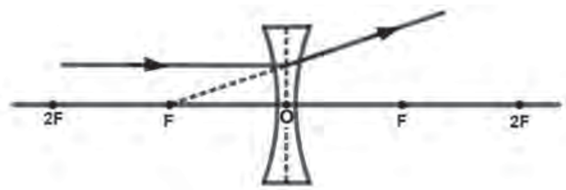


Fig. 2.19 (a)

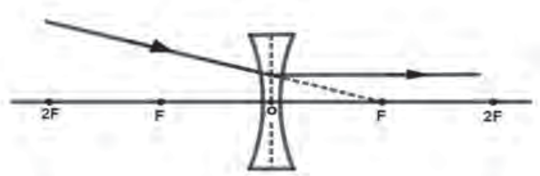


Fig. 2.19 (b)

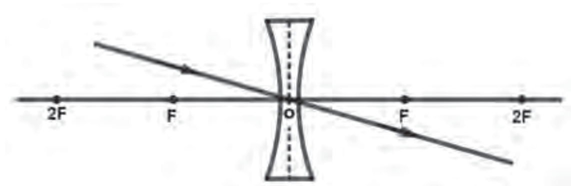


Fig. 2.19 (c)

Rays of light parallel to the optic axis incident on a concave lens (after refraction)	
Light rays passing through the lens directed towards the principal focus on the other side (after refraction)	
Rays of light passing through the optic centre	

Table 2.4

Object between F and 2F

- Position of the image :
- Characteristics of the image :

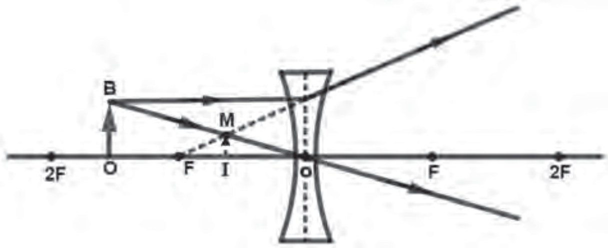


Fig. 2.20

Object between F and Lens

An object is placed between F and the lens. Draw the ray diagram of the image formation in the science diary.

- Position of the image :
- Characteristics of the image:

Complete the given table based on the image formation by a concave lens.

Position of the object	Position of the image	Characteristics of the image		
		Real/ Virtual	Inverted/ Erect	Magnified/ diminished
Between F and 2F				
Between F and the Lens				

Table 2.5

On analysing table 2.5, it is understood that the image formed by a concave lens is virtual. What could be the reason for this?

As concave lens diverges light rays, the image it forms is always virtual. The position of the image is always between F and the lens on the same side of the object.

Can we calculate how far the image from the lens will be, if an object is placed at a given distance?

Lens Equation

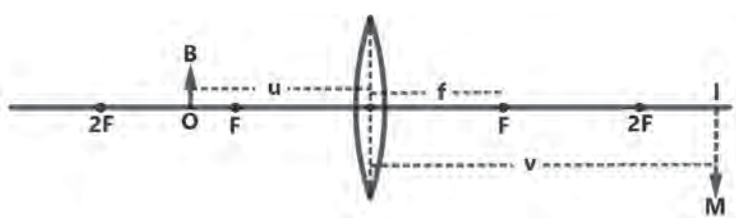


Fig. 2.21

With regard to the image formation by a lens, we consider the focal length, the distance from the optic centre to the object and to the image. Observe these distances marked in the figure.

- Which letter indicates the distance to the object (OB) in the figure?
- Which distance does the letter v represent in the figure?
- Which distance does the letter f stand for?

As the lenses and positions of the object change, appropriate signs for the measurements related to the lens should be considered.

Cartesian sign convention

While solving mathematical problems related to lens, appropriate signs should be given for the measurements. These rules can be used in lenses in general.

- All distances should be measured from the optic centre of the lens.
- Distances measured in the same direction as the incident ray should be considered positive and those in the opposite direction should be considered negative.
- Distances measured above the optic axis should be considered positive and those below should be considered negative.

Cartesian sign convention can be used to solve mathematical problems using general equations in different contexts. There is no need to consider whether the object is on the left or right side of the lens. Observe figures 2.22 (a) and (b) and complete table 2.6 based on Cartesian sign convention.

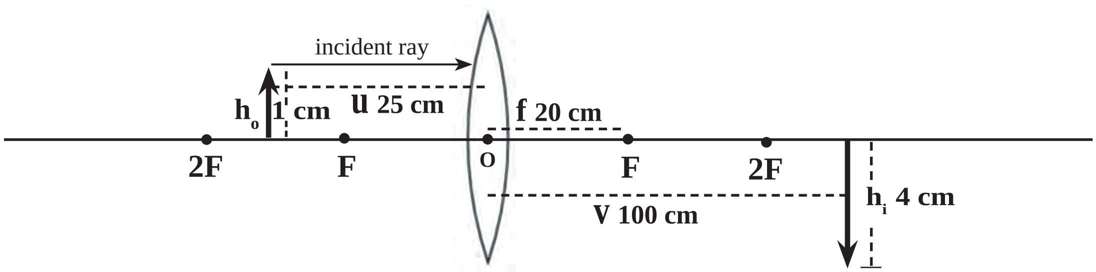


Fig 2.22 (a)

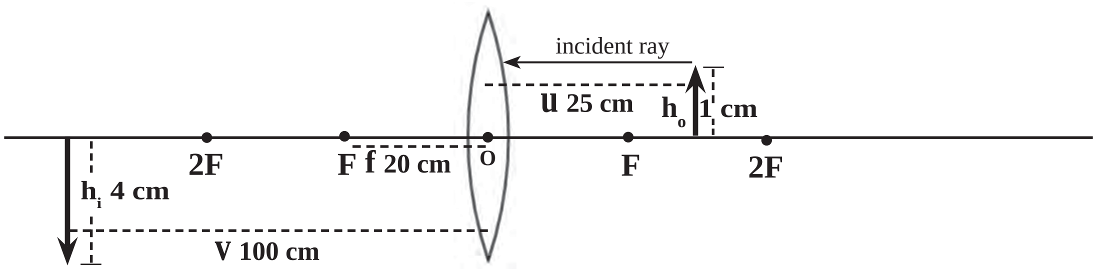


Fig 2.22 (b)

Measurements	Fig. 2.22 (a)		Fig. 2.22 (b)	
	Positive/ negative	Reason	Positive/ negative	Reason
u	negative (-25 cm)	measured from the optic centre in the opposite direction of the incident ray	negative (-25 cm)	measured from the optic centre in the opposite direction of the incident ray
v				
f				
h_o				
h_i				

Table 2.6

The position of the image formed by a lens is determined by the position of the object and the focal length of the lens. The relation between them is made clear by the lens equation.

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$$

f = focal length; u = distance to the object; v = distance to the image

This equation can also be written as

$$f = \frac{uv}{u - v}$$

- Observe the distance to the object and the distance to the image depicted in the figure.

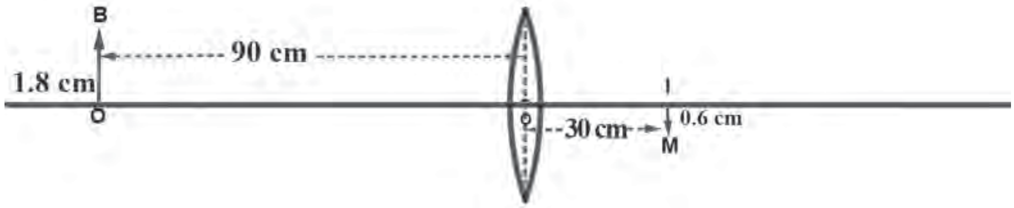


Fig 2.23

a) Write down the measurements using the sign conventions.

b) Calculate the focal length of the lens.

a) Distance to the object, u = − 90 cm (measurement in a direction opposite to that of the incident ray)

Distance to the image, v = + 30 cm (measurement in the same direction as that of the incident ray)

b) $f = \frac{uv}{u - v}$

$$f = \frac{-90\text{ cm} \times {}^{+}30\text{ cm}}{-90\text{ cm} - {}^{+}30\text{ cm}} = \frac{-2700\text{ cm}^2}{-120\text{ cm}} = +22.5\text{ cm}$$

Since the focal length is positive, it can be understood that the principal focus is real and the lens used here is convex.

Is it possible to find how many times the size of the image is to the size of the object?

Magnification

Magnification refers to how many times the height of the object is to the height of the image.

Magnification is the ratio of the height of the image to the height of the object. It has no unit.

$$\text{Magnification} = \frac{\text{Height of the image}}{\text{Height of the object}} = \frac{h_i}{h_o}$$

OR

$$\text{Magnification} = \frac{\text{Distance to the image}}{\text{Distance to the object}} = \frac{v}{u}$$

$$\mathbf{m = \frac{h_i}{h_o} = \frac{v}{u}}$$

According to Cartesian sign convention, it can be understood that the image is erect if magnification is positive and the image is inverted if magnification is negative.

Calculate the magnification using the measurements in the figure 2.23 and write down the characteristics.

$$m = \frac{h_i}{h_o} \quad \text{or} \quad m = \frac{v}{u}$$

$u = -90$ cm $\quad h_o = +1.8$ cm $\quad v = +30$ cm $\quad h_i = -0.6$ cm

$$m = \frac{h_i}{h_o} = \frac{-0.6}{+1.8} = -\frac{1}{3}$$

$$m = \frac{v}{u} = \frac{+30}{-90} = -\frac{1}{3}$$

Since magnification is less than one, it can be understood that the image is smaller than the object.

The negative sign of the magnification indicates that the image is inverted and real.

Complete table 2.7 by considering the relation of magnification with the nature of the image.

Nature of the image	Sign of magnification (positive / negative)
Erect	
Inverted	
Real	
Virtual	

Table 2.7

An object of height 2 cm is placed on the optic axis at a distance of 12 cm from the optic centre of a convex lens. Focal length of the convex lens is 6 cm.

a) Draw a ray diagram based on the given measurements and write down the characteristics of the image.

b) Calculate the magnification by measuring the height of the image.

A concave lens has a focal length of 20 cm. An object of height 2 cm is placed at a distance 30 cm from the lens on the optic axis.

a) Calculate the distance from the lens to the image.

b) How much will the magnification be? What are the characteristics of the image?

Which are the instruments where lenses are used?

The position, nature and size of the images formed by different types of lenses have been found out. Some of the instruments that make use of these are :

Spectacles, simple microscope, compound microscope and telescope.

Have you noticed the prescriptions given by doctors to buy spectacles? Can you identify what is written on it?

- What does +2.00 refer to?

It refers to the power of the lens in the spectacles.

Dr.Brook Pettre
MBBS, DO M.S-Ophthalmology

Rx	SPH	CYL	AXIS	VN	PD
R.E.	+2.00	+0.50	130	6/6	-
L.E.	+2.00	+0.50	140	6/6	-

Remarks : Bptre

Fig 2.24

Power of Lens

Power is a term related to the focal length of the lens. The power of a lens is its ability to converge or diverge light rays incident on it.

Power is the reciprocal of focal length. The lower the focal length, the higher the power of the lens. Power $P = \frac{1}{f}$

The SI unit of power is dioptre. It is denoted by the letter D.

The power of a lens with a focal length of one metre is one dioptre (1 D).

What is the power of a concave lens of focal length 25 cm?

Focal length of concave lens = – 25 cm

Since the focal length is considered in metre while calculating the power of the lens in the SI unit,

$$f = \frac{-25}{100}\,m = -0.25\,m$$

$$\text{Power } P = \frac{1}{f}$$

$$P = \frac{1}{-0.25\,m} = -4\,D$$

If the power is negative, it is identified as concave lens.

- If it is a convex lens, what will be the sign of the power?
- What type of lens is in the doctor's prescription (Fig. 2.24)?

Let's take a look at some of the devices that use lenses.

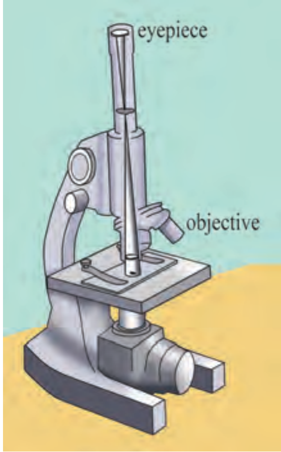


Fig. 2.25 (a)

Compound Microscope

What is the use of a compound microscope?

Have you ever wondered how they magnify objects?

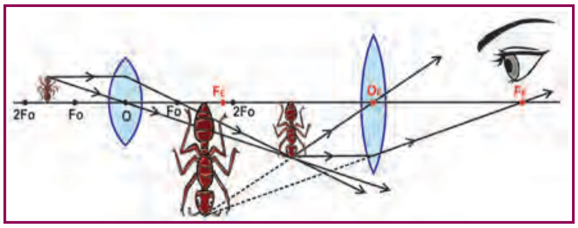
The two main parts of a compound microscope are objective and eyepiece.

Objective :

An objective is a lens placed close to the object to be observed.

Eyepiece :

Eyepiece is the lens through which the image formed by the objective lens is observed. The focal length of the eyepiece is greater than that of the objective.



Magnification is not according to the scale

Fig. 2.25 (b)

Observe figure 2.25 (b) and complete table 2.8 identifying the characteristics of lenses used in compound microscope.

Lens	Convex lens / Concave lens	When objective and eyepiece lenses are compared	Characteristics of the image formed
		focal length more / less	
Objective			
Eyepiece			

Table 2.8

- Where should the object to be observed be kept with reference to the objective?
  (beyond $2F_o$ / between F_o and $2F_o$)
- What is the position of the image formed by the objective?
- What are the characteristics of this image?
- What would be the characteristics of the image formed by the eye piece?
  - ➢ Erect ➢

The object should be placed between F_o and $2F_o$ of the objective. A large, real, inverted image of the object is formed beyond $2F_o$ of the objective. This acts as the object for the eyepiece. Its position is between the optic centre and F_e of the eyepiece. A large and virtual image of this can be seen through the eyepiece.

- Increasing the focal length of the objective lens will not be beneficial in the compound microscope. What is the reason?

If the focal length of the objective lens is longer, the size of image will be smaller. That means the magnification will be lesser. So the objective lens should have a shorter focal length.

A microscope is usually provided with a range of objective lenses to obtain suitable magnification while observing micro objects.

Refracting Telescope

Telescopes are instruments to see distant objects clearly. The invention of the telescope brought about a great change in the study of the universe. There are different types of telescopes that make use of reflection and refraction of light. Let us see the functioning of a telescope whose working is based on the refraction of light.

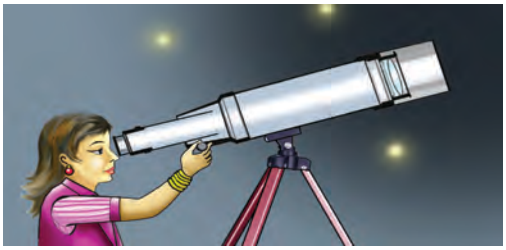


Fig 2.26 (a)

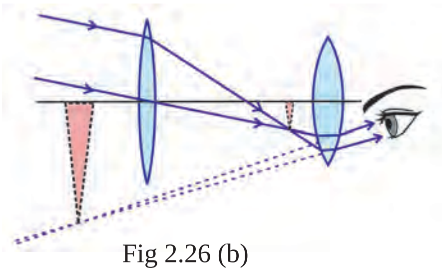


Fig 2.26 (b)

Observe figures 2.26 (a) and 2.26 (b).

The main parts of the telescope are objective and eyepiece. Identify their characteristics and complete the table given below.

Lens	When objective and eyepiece lenses are compared		Characteristics of the image formed
	focal length more / less	aperture more / less	
Objective			
Eyepiece			

Table 2.9

Let's see how the image is formed in the telescope.

- Where is the position of the object?

  (far away / nearby)

- Focal length of the objective is
  (lesser / greater)
- What are the characteristics of the image formed by the objective?
  (small and real / large and virtual)
- Which of the lenses use this image as its object?
  (objective / eyepiece)
- Through which lens is the image viewed?
  (objective / eyepiece)
- The image we see through the eyepiece is
  (real / virtual)

In a telescope, the objective forms a small, real and inverted image of a distant object.

It is the image formed by the objective that we observe through the eyepiece. Since the position of this image is between the focus of the eyepiece and the optic centre, we can see the virtual image formed by the eyepiece.

It is clear that while making a telescope, the length of the telescope tube should be taken by considering the focal length of the objective lens and the focal length of the eyepiece lens.

Now haven't you understood how distant objects can be seen clearly in a telescope?

Let's make a telescope.

Making a Telescope

Materials required

Approximately 1 m long PVC pipe (having a diameter suitable enough to fix the lens), convex lens (of diameter 5 cm /10 cm and focal length 50 cm /100 cm), plastic bottle, eyepiece used for watch repair.

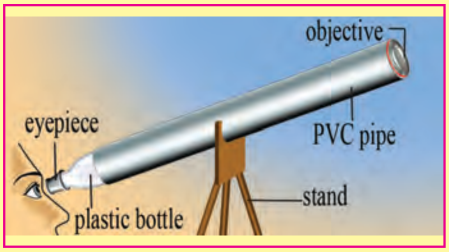


Fig. 2.27

Things to be considered while choosing lenses :

- The focal length and aperture of the objective lens should be greater.
- The focal length and aperture of the eyepiece lens should be lesser.
- Use high quality lenses.

Method of Construction

Fix a convex lens of approximately 10 cm diameter and focal length 100 cm at one end of a PVC pipe having approximately 10 cm diameter. Cut the bottom of a plastic bottle of two litre and insert it into the other end of the pipe. Insert and fix the eyepiece (used for watch repair) at the mouth of the plastic bottle. Distant objects can be observed by adjusting the distance between the eye piece and the objective by pushing or pulling the plastic bottle.

Special Attention

Do not look at the sun through a telescope. It is preferable to fix a telescope on a stand while observing other celestial bodies.

- Why is it said not to look at the sun through a telescope? Search and find out.

Let's Assess

1. The focal length of a convex lens is 20 cm. An object of height 3 cm is located at a distance of 60 cm from its optic centre on the optic axis.
   a) Calculate the height of the image.
   b) What are the characteristics of the image obtained?
2. The focal length of a lens is 20 cm.
   a) An object is placed 30 cm away from the lens. Calculate how far the screen should be placed to get a clear image.
   b) If the height of the object is 1.2 cm, what will be the height of the image appearing on the screen?
3. The focal length of a convex lens is 100 mm. An object of height 15 mm is located 60 mm from the optic centre on its optic axis.
   a) Draw its ray diagram on a graph paper and find the position and height of the image.
   b) Calculate the magnification if the distance to the object is 20 mm.

4. Four statements are given regarding the image formed by a concave lens. Find and choose the correct answer.

   i. It will be diminished and inverted

   ii. It will be diminished and virtual

   iii. It will be magnified and virtual

   iv. It will be diminished and erect

   a) Only the second statement is true

   b) Only the first statement is true

   c) Second statement and fourth statements are true

   d) Only the third statement is true

5. A concave lens has a focal length of 50 cm. What will be its power?

   a) +2 D   b) +0.5 D   c) −2 D   d) −0.5 D

6. Find the most appropriate statement related to a telescope.

   a) The objective lens has a shorter focal length and the eyepiece lens has a longer focal length.

   b) The objective lens has a longer focal length and the eyepiece has a shorter focal length.

   c) Objective lens and eyepiece lens are concave lenses.

   d) Objective lens will be concave lens and eyepiece lens will be convex lens.

7. When an object is placed in front of a lens, the image formed is inverted.

   a) Is it real or virtual?

   b) What will you do if you want another image of this obtained image to be real, erect and of the same size?

8. When an object is placed at the principal focus of a lens, an image that is erect and diminished is obtained.

   a) What kind of lens is this?

   b) Draw the ray diagram of the image formation.

9. The image (IM) obtained when an object is placed in front of a lens is depicted.

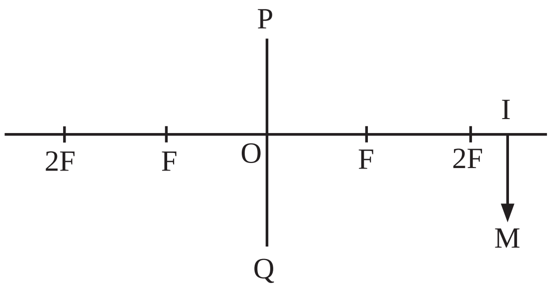


Fig. 2.28

a) If PQ is a lens in the figure, what type of lens does PQ represent?

b) Complete the ray diagram and find the position of the object.

c) The height of the object is .... than the height of the image (greater / lesser).

10. Match the items in the columns A, B and C appropriately.

A	B	C
Magnification	$\frac{1}{f}$	h_i negative
Power of lens	Inverted image	$\frac{v}{u}$
Real image	$\frac{h_i}{h_o}$	h_i positive
	Erect image	dioptre

Table 2.10

Extended activities

1. You may know people who use spectacles for various purposes. Collect, tabulate and analyse information regarding the type of lens used in different types of spectacles, the power of lens, age of the users and the problems faced by them.

2. Collect a transparent polythene bag. Fill it with water and tie to get it almost in the shape of a sphere. Use it as a convex lens to form various sized images of a burning candle.