7. Lenses

- Lenses
- Sign convention
- Defects of vision and their correction
- Uses of lenses
- Ray diagram for refracted light
- Working of human eye and lens

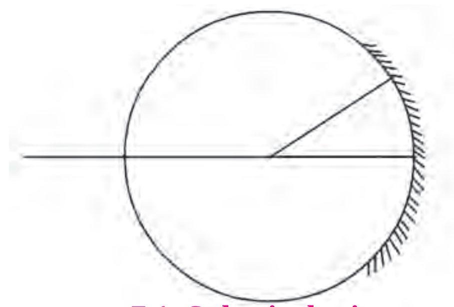
Can you recall?

1. Indicate the following terms related to spherical mirrors in figure 7.1: poles, centre of curvature, radius of curvature, principal focus.
2. How are concave and convex mirrors constructed?

Lenses

You must have seen lenses used in day to day life. Some examples are: the lenses used by old persons for reading, lens embedded in the front door of the house, the lens which the watch maker attaches to his eye etc.

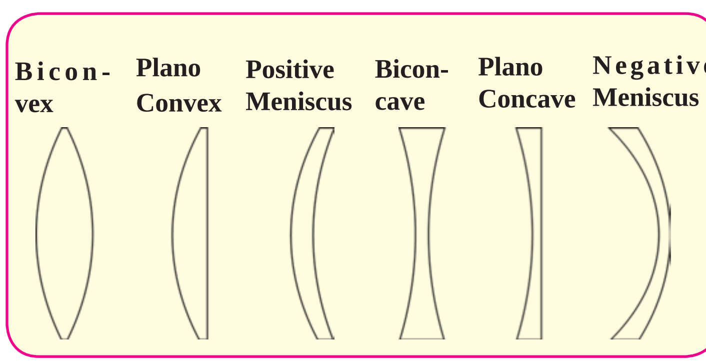
Lenses are used in spectacles. They are also used in telescopes as you have learnt in the previous standard.



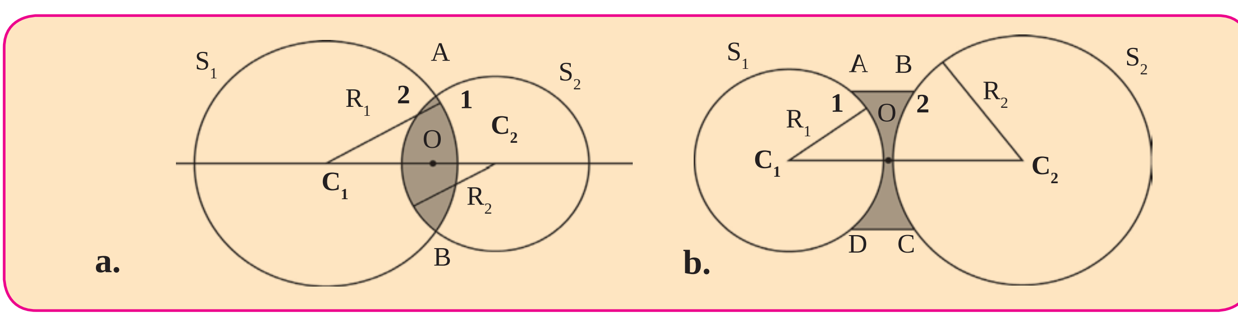
7.1 Spherical mirror

A lens is a transparent medium bound by two surfaces. The lens which has two spherical surfaces which are puffed up outwards is called a convex or double convex lens. This lens is thicker near the centre as compared to the edges. The lens with both surfaces spherical on the inside is called a concave or double concave lens. This lens is thinner at the centre as compared to its edges.

Different types of lenses are shown in figure 7.2. A ray of light gets refracted twice while passing through a lens, once while entering the lens and once while emerging from the lens. The direction of the ray changes because of these refractions. Both the surfaces of most lenses are parts of a sphere.



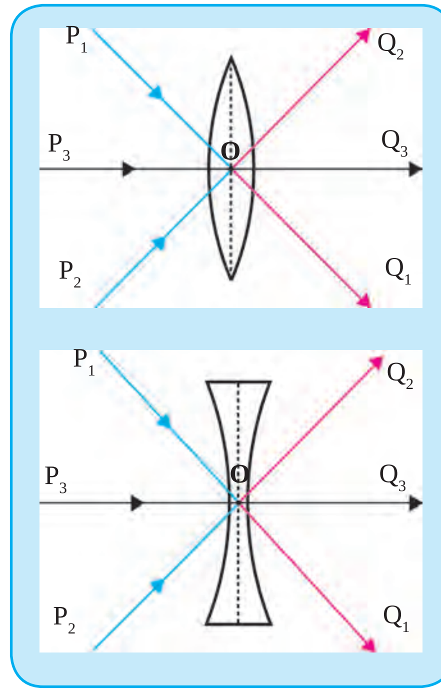
7.2 Types of lenses



7.3 Cross-sections of convex and concave lenses.

The cross-sections of convex and concave lenses are shown in parts a and b of figure 7.3. The surface marked as 1 is part of sphere S_1 while surface 2 is part of sphere S_2.

Centre of curvature (C) : The centres of spheres whose parts form surfaces of the lenses are called centres of curvatures of the lenses. A lens with both surfaces spherical, has two centres of curvature C_1 and C_2.
Radius of curvature (R) : The radii (R_1 and R_2) of the spheres whose parts form surfaces of the lenses are called the radii of curvature of the lens.
Principal axis : The imaginary line passing through both centres of curvature is called the principal axis of the lens.
Optical centre (O) : The point inside a lens on the principal axis, through which light rays pass without changing their path is called the optical centre of a lens. In figure 7.4, rays P_1Q_1, P_2Q_2 passing through O are going along a straight line. Thus O is the optical centre of the lens.
Principal focus (F) : When light rays parallel to the principal axis are incident on a convex lens, they converge to a point on the principal axis. This point is called the principal focus of the lens. As shown in figure 7.5a F_1 and F_2 are the principal foci of the convex lens.

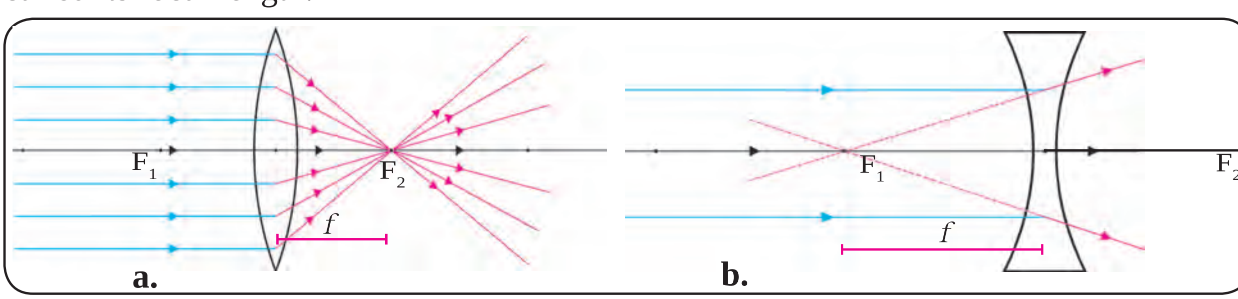


7.4 Optical centre of a lens

Light rays parallel to the principal axis falling on a convex lens come together i.e. get focused at a point on the principal axis. So this type of lens is called a converging lens.

Rays travelling parallel to the principal axis of a concave lens diverge after refraction in such a way that they appear to be coming out of a point on the principal axis. This point is called the principal focus of the concave lens. As shown in figure 7.5b F_1 and F_2 are the principal foci of the concave lens.

Light rays parallel to the principal axis falling on a concave lens go away from one another (diverge) after refraction. So this type of lens is called a divergent lens.
Focal length (f) : The distance between the optical centre and principal focus of a lens is called its focal length.



7. 5 Principal focus of a lens

Try this.

Material: Convex lens, screen, meter scale, stand for the lens etc.

Method:

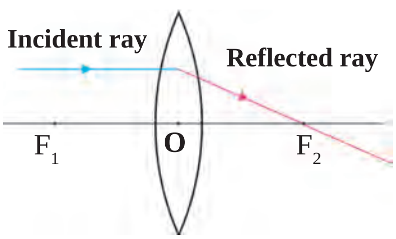
Keeping the screen fixed, obtain a clear image of a distant object like a tree or a building with the help of the lens on the screen. Measure the distance between the screen and the lens with the help of the meter scale. Now turn the other side of the lens towards the screen. Again obtain a clear image of the distant object on the screen by moving the lens forward or backward. Measure the distance between the screen and the lens again.

What is this distance between the lens and the screen called? Discuss the relation between this distance and the radius of curvature of the lens with your teacher. The image of a distant object is obtained close to the focus of the lens, hence, the above distance is the focal length of the lens. What will happen if you use a concave lens in this experiment?

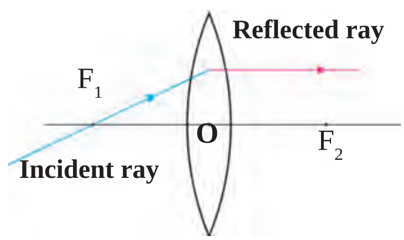
Ray diagram for refraction : You have learnt the rules for drawing ray diagrams for spherical mirrors. Similarly, one can obtain the images formed by lenses with the help of ray diagrams. One can obtain the position, size and nature of the images with the help of these diagrams.

Images formed by convex lenses

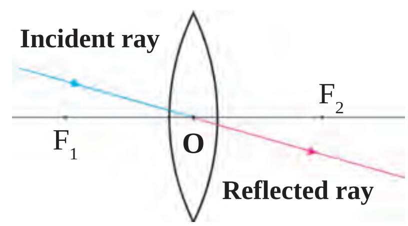
One can use following three rules to draw ray diagrams of images obtained by convex lenses.



Rule 1: When the incident ray is parallel to the principal axis, the refracted ray passes through the principal focus.



Rule 2: When the incident ray passes through the principal focus, the refracted ray is parallel to the principal axis.



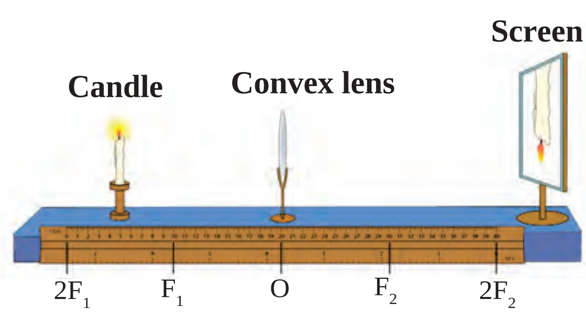
Rule 3: When the incident ray passes through the optical centre of the lens, it passes without changing its direction.

Try This

Material: A convex lens, screen, meter scale, stand for the lens, chalk, candle etc.

Method:

1. Draw a straight line along the centre of a long table.
2. Place the lens on the stand at the central point (O) of the line.
3. Place the screen on one side, of the lens. Move it along the line so as to get a clear image of a distant object. Mark its position as F_1.
4. Measure the distance between O and F_1. Mark a point at distance $2F_1$ from O on the same side of F_1 and mark it as $2F_1$.



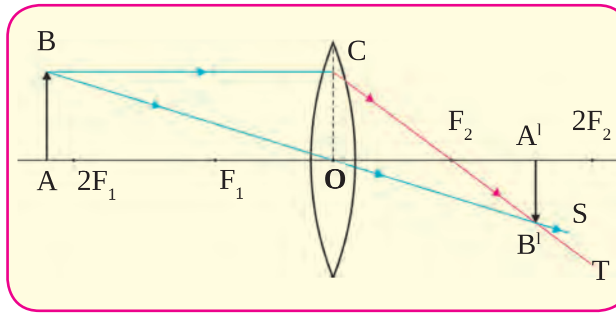
7.6 Arrangement for the experiment

5. Repeat actions 3 and 4 on the other side of the lens and mark F_2 and $2F_2$ on the straight line.
6. Now place the burning candle on the other side of lens far beyond $2F_1$. Place the screen on the opposite side of the lens and obtain a clear image of the candle by moving it forward or backward along the line. Note the position, size and nature of the image.
7. Repeat action 6 by placing the candle beyond $2F_1$, at $2F_1$, between $2F_1$ and F_1, at F_1 and between F_1 and O. Note your observations.

Can you recall?

What are real and virtual images? How will you find out whether an image is real or virtual? Can a virtual image be obtained on a screen?

As shown in the figure 7.7, an object AB is placed beyond the point $2F_1$. The incident ray BC, starting from B and going parallel to the principal axis, goes through the principal focus F_2 after refraction along CT. The ray BO, starting from B and passing through the optical centre O of the lens goes along OS without changing its direction. It intersects CT in B′. This means that the image of B is formed at B′.

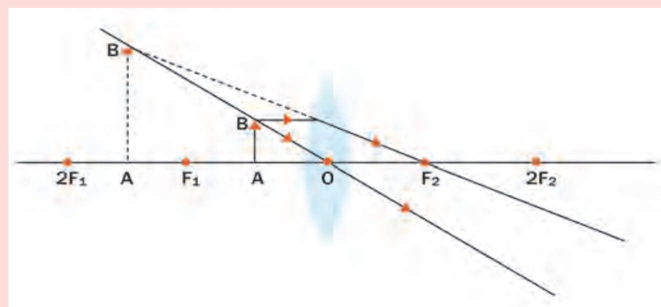


7.7 Real image formed by a convex lens

As A is situated on the principal axis, its image will also be located along the principal axis at A′, vertically above B′. Thus, A′B′ will be the image of AB formed by the lens. So we learn that if an object is placed beyond $2F_1$, the image is formed between F_2 and $2F_2$. It is real and inverted and its size is smaller than that of the object.

Observe

Study figure 7.8. Determine the position, size and nature of images formed for different positions of an object with the help of ray diagrams. Check your conclusions and observations in the previous activity with those given in the table.



7.8 Images formed by position of an object

Images formed by convex lenses for different positions of the object.

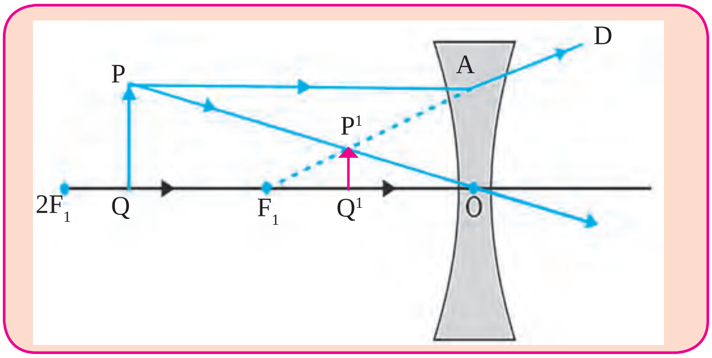
S. No.	Position of the object	Position of the image	Size of the image	Nature of the image
1	At infinity	At focus F_2	Point image	Real and inverted
2	Beyond $2F_1$	Between F_2 and $2F_2$	Smaller	Real and inverted
3	At $2F_1$	At $2F_2$	Same size	Real and inverted
4	Between F_1 and $2F_1$	Beyond $2F_2$	Larger	Real and inverted
5	At focus F_1	At infinity	Very large	Real and inverted
6	Between F_1 and O	On the same side of the lens as the object	Very large	Virtual and erect

Images formed by concave lenses

We can obtain the images obtained by concave lenses using the following rules.

1. When the incident ray is parallel to the principal axis, the refracted ray when extended backwards, passes through the focus.
2. When the incident ray passes through the focus, the refracted ray is parallel to the principal axis.

As shown in figure 7.9, object PQ is placed between F_1 and $2F_1$ in front of a concave lens. The incident ray PA, starting from P and going parallel to the principal axis goes along AD after refraction. If AD is extended backwards, it appears to come from F_1. The incident ray PO, starting from P and passing through O, goes along the same direction after refraction. PO intersects the extended ray AF_1 at P^1, i.e. P^1 is the image of P.



7.9 Image formed by a concave lens

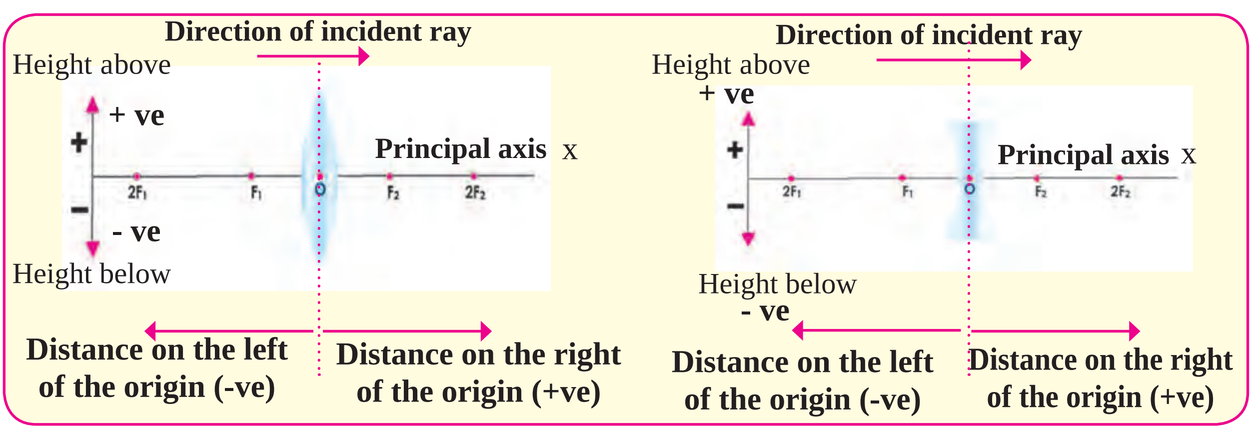
As the point Q is on the principal axis, its image is formed along the axis at the point Q^1 directly below P^1. Thus, P^1Q^1 is the image of PQ. The image formed by a concave lens is always virtual, erect and smaller than the object.

Sr. No.	Position of the object	Position of the image	Size of the image	Nature of the image
1	At infinity	On the first focus F_1	Point image	Virtual and erect
2	Anywhere between optical centre O and infinity	Between optical centre and focus F_1	Small	Virtual and erect

Can you recall?

What is the Cartesian sign convention used for spherical mirrors?

Sign convention



7.10 Cartesian sign convention

Lens formula

The formula showing the relation between distance of the object (u), the distance of the image (v) and the focal length (f) is called the lens formula. It is given below.

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

The lens formula is same for any spherical lens and any distance of the object from the lens. It is however necessary to use the sign convention properly.

According to the Cartesian sign convention, the optical centre (O) is taken to be the origin. The principle axis is the X-axis of the frame of reference. The sign convention is as follows.

1. The object is always placed on the left of the lens, All distances parallel to the principal axis are measured from the optical centre (O).
2. The distanced measured to the right of O are taken to be positive while those measured to the left are taken to be negative.
3. Distances perpendicular to the principal axis and above it are taken to be positive.
4. Distances perpendicular to the principal axis and below it are taken to be negative.
5. The focal length of a convex lens is positive while that of a concave lens is negative.

Magnification (M)

The magnification due to a lens is the ratio of the height of the image (h_2) to the height of the object (h_1).

$$\text{Magnification} = \frac{\text{Height of the Image}}{\text{Height of the object}} \quad \text{i.e. } M = \frac{h_2}{h_1} \qquad \text{.................. (1)}$$

The magnification due to a lens is also related to the distance of the object (u) and that of the image (v) from the lens.

$$\text{Magnification} = \frac{\text{Distance of the Image}}{\text{Distance of the object}} \quad \text{i.e. } M = \frac{v}{u} \qquad \text{.................. (2)}$$

Use your brain power !

From equations (1) and (2) what is the relation between h_1, h_2, u and v?

Take two convex lenses of different sizes. Collect sunlight on a paper using one of the lenses. The paper will start burning after a while. Note the time required for the paper to start burning. Repeat the process for the second lens. Is the time required the same in both cases? What can you tell from this ?

Power of a lens

The capacity of a lens to converge or diverge incident rays is called its power (P). The power of a lens depends on its focal length. Power is the inverse of its focal length (f); f is expressed in meters.

The unit of the power of a lens is Dioptre (D).

$$P = \frac{1}{f\,(m)} \qquad \qquad 1 \text{ Dioptre} = \frac{1}{1\,m}$$

Combination of lenses

If two lenses with focal lengths f_1 and f_2 are kept in contact with each other, the combination has an effective focal length given by

$$\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2}$$

If the powers of the two lenses are P_1 and P_2 then the effective power of their combination is $P = P_1 + P_2$. Thus, when two lenses are kept touching each other, the power of the combined lens is equal to the sum of their individual powers.

Solved Examples

1. An object is placed vertically at a distance of 20 cm from a convex lens. If the height of the object is 5 cm and the focal length of the lens is 10 cm, what will be the position, size and nature of the image? How much bigger will the image be as compared to the object?

Given:
Height of the object (h_1) = 5 cm,
focal length (f) = 10 cm,
distance of the object (u) = - 20 cm
Image distance (v) = ?,
Height of the image (h_2) = ?,
Magnification (M) = ?

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

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

$$\frac{1}{v} = \frac{1}{-20} + \frac{1}{10}$$

$$\frac{1}{v} = \frac{-1+2}{20}$$

$$\frac{1}{v} = \frac{1}{20},$$

v = 20 cm

The positive sign of the image distance shows that image is formed at 20 cm on the other side of the lens.

$$\text{Magnification (M)} = \frac{h_2}{h_1} = \frac{v}{u}$$

$$h_2 = \frac{v}{u} \times h_1$$

$$h_2 = \frac{20}{-20} \times 5$$

$$h_2 = (-1) \times 5$$

$$h_2 = -5 \text{ cm}$$

$$M = \frac{v}{u} = \frac{20}{-20} = -1$$

The negative sign of the height of the image and the magnification shows that the image is inverted and real. It is below the principal axis and is of the same size as the object.

2. The focal length of a convex lens is 20 cm. What is its power?
Given: Focal length = f = 20 cm = 0.2 m
Power of the lens = P = ?

$$P = \frac{1}{f\,(m)} = \frac{1}{0.2} = 5 \text{ D}$$

The power of the lens is 5 D.

Observe and Discuss

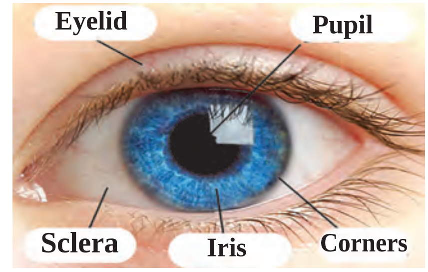
Study the model depicting the construction of human eye with the help of teachers.

Human eye and working of its lens

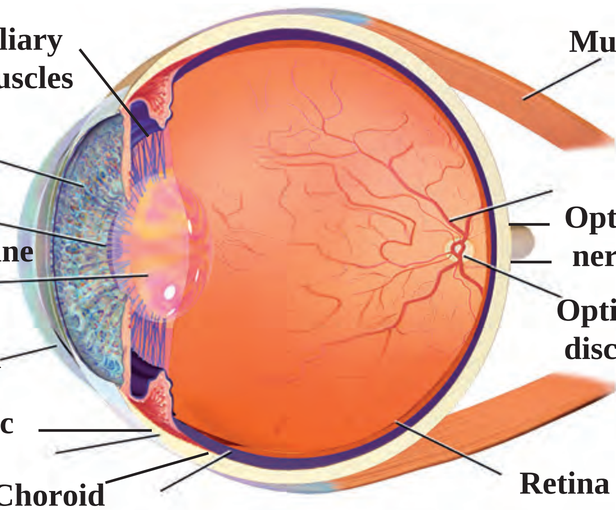
There is a very thin transparent cover (membrane) on the human eye. This is called cornea (fig 7.11). Light enters the eye through it. Maximum amount of incident light is refracted inside the eye at the outer surface of the cornea. There is a dark, fleshy screen behind the cornea. This is called the Iris. The colour of the Iris is different for different people. There is a small hole of changing diameter at the centre of the Iris which is called the pupil. The pupil controls the amount of light entering the eye. If the light falling on the eye is too bright, pupil contracts while if the light is dim, it widens. On the surface of the iris, there is bulge of transparent layers. There is a double convex transparent crystalline lens, just behind the pupil. The lens provides small adjustments of the focal length to focus the image. This lens creates real and inverted image of an object on the screen inside the eye.

This screen is made of light sensitive cells and is called the retina. These cells get excited when light falls on them and generate electric signals. These signals are conveyed to the brain through optic nerve. Later, the brain analyses these signals and converts them in such a way that we perceive the objects as they actually are.

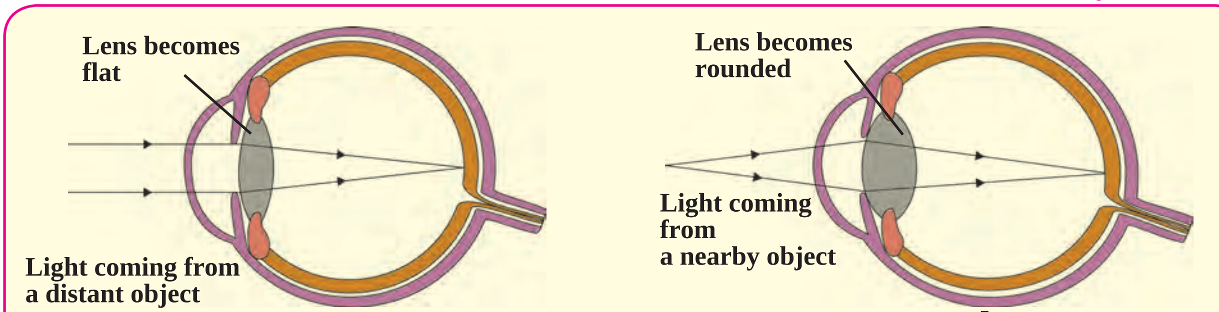
While seeing objects at large, infinite distances, the lens of the eye becomes flat and its focal length increases as shown in part a of the figure 7.12. While seeing nearby objects the lens becomes more rounded and its focal length decreases as shown in part b of the figure 7.12. This way we can see objects clearly irrespective of their distance.



The capacity of the lens to change its focal length as per need is called its power of accommodation. Although the elastic lens can change its focal length, to increase or decrease it, it can not do so beyond a limit.



7.11 Construction of human eye



7.12 The change in the shape of the lens while seeing distant and nearby objects.

The minimum distance of an object from a normal eye, at which it is clearly visible without stress on the eye, is called as minimum distance of distinct vision. The position of the object at this distance is called the near point of the eye, for a normal human eye, the near point is at 25 cm. The farthest distance of an object from a human eye, at which it is clearly visible without stress on the eye is called farthest distance of distinct vision. The position of the object at this distance is called the far point of the eye. For a normal human eye, the far point is at infinity.

Do you know ?

The eye ball is approximately spherical and has a diameter of about 2.4 cm. The working of the lens in human eye is extremely important. The lens can change its focal length to adjust and see objects at different distances. In a relaxed state, the focal length of healthy eyes is 2 cm. The other focus of the eye is on the retina.

Try this.

1. Try to read a book keeping it very far from your eyes.
2. Try to read a book keeping it very close to your eyes.
3. Try to read a book keeping it at a distance of 25 cm from your eyes.

At which time you see the alphabets clearly? Why?

Defects of Vision and their corrections

Some people can not see things clearly due to loss of accommodation power of the lenses in their eyes. Because of defective refraction by the lenses their vision becomes faint and fuzzy. In general, there are three types of refraction defects.

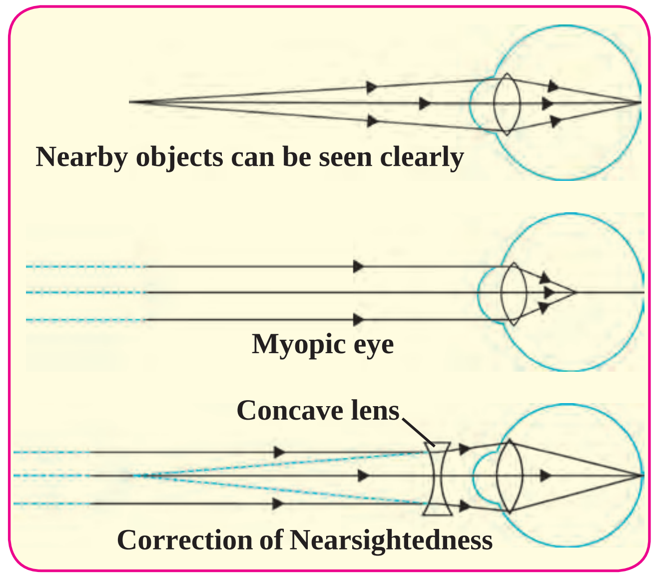
1. Nearsightedness/ Myopia

In this case, the eye can see nearby objects clearly but the distant objects appear indistinct.

This means that the far point of the eye is not at infinity but shifts closer to the eye. In nearsightedness, the image of a distant object forms in front of the retina (see figure 7.13). There are two reasons for this defect.

1. The curvature of the cornea and the eye lens increases.The muscles near the lens can not relax so that the converging power of the lens remains large.

2. The eyeball elongates so that the distance between the lens and the retina increases.



7.13 Nearsightedness

This defect can be corrected by using spectacles with concave lens of proper focal length. This lens diverges the incident rays and these diverged rays can be converged by the lens in the eye to form the image on the retina. The focal length of concave lens is negative, so a lens with negative power is required for correcting nearsightedness. The power of the lens is different for different eyes depending on the magnitude of their nearsightedness.

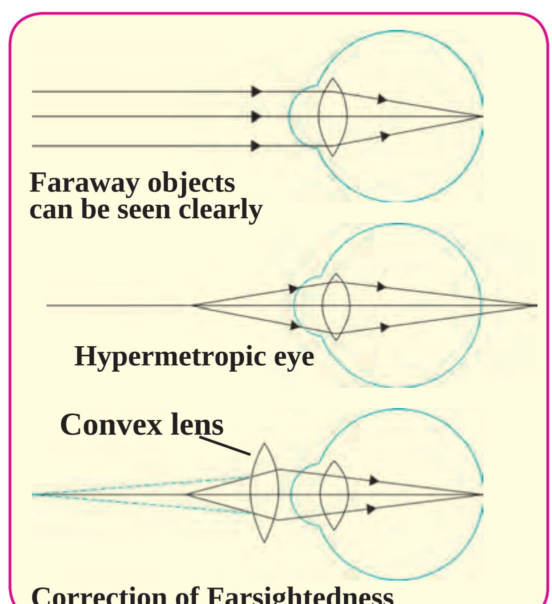
2. Farsightedness or hypermetropia

In this defect the human eye can see distant objects clearly but cannot see nearby objects distinctly. This means that the near point of the eye is no longer at 25 cm but shifts farther away. As shown in the figure (7.14), the images of nearby objects get formed behind the retina.

There are two reasons for farsightedness.

1. Curvature of the cornea and the eye lens decreases so that, the converging power of the lens becomes less.

2. Due to the flattening of the eye ball the distance between the lens and retina decreases.



7.14 Farsightedness

This defect can be corrected by using a convex lens with proper focal length. This lens converges the incident rays before they reach the lens. The lens then converges them to form the image on the retina.

The focal length of a convex lens is positive thus the spectacles used to correct farsightedness has positive power. The power of these lenses is different depending on the extent of farsightedness.

3. Presbyopia

Generally, the focusing power of the eye lens decreases with age. The muscles near the lens lose their ability to change the focal length of the lens. The near point of the lens shifts farther from the eye. Because of this old people cannot see nearby objects clearly.

Sometimes people suffer from nearsightedness as well as farsightedness. In such a case bifocal lenses are required to correct the defect. In such lenses, the upper part is concave lens and corrects nearsightedness while the lower part is a convex lens which corrects the farsightedness.

Try this.

1. Make a list of students in your class using spectacles.
2. Record the power of their lenses.

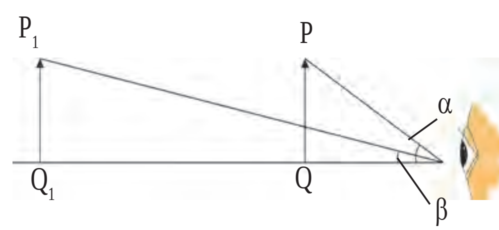
Find out and note which type of defect of vision they suffer from. Which defect is most common among the students?

Internet my friend

Get more information from the following websites.
www.physics.org
www.britannica.com

Apparent size of an object

Consider two objects, PQ and P_1Q_1, having same size but kept at different distances from an eye as shown in figure 7.15. As the angle α subtended by PQ at the eye is larger than the angle β subtended by P_1Q_1, PQ appears bigger than P_1Q_1. Thus, the apparent size of an object depends on the angle subtended by the object at the eye.



7.15 Apparent Size of An object.

Use your brain power !

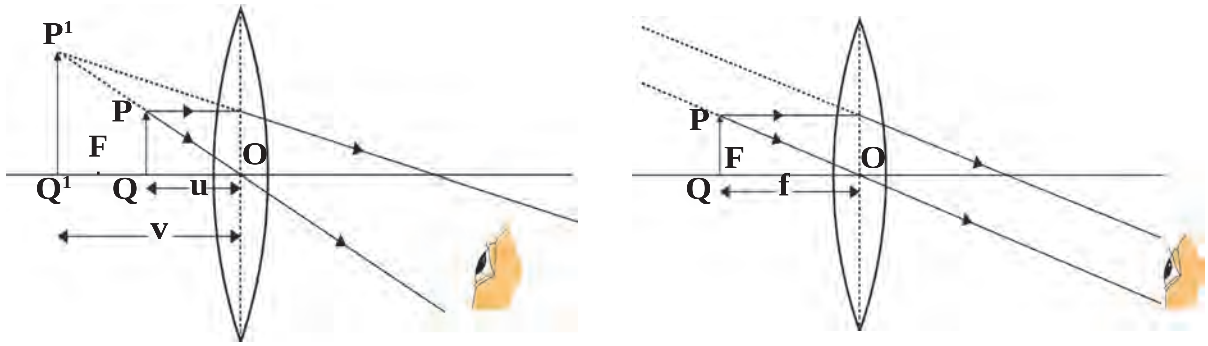
1. Why do we have to bring a small object near the eyes in order to see it clearly?
2. If we bring an object closer than 25 cm from the eyes, why can we not see it clearly even though it subtends a bigger angle at the eye?

Use of concave lenses

a. Medical equipments, scanner, CD player – These instuments use laser light. For proper working of these equipments concave lenses are used.
b. The peep hole in door- This is a small safety device which helps us see a large area outside the door. This uses one or more concave lenses.
c. Spectacles- Concave lenses are used in spectacles to correct nearsightedness.
d. Torch- Concave lens is used to spread widely the light produced by a small bulb inside a torch.
e. Camera, telescope and microscope- These instruments mainly use convex lenses. To get good quality images a concave lens is used in front of the eyepiece or inside it.

Use of convex lenses

a. Simple microscope : A convex lens with small focal length produces a virtual, erect and bigger image of an object as shown in the figure. Such a lens is called simple microscope or magnifying lens. One can get a 20 times larger image of an object using such microscopes. These are used for watch repair, testing precious gems and finding their defects.



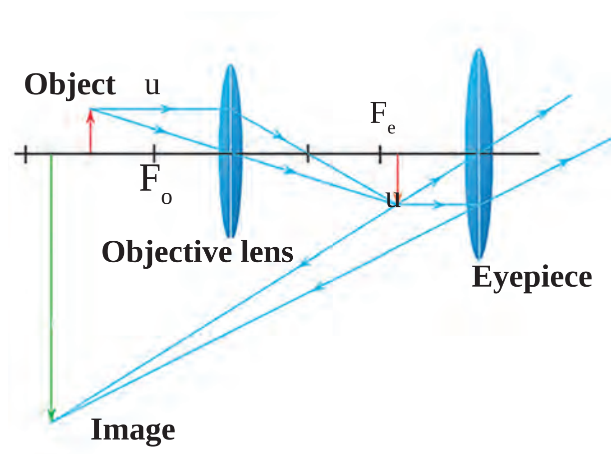
a. Object is close to the lens

b. Object is at the focus

7.16 Simple microscope

b. Compound microscope

Simple microscope is used to observe small sized objects. But minute objects like blood cells, cells of plants and animals and minute living beings like bacteria cannot be magnified sufficiently by simple microscope. Compound microscopes are used to study these objects. A compound microscope is made of two convex lenses: objective and eye piece. The objective has smaller cross-section and smaller focal length. The eye piece has bigger cross-section, its focal length is also larger than that of the objective. Higher magnification can be obtained by the combined effect of the two lenses.



7.17 A compound microscope

As shown in the figure 7.17, the magnification occurs in two stages. The image formed by the first lens acts as the object for the second lens. The axes of both lenses are along the same line. The lenses are fitted inside a metallic tube in such a way that the distance between can be changed.

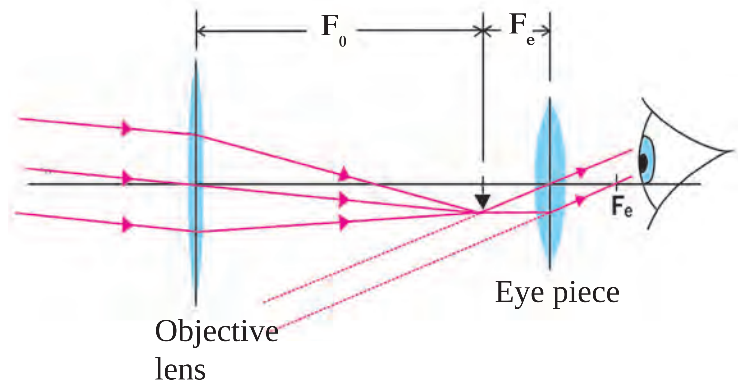
c. Telescope

Telescope is used to see distant objects clearly in their magnified form. The telescopes used to observe astronomical sources like the stars and the planets are called astronomical telescopes. Telescopes are of two types.

1. Refracting telescope – This uses lenses
2. Reflecting telescope – This uses mirrors and also lenses.

In both of these, the image formed by the objective acts as object for the eye piece which forms the final image. Objective lens has large diameter and larger focal length because of which maximum amount of light coming from the distant object can be collected.

On the other hand the size of the eyepiece is smaller and its focal length is also less. Both the lenses are fitted inside a metallic tube in such a way that the distance between them can be changed. The principal axes of both the lenses are along the same straight line. Generally, using the same objective but different eye pieces, different magnification can be obtained.



7.18 Refracting telescope

d. Optical instrument

Convex lenses are used in various other optical instruments like camera, projector, spectrograph etc.

e. Spectacles

Convex lenses are used in spectacles for correcting farsightedness .

Try this.

1. Take a burning incense stick in your hand and rotate it fast along a circle.
2. Draw a cage on one side of a cardboard and a bird on the other side. Hang the cardboard with the help of a thread. Twist the thread and leave it. What do you see and why?

Persistence of vision

We see an object because the eye lens creates its image on the retina. The image is on the retina as long as the object is in front of us. The image disappears as soon as the object is taken away. However, this is not instantaneous and the image remains imprinted on our retina for 1/16th of a second after the object is removed. The sensation on retina persists for a while. This is called persistence of vision. What examples in day to day life can you think about this?

Can you tell? How do we perceive different colours?

The retina in our eyes is made up of many light sensitive cells. These cells are shaped like a rod and like a cone. The rod like cells respond to the intensity of light and give information about the brightness or dimness of the object to the brain. The conical cells respond to the colour and give information about the colour of the object to the brain. Brain processes all the information received and we see the actual image of the object. Rod like cells respond to faint light also but conical cells do not. Thus we perceive colours only in bright light. The conical cells can respond differently to red, green and blue colours. When red colour falls on the eyes, the cells responding to red light get excited more than those responding to other colours and we get the sensation of red colour. Some people lack conical cells responding to certain colours. These persons cannot recognize those colours or cannot distinguish between different colours. These persons are said to be colour blind. Apart from not being able to distinguish between different colours, their eye sight is normal.

Exercise

1. **Match the columns in the following table and explain them.**

Column 1	Column 2	Column 3
Farsightedness	Nearby object can be seen clearly	Bifocal lens
Presbyopia	Far away object can be seen clearly	Concave lens
Nearsightedness	Problem of old age	Convex lens

2. **Draw a figure explaining various terms related to a lens.**
3. **At which position will you keep an object in front of a convex lens so as to get a real image of the same size as the object ? Draw a figure.**
4. **Give scientific reasons:**
   a. Simple microscope is used for watch repairs.
   b. One can sense colours only in bright light.
   c. We can not clearly see an object kept at a distance less than 25 cm from the eye.
5. **Explain the working of an astronomical telescope using refraction of light.**
6. **Distinguish between:**
   a. Farsightedness and Nearsightedness
   b. Concave lens and Convex Lens
7. **What is the function of iris and the muscles connected to the lens in human eye?**
8. **Solve the following examples.**
   i. Doctor has prescribed a lens having power +1.5 D. What will be the focal length of the lens? What is the type of the lens and what must be the defect of vision?
   (Ans: +0.67m, farsightedness)
   ii. 5 cm high object is placed at a distance of 25 cm from a converging lens of focal length of 10 cm. Determine the position, size and type of the image.
   (Ans : 16.7 cm, 3.3 cm, Real)
   iii. Three lenses having power 2, 2.5 and 1.7 D are kept touching in a row. What is the total power of the lens combination?
   (Ans : 6.2 D)
   iv. An object kept 60 cm from a lens gives a virtual image 20 cm in front of the lens. What is the focal length of the lens? Is it a converging lens or diverging lens?
   (Ans: -30 cm, lens is diverging or concave)

Project

Make a Power point presentation about the construction and use of binoculars.

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