Lenses- Worksheet

1. Look at the lenses in front of you and try to distinguish the different types of lenses? Describe each type and record its characteristics.

2. Using the lenses in front of you, look at different objects in the laboratory and record your observation. Which lens magnified the object and which made it look smaller?

(Use a ray box to answer questions 3 to 7)

3. A convex lens is called a converging lens whereas a concave lens is called a diverging lens. Using a ray box explain why these lenses are named is such a way.

4. Using the ray box, calculate the focal length f of the convex lens. Note, parallel rays of light converge at the focus point. The distance between the focal point and the lens is called the focal length f of the lens.

5. On which side is the focus point of a convex lens located with reference to the object?

6. Repeat step ‘4’ using a concave lens. Where is the focus point located in this case? Describe the way the image is formed and how this relates to step ‘3’ above.

7. The power of a lens is equal to the reciprocal of the focal length of the lens and is measured in diopeter. What is the power of each of the lenses in front of you? Take care of the signs! What is the sign of the focal length of concave and convex lenses? Record the values of the focal lengths for the two lenses in front of you.

(Use an optical bench to answer questions 8 to 7)

8. Can you project an image on a screen using the different types of lenses?

9. When an image can be seen on a screen we call this image a real image. If the picture looks fuzzy we call it a virtual image. Can you determine which lens produces a real image and which produces a virtual image? How does this relate to what you observed in step ‘5’ and ‘6’ above?

10. Starting as far away as possible from the object, use a convex lens to produce a sharp image on a screen and describe that image. Move the lens gradually toward the object and search each time for the best image. At what distance between the object and the lens does the image changes any of its properties? At what distance does it become virtual? Record your readings.

11. What are the variables that affect the appearance of the image?

12. Change the distance s between the object and the lens and obtain the best image. Record s and the corresponding distance s' between the lens and the image. Repeat this step several times and tabulate your data.

13. In your opinion what are the independent and the dependent variables.

14. Draw a graph between the reciprocal of the distance between the lens and the object and the reciprocal of the distance between the lens and the image. What is the relation between your two parameters?

15. The general law of lenses states that $1/f = 1/s + 1/s'$. From your graph, can you determine the focal length of the convex lens?

16. What does the vertical intercept in the graph represent? What should the slope of the line be?

17. Compare the value of f calculated from the graph with the values you found in step 10 and justify your answer?

18. Can you determine the focal length of a lens by just looking at it?

19. Nearsightedness and farsightedness are common defects in eyesight. In nearsightedness the image is formed in front of the retina and in farsightedness the image is formed behind the retina. Using the knowledge you obtained from this lab, determine which type of lens is suitable for correction of eyesight defects and explain why.

Lenses

All of us at some time or the other have seen or used lenses. Lenses naturally occur in eyes and are a good example. If natural lenses deteriorate, extra lenses (spectacles, contact lenses) have to be added for obtaining a better vision. Lenses are used in cameras, microscopes, binoculars and other optical equipment.

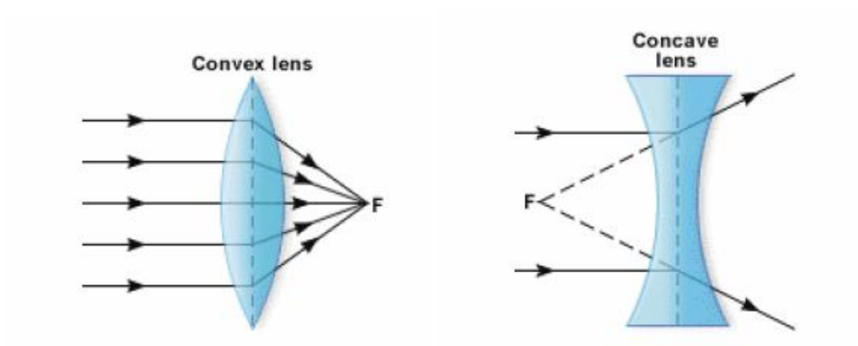
Lenses are optical elements used to focus or defocus images. They are generally made of high quality glass, but these days, high quality plastics or polymers are also used. The surface of a lens can be convex, concave, plane or a combination of these.

A lens is not coated as a mirror, but because of the way the surface is curved, they can make light rays passing through them diverge or converge. They refract light rays and not reflect them.

There are two types of lenses: diverging or concave lens and converging or a convex lens.

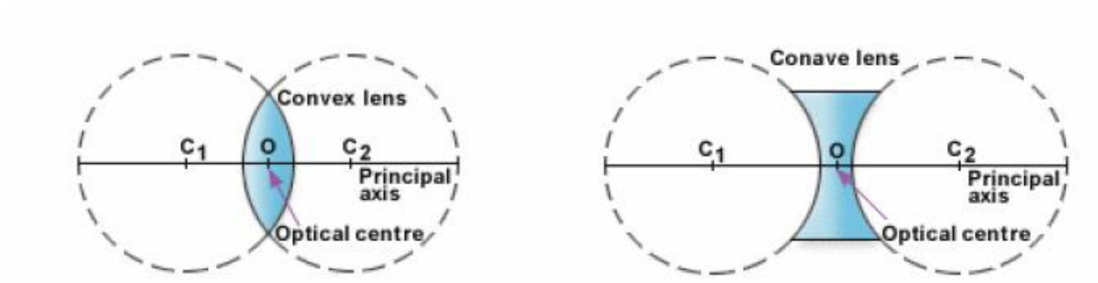
Convex Lens: A convex lens focuses light rays coming from infinite distance at its focal point. The lens is thicker in the middle.

Concave Lens: A concave lens defocuses light rays coming from infinite distance. The parallel light rays appear to diverge from the focal point of the lens. The lens is thinner in the middle.

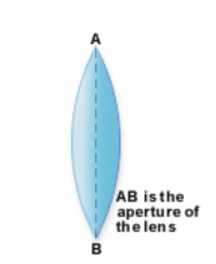


Some definitions regarding convex and concave lenses

Centre of curvature: The centre of curvature of a lens is defined as the centre of the spherical surfaces from which the lens has been cut. Thus there will two centers of curvatures. The letter C1 and C2 represent them.



Aperture: The maximum portion of the spherical surfaces from which the lens actions take place is called the aperture of the lens. In the figure, the distance AB is the aperture of the lens.



Principal axis: The line joining the centers of curvatures is known as the principal axis of the lens. The principal axis of a spherical lens, functions similar to the normal of the plane mirror. A ray of light passing along the principle axis will not be refracted.

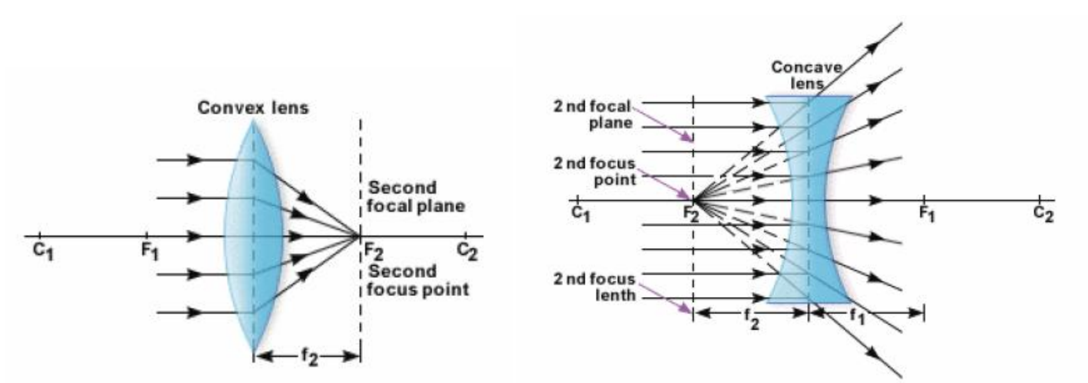
Optical centre: The intersection of the line joining the lens aperture and the principal axis is called the optic centre of the lens. Any ray of light passing through the optic centre emerges parallel to the direction of the incident ray. (we shall see this later). The optic centre is denoted by O.

Principal focus and focal plane: Since a lens consists of two surfaces, there are thus first and second focus and first and second focal plane.

The principal or first focus F1 of a convex lens is the point on the principal axis from which when the light rays start, on passing through the lens will become parallel. The second focus F2 of a convex lens is just the opposite of the first focus, the parallel light rays impinging on the lens converge at a point on the principle axis. This point is called the second focus. The distance between the optical centre O and the first focal point is known as the first focal length f1. The distance between the optical centre O and the second focal point is known as the second focal length f2. Similarly, a vertical plane passing through F1 is known as the first focal plane and a vertical plane passing F2 through is called the second focal plane. For a symmetric convex lens f1 = f2 and the values are positive.

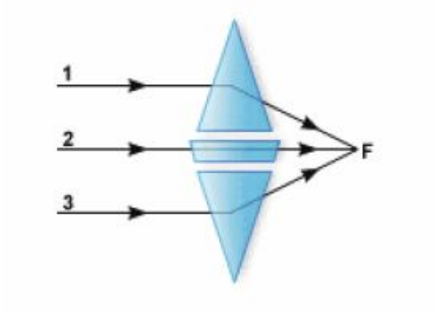
The principal or first focus F1 of a concave lens is the point on the principal axis from which when the light ray start, on passing through the lens will appear to become parallel rays on the same side of the light source. The second focus F2 of a concave lens that point on the principle axis where the parallel light rays impinging on the lens appear to converge on the same side of the lens. This point is called the second focus. The distance between the optical centre O and the first focal point is known as the first focal length f1.

The distance between the optical centre O and the second focal point is known as the second focal length f2. Similarly, a vertical plane passing through F1 is known as the first focal plane and a vertical plane passing F2 through is called the second focal plane. For a symmetric concave lens f1 = f2 and the values are conventionally taken as negative.



Ray diagram for a convex lens

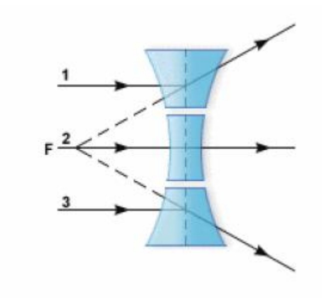
Figure below shows how light rays are focused by a convex lens. A convex lens may be considered to be made up of two prisms and a solid glass block in the centre. Prisms divert or refract light rays toward the direction of their bases. The prisms have their bases towards the optical centre. Ray 1 is parallel to the principal axis. After passing through the upper prism, it bends towards its base and passes through the focus F. Similarly for ray 3, Ray 2 on the other hand is along the principal axis and is normal on the rectangular glass block. This ray passes un-deviated along the principal axis. All the rays meet at F. This is the reason why a convex lens is called a converging lens.



Ray diagram for a concave lens

Figure below shows how light rays are focused by a concave lens. A concave lens may be considered to be made up of two prisms and a solid glass block in the centre. Prisms divert or refract light rays toward the direction of their bases. The prisms have their bases away from the optical centre. The central glass block is also placed edge on. Thus the arrangements of prisms and the glass block differ considerably in a concave lens.

Ray 1 is parallel to the principal axis. After passing through the upper prism, it bends towards its base and away from the principal axis. Similarly for ray 3. Ray 2 on the other hand is along the principal axis and is normal on the rectangular glass block. This ray passes undeviated along the principal axis. All the rays appear to meet at F behind the concave lens. This is the reason why a concave lens is called a diverging lens.



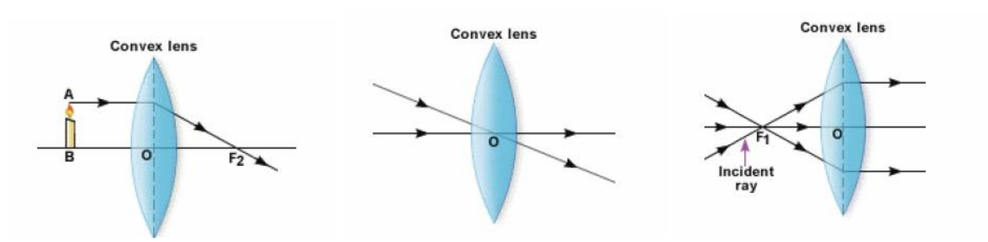
Images by convex lenses

To find out how images are formed with convex lenses, we have to consider certain rules as regards to rays of lights coming from different directions on the surface of the lenses and how they get refracted.

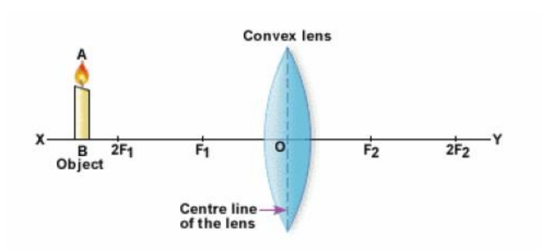
First rule: A ray of light parallel to the principal axis XY, on refraction passes through the focal point F. This is shown in the figure given below.

Second rule: A ray of light passing through the optical centre O of a convex lens, goes un-deviated along the same path.

Third rule: The third rule is inverse of the first rule. When a ray of light passes through the focus F and strikes a convex lens, the refracted ray is parallel to the principal axis XY.



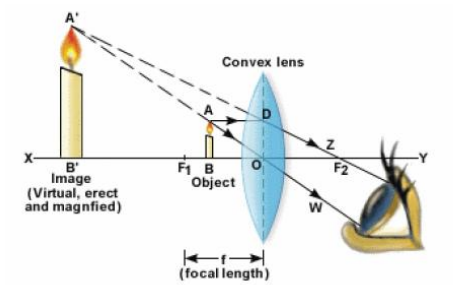
From the above three rules, we can now study how images are formed with the help of convex lenses. The type of images formed depends on where the object is positioned in front of the lens. We will study a few typical cases.



Case 1: object is placed between the optical centre O and the focus F1
Case 2: object is placed at focus F1
Case 3: object is placed between the focus F1 and 2 F1
Case 4: object is placed at 2 F1
Case 5: object is placed at a distance beyond 2 F1
Case 6: object is placed at a far off distance beyond 2 F1 (or at infinite distance).

Case 1

Image formed by a convex lens when the object is placed between the optical centre O and the focus F1. Consider the following figure.



Let the object be a candle AB placed between F1 and O.
Consider two rays of light starting from A. A light ray from A, parallel to the principal axis XY will strike the lens at D. This ray of light, on refraction will pass through F2 (rule 1) to become ray DZ. The second light ray from A passing through AO, will go undeviated and will get refracted along OW (rule 2).

The other end of the candle B. is placed along the principle axis XY. So any ray of light BO will go along BO itself (rule 2).

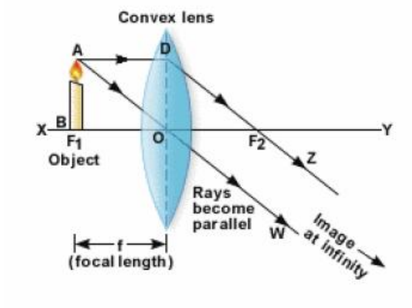
The rays DZ and OW reach your eye positioned appropriately. You will notice that the rays emanating from A are intersecting at a point A'. Rays of light from B extending behind the lens, form an image B'. The refracted image is A'B' behind the lens. You can see that the size of A'B' is larger than AB.
Thus we can conclude that for an image of an object placed between F1 and O of a convex lens:

- The image is behind the lens and hence is virtual
- The image is erect and not inverted
- The image is magnified

This shows why a convex lens is used as a simple magnifying glass. It should be borne in mind that in order to have magnification effects the object viewed should be within the focal length of the lens.

Case 2

Image formed by a convex lens when the object is placed at focus F1.
Consider the following figure.



Let the object be a candle AB at F1.
Consider two rays of light from point A. AD is parallel to the principal axis XY and AO passing through O. From rule 1 and 2, we see that ray of light AD will be refracted along DF2Z, passing through the focal point F2. Similarly ray AO will go un-deviated.

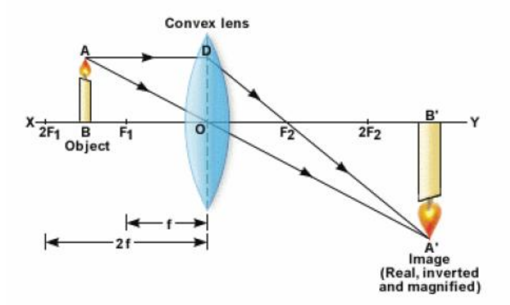
The two refracted rays are parallel to each other and will meet at infinity!! Thus the image of point A will be at infinity. You can also see that the image of A will be on the opposite side of the principle axis XY, hence the image is also inverted besides being formed at infinity. As you extrapolate the two lines, you will see that the image of A will be highly magnified. The image of B will be fall on the line XY itself (rule 2).

Thus we can conclude that for an image of an object placed at the focus F1 of a convex lens:

- The image is formed at infinity
- The image is inverted and real
- The image is highly magnified

Case 3

Image formed by a convex lens when the object is placed between the focus F1 and 2 F1.
Consider the following figure.



Let the object be a candle AB placed between F1 and 2 F1.

Consider two rays of light emanating from point A. AD is parallel to XY. AD is refracted along DF2A' (rule 1). The second ray of light AO is cutting the principle axis XY at O. Hence by rule 2, the refraction of AO will be along the same line. Lines DF2A' and AO meet at A', which is the reflected image of A. Again, as explained earlier, light from B will go un-deflected along XY path.
The image of AB is A'B'. Clearly the image is magnified and inverted.

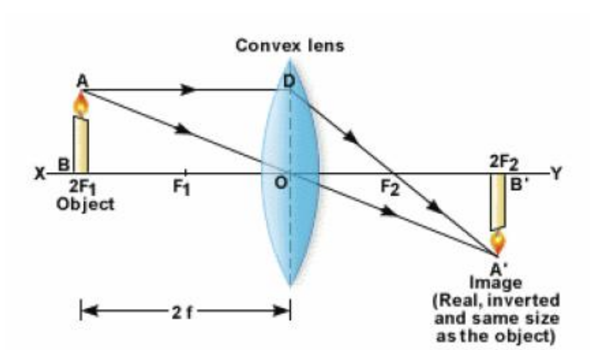
Thus we can conclude that for an image of an object placed between focus F1 and 2 F1 of a convex lens:

- The image is formed beyond 2 F1
- The image is inverted and real
- The image is magnified.

A slide film projector uses this type of geometry for projecting a magnified image. The slides are always kept inverted so that the image of the slide is erect and is captured on a screen.

Case 4

Image formed by a convex lens when the object is placed at 2 F1.
Consider the following figure.



Let the object be a candle AB placed at 2 F1.
As before, consider two rays emanating from A; one AD is parallel to XY the principal axis. The second ray is AO passing through the optical centre O. From rule 1, we see that ray AD will be refracted by the lens and pass through the focal point F2.

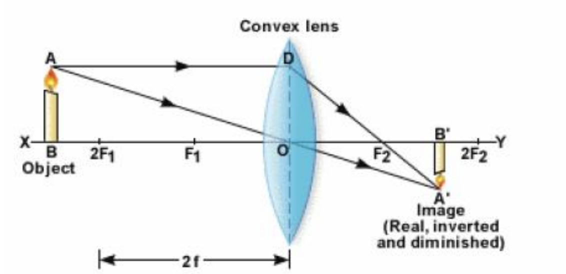
The second ray AO, will go along OA' un-deviated (rule 2). Again, as explained earlier, light from B will go un-deflected along XY path. The image of AB is A'B'. Clearly the image is un-magnified and inverted and is formed at 2 F2.

Thus we can conclude that for an image of an object is placed at 2 F1 of a convex lens:

- The image is formed at 2 F2 on the other side of the lens
- The image is inverted and real
- The image is same size as that of the object.

Case 5

Image formed by a convex lens when the object is placed at a distance beyond 2 F1.
Consider the following figure.



Let the object be a candle AB placed at a distance beyond 2 F1.
Applying similar treatments for the rays of light emanating from two extremes of the candle AB. A ray of light AD parallel to XY will be deflected along DF2A' (rule1). Another ray of light AO will be refracted along AOA' (rule 2). Where the two rays DF2A'and AOA' meet, we get the image of A as A'. As explained earlier, light from B will go un-deflected along XY path. The image of AB is A'B'. Clearly the image is reduced and inverted. The image is formed between F2 and 2 F2.

Thus we can conclude that for an image of an object placed at a distance beyond the 2 F1 of a convex lens:

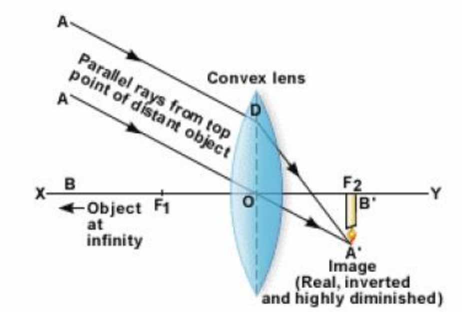
- The image is formed between F2 and 2 F2
- The image is inverted and real
- The image is reduced in size.

The above geometry is used in a simple camera lens, where the picture is reduced in size and is taken on a photographic film.

Case 6

Image formed by a convex lens when the object is placed at a distance far off (or infinite distance) beyond 2 F1.

Consider the following figure.



Let the object be a candle AB placed at infinity. B is still on line XY. Rays emanating from A are striking the mirror in parallel fashion. They will be refracted and they will meet at the focal point F2 (rule 3). The image is thus highly diminished.

Thus we can conclude that for an image of an object placed at an infinite distance beyond 2 F1 of a convex lens:

- The image is formed at F2
- The image is inverted and real
- The image is highly reduced in size

The geometry used in case 6 is what happens in a telescope that collects light from objects such as stars placed at infinity.

Uses of convex lenses

From the cases studied above, we can now understand why convex lenses are widely used to capture or project images.

- Case 1 shows why convex lenses are used as magnifying glasses or in microscopes.
- Case 3 shows why convex lenses are used in a slide film projector.
- Case 5 shows why convex lenses are used in cameras.
- Case 6 shows why convex lenses are used in telescopes.

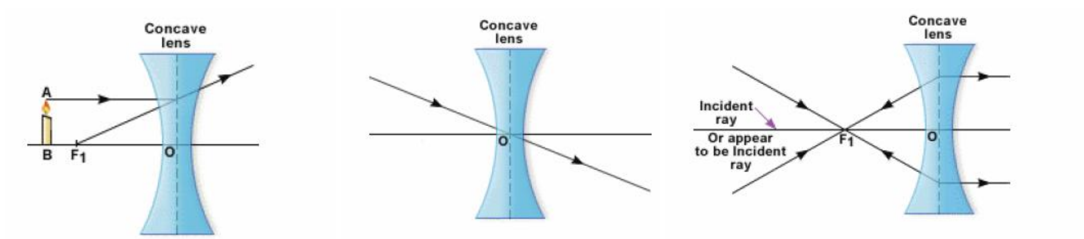
Images by concave lenses

To find out how images are formed with the concave lenses, we have to consider certain rules as regards to rays of light coming from different directions on the surface of the lens and how they get refracted.

First rule: A ray of light parallel to the principle axis XY, on refraction diverges. The line diverging ray can be extended backwards. It can be seen that the line meets XY at the focal point F1. This is shown in the figure given below.

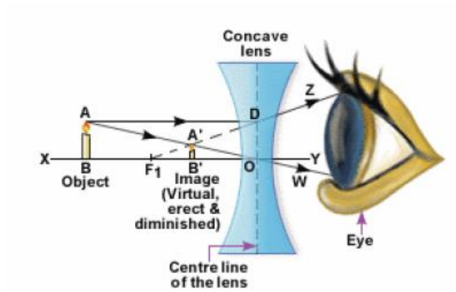
Second rule: A ray of light passing through the optical centre O of a concave lens, goes un-deviated along the same path.

Third rule: The third rule is inverse of the first rule. When a ray of light passes through the focus F1 and strikes a concave lens, the refracted ray is parallel to the principal axis XY.



Unlike the different cases seen in case of convex lens, the images formed by concave lenses are always the same!

Consider the figure given below.



Place the candle AB anywhere in front of a concave lens. A light ray AD is parallel to the principal axis. On refraction through the concave lens it will take the path DZ (rule 1). Line DZ can be extended behind the concave lens where it appears to emerge from the focus F1. Another ray of light AO will go un-deviated (rule 2) and take the path AOW. The rays meet behind the concave lens at A'. Rays of light from the other end of the candle B will be refracted along BO line itself. The image of the candle AB is A'B' as shown. The image is formed within the focal length of the lens.

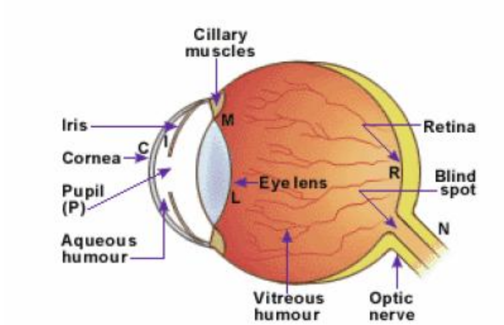
Thus whatever the position of the object in front of a concave lens, the image is always:

- Formed behind the mirror between the optical centre O and the focus F1.
- The image is erect and virtual
- The image is diminished and reduced in size.

The use of concave lenses is most widely seen in the use of spectacles for correcting short sightedness. This we shall see in details in later sections.

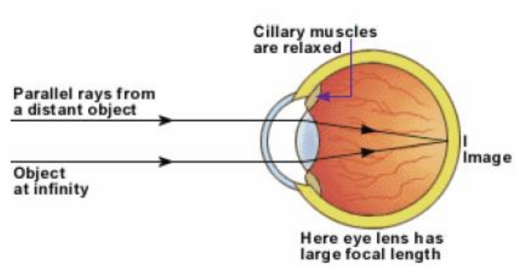
Human Eye as a Lens

Lens within the human eye is one of the best examples of how lenses behave to focus light rays. Figure below shows the schematic diagram of the human eye.



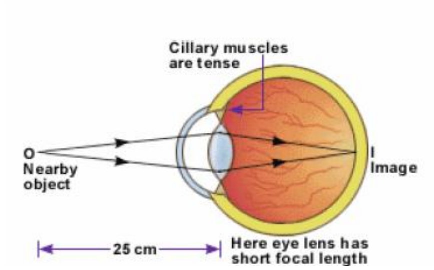
Externally the eye consists or the cornea and the iris. Cornea is a transparent membrane that protects the eye. Iris is made up of tissues that are dark in color and are opaque to light. Iris has a small hole in the middle called the pupil. Pupil looks darker than the iris as no light rays are reflected out of the eye. After the pupil there is a convex lens made up of transparent tissues. Ciliary muscles that are either in a relaxed or in a tensed state hold the convex lens. The ciliary muscles are capable of changing the shape of the convex lens. The light rays are focused on a screen called the retina. Retina has optically sensitive tissues (rods and cones) which gives us the sense of sight (and color). The eye “sees” an object because an image of the object is formed on the retina. As expected, the image of the convex lens is always inverted. So on the retina we get an inverted image. Our brains have been trained to “see” the image as inversion of the inverted image. Hence we see the objects as they are.

The convex lens on the retina focuses light rays reflected from objects kept in front of the pupil. The amount of light entering the eye can be adjusted by the size of the pupil. In too bright light, the iris adjusts so that the pupil narrows. In the dark, the pupil expands to take in more light. All of us have experienced this. For example, if there is a sudden electricity failure at night, instantly we cannot see anything; but after a short while we are able to see even in the darkness. The reason for this is the iris takes a little time to expand the pupil to accommodate more light. Once more light enters the eye, we can somewhat see even in darkness. In pitch darkness, where there is no light reflected from anywhere, we would be unable to see anything.
Figure below shows how an eye focuses objects at a far off distance from where parallel rays of light are impinging on the eye.



When the eye is focusing distant objects, the ciliary muscles are relaxed and the lens of the eye is less convex. The ciliary muscles adjust in such a manner that the size of the eye is the focal length of the convex lens. The distant object is focused at the focal plane (retina) in a convex lens, as seen in earlier sections.

Figure below shows how an eye focuses objects at a nearby distance.

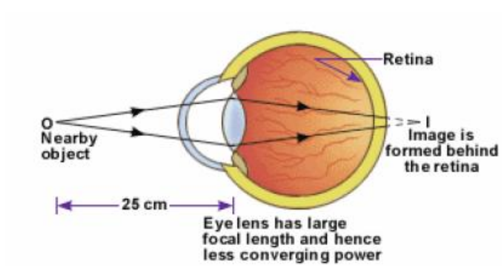


In this case the ciliary muscles contract, making the central portion of the convex lens bulge. The focal length of the convex lens now decreases. The rays from the object, after passing through the lens converge at the focal plane, which is the retina.

Thus our eyes can see distant as well as nearby objects by changing the shape of the lens. This ability to focus objects at various distances is called as the accommodation of the eye. But the accommodation has limitations. Closer than 25cm, our eyes will see objects in a defocused fashion. Also objects at far off distances may not always be clear to our eyes.

From the above discussions we can say that there are two types of eye defects that occur in most common cases. The two types are : long sightedness or hypermetropia where one is able to see distant objects clearly but not near by objects; and short sightedness or myopia where one is able to see nearby objects clearly but not far off objects. These defects occur either due to the shape of the inner eye or due to aging where the ciliary muscles do not function as expected.

Figure below shows the shape of the eye that is suffering from for long sightedness or hypermetropia.



The image of an object that is nearby is formed behind the retina. So at the retinal screen, a diffused, defocused image is seen. To correct this defect, a convex lens has to be worn by the person. The focal length of the convex lens is adjusted in such a manner that the image of the object is on the retina.

People suffering from long sightedness can see distant objects clearly but are unable to read from a book held close. Hence they need only reading glasses.

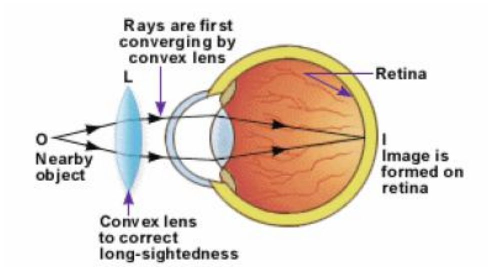
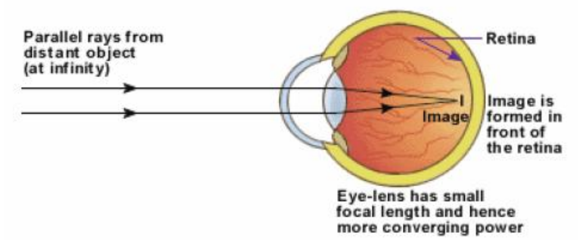
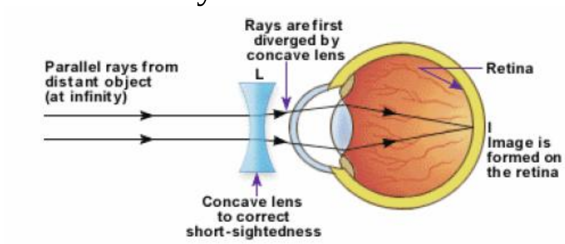


Figure below shows the shape of the eye that is suffering from short sightedness or myopia.



In this case the image of an object placed at far off distance is formed in front of the retina. To correct this defect, a concave lens has to be worn by the person. The focal length of the concave lens is such that the parallel light rays coming from distant objects are first diverged a little and then are converged by the eye lens. The adjustment of the focal length of the concave lens has to be in such a manner that a well focused image is formed at the retina. People suffering from short sightedness cannot see distant objects but can read a book held close clearly!



Some people suffer from both short as well as long sightedness. These persons use bi-focal lenses or two sets of spectacles, one for correcting their near sighted vision; the second pair of spectacles for correcting their far sighted vision.

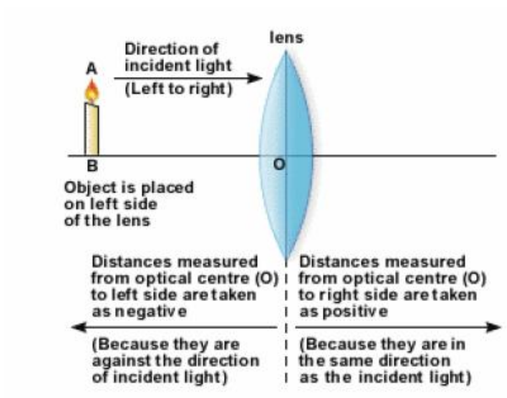
There is a third type of vision defect: this is called astigmatism. In the natural eye, cornea and lens have inherent density defect because of which, a distant point object will be seen as a vertical, horizontal or inclined line. Complicated cylindrical lenses correct this defect.

In animals such as cats, cows, dears, etc. at night their eyes are seen to shine. This is because to see clearly in the dark the inside of their eye is made of up materials which reflect light. Multiple reflection within the eye gives them a better vision in the dark. Some of the reflected light escapes through the pupil and hence the eyes of these animals glow in the dark.

Lens formula, power of a lens and magnification

We can determine the focal length of a lens by using a certain formula. All of us have heard of power of spectacles, this is nothing but inverse of the focal length. Lenses, as you have seen in the earlier section, can produce images which are larger or smaller than the object; with the lens formula one can determine the magnification produced by a lens. But before we see the lens formula, first lets learn a bit about the sign conventions used for lens geometry.

Sign convention:



1. All distances are measured from the optical centre O.
2. Distances measured in the direction of the incident light rays are taken as positive.
3. Distances measured in the direction opposite to that of the incident rays, is taken as negative.
4. Distance measured upward from the principle axis is taken as positive distance.

5. Distance measured downward from the principle axis is taken as negative distance.

Let u = distance of the object from O.
v = distance of the image from O.

In a convex or concave lens, u is always negative, as BO distance is measured in the direction opposite to that of the light rays striking the lens. In a convex lens, v can sometimes be positive and sometimes be negative. For concave lens, v is always positive.

Unlike mirrors, since lenses have two foci, there may be a confusion as to which focal length is taken as positive or otherwise.
Conventionally the focal length of concave lens is taken as negative and that of a convex lens is taken as positive.

Lens formula

The lens formula gives the relationship between the object distance u, the image distance v and the focal length f. The formula is written as:

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

Thus if we know two of the three quantities from u,v,f, we will be able to find the third quantity. The values of u,v and f have to be inserted with proper sign convention.

Linear magnification of lenses

We have seen earlier with different position of the object in front of the lenses, the image can be either magnified or diminished; the image can be either erect or inverted. The ratio of the height of the image to the height of the object is known as the magnification.

$$\text{Magnification} = \frac{\text{Hight of image}}{\text{Hight of object}}$$

If we say that
h1 = Height of the object
h2 = Height of the image,

The magnification is m =h2/h1.

From the sign convention mentioned earlier, a positive sign of m indicates that the image is virtual and erect. A negative sign of m indicates that the image is real and inverted.

Magnification is called as the linear magnification, because we are calculating the linear height of the object and images.

Those of you familiar with similar triangles, will immediately understand that

m = h2/h1 = v/u

The sign is different from that of the magnification for mirrors. The sign convention gives correct values of magnification for either convex or concave lenses.

Power of a lens

Power of a lens is given as the inverse of its focal length measured in meters. The letter P denotes power of lens.

$$P = \frac{1}{\text{Focal length of the lens (in meters)}} = \frac{1}{f}$$

The standard unit for measuring P is dioptre and is denoted by D. Dioptre = 1, means a lens whose focal length is 1 meter. The power of a convex lens is positive (+ sign). The power of a concave lens is taken as negative (- sign).