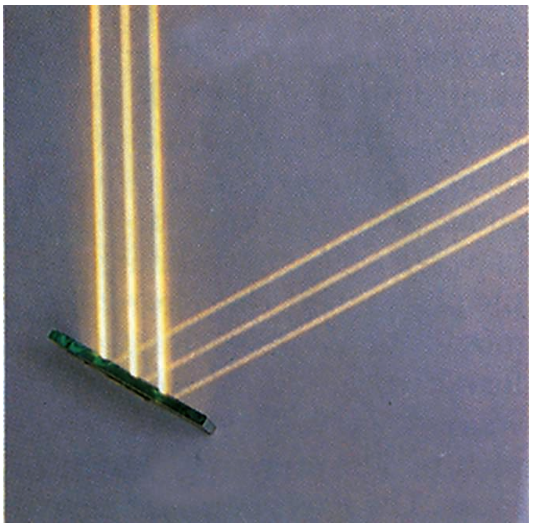
CHAPTER

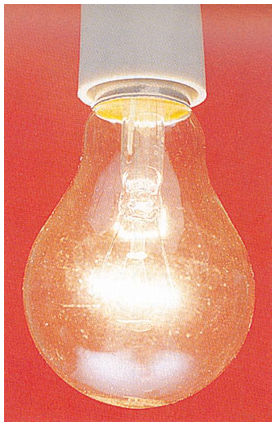
4



Reflection of Light

Light is a form of energy. Light is needed to see things around us. We are able to see the beautiful world around us because of light. We can read a book, see pictures in a magazine, and watch television and movies due to the existence of light. And it is light which makes us see our image in a looking mirror. **We detect light with our eyes**. Though we see the various objects (or things) around us with our eyes but eyes alone cannot see any object. We also need a source of light to make objects visible. For example, we cannot see any object in a dark room or in the darkness of night because there is no light in a dark room or in the night to make objects visible. But as soon as an electric bulb (a tube-light or a torch, etc.) is switched on and light falls on the objects, we are able to see them clearly. *It is only when light coming from an object enters our eyes that we are able to see that object*. This light may have been *emitted* by the object itself or it may have been *reflected* by the object.

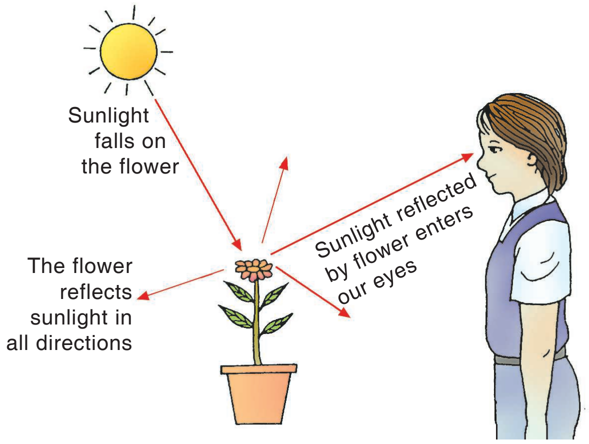
Light enables us to see objects from which it comes or from which it is reflected. For example, the sun gives out light. We can see the sun because the light coming from the sun enters our eyes. **The objects like the sun, other stars, electric bulb, tube-light, torch, candle and fire, etc., which emit their own light are called luminous objects** (see Figure 1). We can see the luminous objects due to the light emitted by them. Though luminous objects are very small in number but they help us to see a large variety of non-luminous objects around us. The objects like a flower, a chair or a table do not have light of their own but even then we are able to see them. This can be explained as follows: Though the objects like a flower, a chair or a table, etc., do not emit light themselves, we can see them by the light which they reflect (or scatter) by taking it from a luminous object like the sun or an electric bulb, etc. (see Figure 2). So, when the sunlight or bulb light falls on a flower or chair (or any other object), some of this light is reflected towards us. And



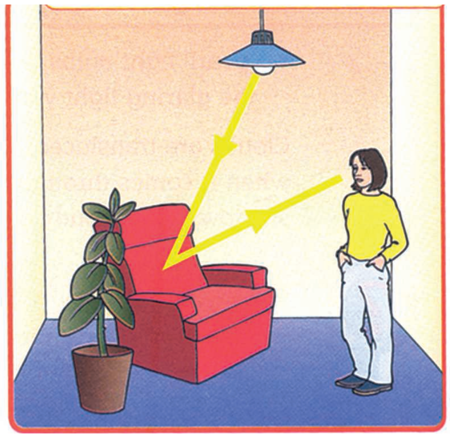
(*a*) An electric bulb gives its own light. It is a luminous object.

(*b*) A flower does not give its own light. It is a non-luminous object.

Figure 1. Luminous and non-luminous objects.



(*a*) We can see the flower during day time because it reflects sunlight falling on it into our eyes.



(*b*) We can see the chair at night because it reflects bulb light falling on it into our eyes.

Figure 2. We see most of the objects around us by the light reflected from them.

when this reflected light enters our eyes, then we are able to see the flower or chair (because to our eyes, this light appears to be coming from the flower or chair) (see Figure 2). **Those objects which do not emit light themselves but only reflect (or scatter) the light which falls on them, are called non-luminous objects** (see Figure 2). A flower, chair, table, book, trees, other plants, human beings, fan, bed, mirror, diamond, walls, floor, and road, etc., are all non-luminous objects. In fact, *most of the objects around us are non-luminous objects.* **We can see the non-luminous objects because they reflect light (received from a luminous object) into our eyes**. Even the moon is a non-luminous object (because it does not have its own light). We can see the moon because it reflects the sunlight falling on its surface towards us (on the earth).

From the above discussion we conclude that light is a form of energy which causes in us the sensation of sight. **Light travels in straight lines**. The fact that a small source of light casts a sharp shadow of an opaque object tells us that light travels in a straight line path. This is because if light could bend easily and go behind the opaque object, then no shadow could be formed. We will now discuss the nature of light.

Nature of Light

There are two theories about the nature of light : wave theory of light and particle theory of light. **According to wave theory : Light consists of electromagnetic waves which do not require a material medium (like solid, liquid or gas) for their propagation.** The wavelength of visible light waves is very small (being only about 4×10^{-7} m to 8×10^{-7} m). The speed of light waves is very high (being about 3×10^{8} metres per second in vacuum). **According to particle theory : Light is composed of particles which travel in a straight line at very high speed.** The elementary particle that defines light is the '*photon*'.

Some of the phenomena of light can be explained only if light is considered to be made up of waves whereas others can be explained only if light is thought to be made up of particles. For example, the phenomena of *diffraction* (bending of light around the corners of tiny objects), *interference* and *polarization* of light can only be explained if light is considered to be of wave nature. The particle theory of light cannot explain these phenomena. On the other hand, the phenomena of *reflection* and *refraction* of light, and *casting of shadows* of objects by light, can be explained only if light is thought to be made of particles. Wave theory of light cannot explain these phenomena. Thus, there is evidence for the wave nature of light as well as for particle nature of light.

Physics experiments over the past hundred years or so have demonstrated that **light has a dual nature (double nature) : light exhibits the properties of both waves and particles (depending on the situation it is in).** The modern theory of light called 'Quantum Theory of Light' combines both the wave and particle models of light.

REFLECTION OF LIGHT

When light falls on the surface of an object, some of it is sent back. **The process of sending back the light rays which fall on the surface of an object, is called reflection of light.** The reflection of light is shown in Figure 3. When a beam of light *AO* falls on a mirror at point *O*, it is sent back by the mirror in another direction *OB* (see Figure 3). And we say that the mirror has reflected the beam of light falling on it. We can compare the reflection of light to the bouncing back of a tennis ball on hitting a wall. For example, if we throw a tennis ball at a wall, the ball bounces back. This means that the wall sends it back. Similarly, when light falls on the surface of an object, the object sends the light back. And we say that the object reflects the light. Most of the objects reflect light which falls on them. Some objects reflect more light whereas other objects reflect less light. **The objects having polished, shining surfaces reflect more light than objects having unpolished, dull surfaces.**

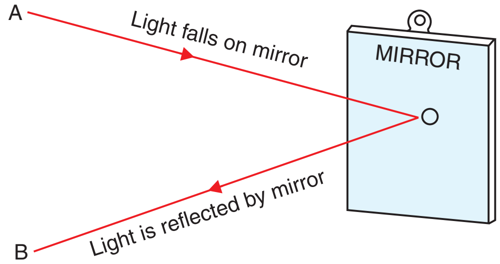
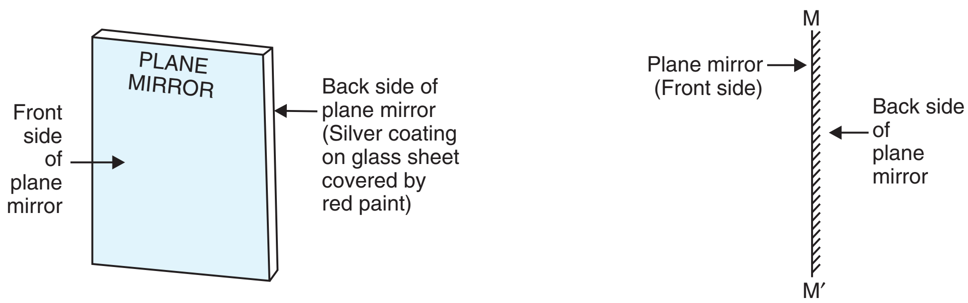


Figure 3. A mirror reflects the light falling on it.

We know that an object (say, a chair) kept in a room can be seen from all the parts of the room. This is due to the fact that usually, because of its rough surface, an object reflects light (or scatters light) in all the directions. Since the reflected light reaches all the parts of the room, the object can be seen from all the parts of the room. If, however, the surface of an object is smooth (like that of a mirror), then the light falling on it is reflected in only one direction (as shown in Figure 3).

Silver metal is one of the best reflectors of light. For example, a polished block of silver metal reflects almost all the light falling on it and does not transmit any light through it. But the surface of silver metal is easily scratched and soon becomes rough. So, **ordinary mirrors are made by depositing a thin layer of silver metal on the back side of a plane glass sheet. The silver layer is then protected by a coat of red paint. The reflection of light in a plane mirror (or any other mirror) takes place at the silver surface in it.** Thus, a plane mirror is a thin, flat and smooth sheet of glass having a shining coating of silver metal on one side. The silver coating is protected by a red paint. These days mirrors are being made increasingly by depositing a thin coating of aluminium metal at the back of a glass sheet (instead of silver coating). This is because aluminium is much cheaper than silver and it reflects light very well. A plane mirror is shown in Figure 4(*a*). The mirror on our dressing table in which we see our face is a plane mirror.



(*a*) A plane mirror.

(*b*) This is how a plane mirror is represented in diagrams.

Figure 4.

In our everyday life, we use plane mirrors of different shapes and sizes depending on where they are being used. But in a science laboratory, a small rectangular strip of plane mirror is usually used for performing experiments on the reflection of light. **In our diagrams, a plane mirror is represented by a straight line having a number of short, oblique lines on one side** [see Figure 4(*b*)]. The plane side of straight line is the front side of the mirror (where the reflection of light takes place). And the side having short, oblique lines represents the back side of the plane mirror. In Figure 4(*b*), the straight line *MM*′ (read as : *MM-dash*) represents a plane mirror.

We will also be using rays of light in constructing the ray-diagrams. **A ray of light is the straight line along which light travels.** The arrow head put on the straight line tells us the direction in which the light is travelling. **A 'bundle of light rays' is called a 'beam of light'.** We will now study the reflection of light from the plane surfaces like that of a plane mirror. This is necessary to understand the reflection of light from spherical mirrors.

REFLECTION OF LIGHT FROM PLANE SURFACES : PLANE MIRROR

When a ray of light falls on a plane mirror (or any other plane surface), it is reflected according to some laws, called the laws of reflection of light. In order to understand the laws of reflection of light, we should first know the meaning of the terms : incident ray, point of incidence, reflected ray, normal (at the point of incidence), angle of incidence, and angle of reflection. So, we will discuss these terms first.

In Figure 5, we have a plane mirror *MM′*. **The ray of light which falls on the mirror surface is called the incident ray**. In Figure 5, *AO* is the incident ray of light. The incident ray gives the direction in which light falls on the mirror. **The point at which the incident ray falls on the mirror is called the point of incidence**. In Figure 5, point *O* on the surface of the mirror is the point of incidence (because the incident ray *AO* touches the mirror surface at this point). We know that when a ray of light falls on a mirror, the mirror sends it back in another direction and we say that the mirror has reflected the ray of light. **The ray of light which is sent back by the mirror is called the reflected ray.** In Figure 5, *OB* is the reflected ray of light. The reflected ray of light shows the direction in which the light goes after reflection from the mirror.

Another term that we will be using is the 'normal'. **The 'normal' is a line at right angle to the mirror surface at the point of incidence.** In other words, *'normal' is a line which is perpendicular to the mirror at the point of incidence*. In Figure 5, the mirror is *MM′* and the point of incidence is *O*. So, the line *ON* is the normal to the mirror surface at point *O*. The normal has been represented by a dotted line to distinguish it from the incident ray and the reflected ray. Please note that 'normal' is just a 'perpendicular line' to the mirror, and it should not be called the 'normal ray' like the incident ray or reflected ray. The normal is a line at right angles to the mirror surface. In other words, normal makes an angle of 90° with the surface of the plane mirror. We will now discuss the angle of incidence and the angle of reflection.

The angle of incidence is the angle made by the incident ray with the normal at the point of incidence. In other words, the angle between the incident ray and normal is called the angle of incidence. In Figure 5, the incident ray is *AO* and the normal is *ON*, so the angle *AON* is the angle of incidence. The angle of incidence is denoted by the letter i.

The angle of reflection is the angle made by the reflected ray with the normal at the point of incidence. In other words, the angle between the reflected ray and normal is called the angle of reflection. In Figure 5, the reflected ray is *OB* and the normal is *ON*, so the angle *NOB* is the angle of reflection. The angle of reflection is denoted by the letter r. Keeping these points in mind, we will now describe the laws of reflection of light.

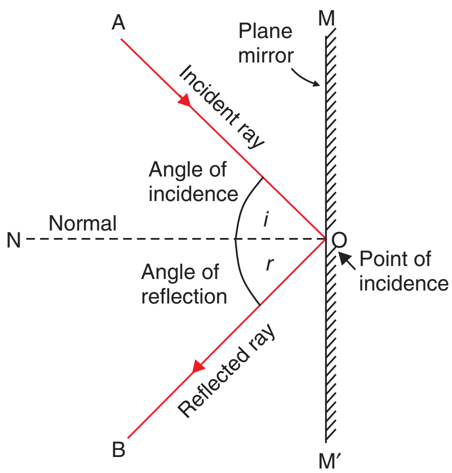


Figure 5. Reflection of light from a plane mirror.

Laws of Reflection of Light

The reflection of light from a plane surface (like that of a plane mirror) or from a spherical surface (like that of a concave mirror or convex mirror) takes place according to two laws, which are known as the laws of reflection of light. The laws of reflection of light are given below :

1. First Law of Reflection. According to the first law of reflection of light : **The incident ray, the reflected ray, and the normal (at the point of incidence), all lie in the same plane.** For example, in Figure 5, the incident ray *AO*, the reflected ray *OB* and the normal *ON*, all lie in the same plane, the plane of paper. They are neither coming up out of the paper; nor going down into the paper.

2. Second Law of Reflection. According to the second law of reflection of light : **The angle of reflection is always equal to the angle of incidence.** We can also state the second law of reflection of light as follows by writing the angle of incidence first : *The angle of incidence is equal to the angle of reflection*. If the angle of incidence is i and the angle of reflection is r, then according to the second law of reflection :

$$\angle i = \angle r$$

For example, if we measure the angle of reflection *NOB* in Figure 5, we will find that it is exactly equal to the angle of incidence *AON*.

The second law of reflection of light means that if the angle of incidence is 35°, then the angle of reflection will also be 35° (see Figure 6). And if the angle of incidence is changed to 45°, then the angle of reflection will also change and become 45° (see Figure 7). *In every case, the angle of reflection remains equal to the angle of incidence*.

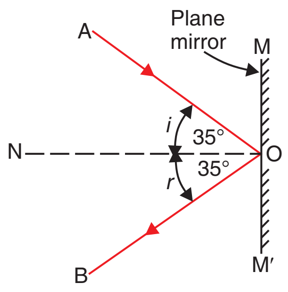


Figure 6. If the angle of incidence is 35°, then the angle of reflection is also 35°.

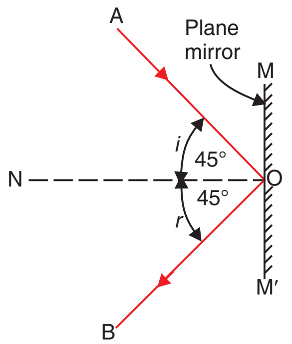


Figure 7. When the angle of incidence is changed to 45°, the angle of reflection also becomes 45°.

We will now describe **what happens when a ray of light falls normally (or perpendicularly) on the surface of a mirror.** If a ray of light is incident normally on a mirror, it means that it is travelling along the normal to the mirror. So, the angle of incidence (i) for such a ray of light is zero (0). And since the angle of incidence is zero, therefore, according to the second law of reflection, its angle of reflection (r) will also be zero (0). This means that **a ray of light which is incident normally (or perpendicularly) on a mirror, is reflected back along the same path (because the angle of incidence as well as the angle of reflection for such a ray of light are zero).** For example, in Figure 8, a ray of light falls on the plane mirror along the normal *NO*, therefore, it will be reflected along the same path *ON*. So, in this case, the incident ray will be *NO* and the reflected ray will be *ON*. In other words, the same line represents incident ray, normal and reflected ray. We should, however, put two arrow heads on the same 'normal' line pointing in opposite directions – one arrow to represent incident ray and the other arrow to represent reflected ray (as shown in Figure 8).

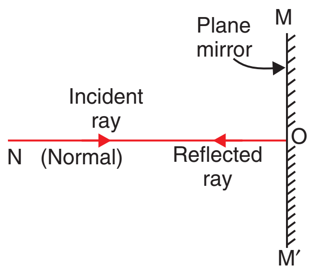


Figure 8. A ray of light incident normally (at 90°) to the mirror surface is reflected back along the same path.

Please note that **the laws of reflection of light apply to all kinds of mirrors, plane mirrors as well as spherical mirrors (like concave mirrors and convex mirrors).** By using the laws of reflection of light, we can find out the nature and position of the images (of objects) formed by the various types of mirrors.

Regular Reflection and Diffuse Reflection of Light

In regular reflection, a parallel beam of incident light is reflected as a parallel beam in one direction. In this case, parallel incident rays remain parallel even after reflection and go only in one direction (see Figure 9). **Regular reflection of light occurs from smooth surfaces like that of a plane mirror (or highly polished metal surfaces).** For example, when a parallel beam of light falls on the smooth surface of a plane mirror, it is reflected as a parallel beam in only one direction as shown in Figure 9. Thus, **a plane mirror produces regular reflection of light.** Images are formed by regular reflection of light. For example, a smooth surface (like that of a plane mirror) produces a clear image of an object due to regular reflection of light. A highly polished metal surface and a still water surface also produce regular reflection of light and form images. This is why we can see our face in a polished metal object as well as in the still water surface of a pond or lake. A polished wooden table is very smooth and hence produces regular reflection of light.

The regular reflection of light from a smooth surface can be explained as follows : All the particles of a smooth surface (like a plane mirror) are facing in *one direction*. Due to this the angle of incidence for all the parallel rays of light falling on a smooth surface is the same and hence the angle of reflection for all the rays of light is also the same. *Since the angle of incidence and the angle of reflection are the same (or equal), a beam of parallel rays of light falling on a smooth surface is reflected as a beam of parallel light rays in one direction only* (see Figure 9).

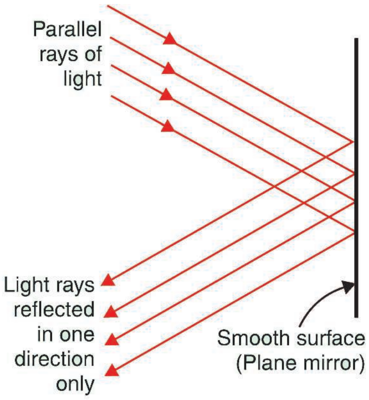


Figure 9. Regular reflection : Incident light is reflected in only one direction.

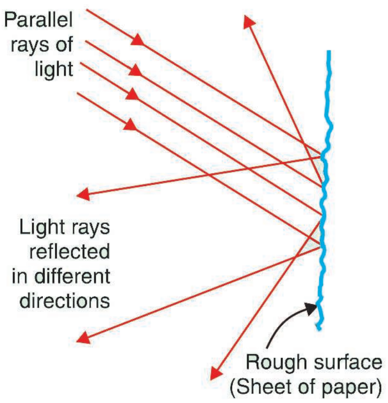


Figure 10. Diffuse reflection : Incident light is reflected in different directions.

In diffuse reflection, a parallel beam of incident light is reflected in different directions. In this case, the parallel incident rays do not remain parallel after reflection, they are scattered in different directions (see Figure 10). The diffuse reflection is also known as *irregular reflection* or scattering. **The diffuse reflection of light takes place from rough surfaces like that of paper, cardboard, chalk, table, chair, walls and unpolished metal objects.** For example, when a parallel beam of light rays falls on the rough surface of a sheet of paper, the light is scattered by making reflected rays in different directions (see Figure 10). Thus, **a sheet of paper produces diffuse reflection of light.** No image is formed in diffuse reflection of light. For example, a rough surface (like that of paper) does not produce an image of the object due to diffuse reflection of light. Actually, the light rays falling on the rough surface of paper are scattered in all directions and hence no image is formed.

The diffuse reflection of light from a rough surface can be explained as follows : The particles of a rough surface (like that of paper) are all facing in *different directions*. Due to this, the angles of incidence for all the parallel rays of light falling on a rough surface are different and hence the angles of reflection for all the rays of light are also different. *Since the angles of incidence and the angles of reflection are different, the parallel rays of light falling on a rough surface go in different directions* (see Figure 10). **Please note that the diffuse reflection of light is not due to the failure of the laws of reflection.** Diffuse reflection is caused by the roughness (or irregularities) in the reflecting surface of an object (like paper or cardboard, etc.). The laws of reflection are valid at each point even on the rough surface of an object.

The surfaces of most of the objects are rough (or uneven) to some extent. So, **most of the objects around us cause diffuse reflection of light and scatter the light falling on them in all directions.** In fact, we can see these objects only because they scatter light rays falling on them in all directions. For example, a book lying on a table can be seen from all parts of the room due to diffuse reflection of light from its surface. The surface of book, being rough, scatters the incident light in all parts of a room. Hence the book can be seen from all parts of the room. A cinema screen has a rough surface and causes diffuse reflection of light falling on it. The cinema screen receives light from a film projector and scatters it in all directions in the cinema hall so that people sitting anywhere in the hall can see the picture focused on the screen.

Objects and Images

In the study of light, the term 'object' has a special meaning. **Anything which gives out light rays (either its own or reflected by it) is called an object.** A bulb, a candle, a pin-head, an arrow, our face, or a tree, are all examples of objects from the point of view of study of light. The objects can be of two types : very small objects (called point objects) or large objects (called extended objects). In drawing the ray-diagrams for the formation of images, we will be using both type of objects according to our convenience. In ray-diagrams, the point objects (like point sources of light or a pin-head) are represented by a 'dot', and the extended objects are represented by drawing 'an arrow pointing upwards'.

In physics, **image is an optical appearance produced when light rays coming from an object are reflected from a mirror (or refracted through a lens).** This will become clear from the following example. When we look into a mirror, we see our face. What we see in the mirror is actually a 'reflection' of our face and it is called 'image' of our face. Thus, **when we look into a mirror, we see the image of our face in it.** In this case, 'our face' is the 'object' and what we see in the mirror is the 'image'. The image of our face appears to be situated behind the mirror. **While watching a movie in the cinema hall, we see the images of actors and actresses on the cinema screen.** Please note that *an image is formed when the light rays coming from an object meet (or appear to meet) at a point, after reflection from a mirror* (*or refraction through a lens*). The images are of two types : real images and virtual images. These are discussed below.

Real Images and Virtual Images

The image which *can* be obtained on a screen is called a real image. In a cinema hall, we see the images of actors and actresses on the screen. So, **the images formed on a cinema screen is an example of real images** (see Figure 11). A real image is formed when light rays coming from an object actually meet at a point after reflection from a mirror (or refraction through a lens). A real image can be formed on a screen because light rays actually pass through a real image. Real images can be formed by a concave mirror. A convex lens can also form real images. We will study the formation of real images with the help of ray-diagrams after a while.

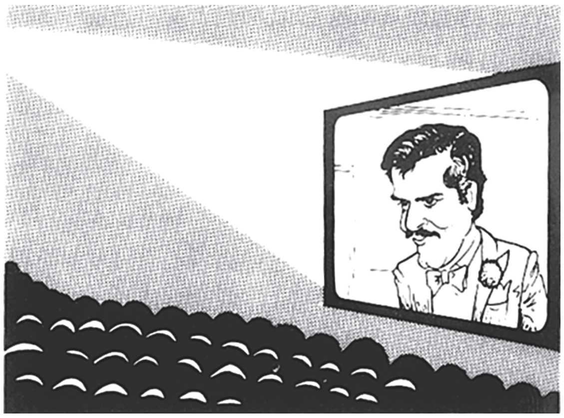


Figure 11. The image of actors and actresses formed on a cinema screen is a *real* image.

Figure 12. When we look into a mirror, we see our image in it. The image formed in a plane mirror is a *virtual* image.

The image which *cannot* be obtained on a screen is called a virtual image. A virtual image can be seen only by looking into a mirror (or a lens). The image of our face formed by a plane mirror cannot be obtained on a screen, it can be seen only by looking into the mirror. So, **the image of our face in a plane mirror is an example of virtual image** (see Figure 12). Virtual images are also called unreal images. **A**

virtual image is just an illusion. A virtual image is formed when light rays coming from an object only appear to meet at a point when produced backwards (but do not actually meet) after reflection from a mirror (or refraction through a lens). A virtual image cannot be formed on a screen because light rays do not actually pass through a virtual image. A plane mirror always forms virtual images. Similarly, a convex mirror also forms only virtual images. A concave mirror can form a virtual image only when the object is kept within its focus. As we will study in the topic on lenses, a concave lens always forms virtual images but a convex lens forms a virtual image only when the object is within its focus. We will study the formation of virtual images with the help of ray-diagrams after a while.

We will now describe the formation of image in a plane mirror. Before we do that please remember that an object gives out a large number of light rays in all the directions but we will use only two light rays coming from the object to show the formation of image. This is done just to keep the ray-diagram simple. Another point to be noted is that the real rays of light are represented by full lines (solid lines) whereas virtual rays of light are represented by dotted lines (broken lines). The real rays of light can exist only in front of a mirror. The virtual rays of light are those which we show behind a mirror. The virtual light rays do not exist at all (because light cannot reach behind the mirror by passing through it). They just appear to be coming from behind the mirror. We will now describe how the image of an object is formed in a plane mirror by using the laws of reflection of light.

Formation of Image in a Plane Mirror

Consider a small object *O* (say, a point source of light) placed in front of a plane mirror *MM*′ (see Figure 13). The mirror will form an image *I* of the object *O*. Now, we want to know how this image has been formed. This happens as follows : The object *O* gives out light rays in all directions but we need only two rays of light to locate the image. Now, a ray of light *OA* coming from the object *O* is incident on the plane mirror at point *A* and it gets reflected in the direction *AX* according to the laws of reflection of light making the angle of reflection r_1 equal to the angle of incidence i_1 (see Figure 13). Another ray of light *OB* coming from the object *O* strikes the mirror at point *B* and gets reflected in the direction *BY*, again making the angle of reflection r_2 equal to the angle of incidence i_2.

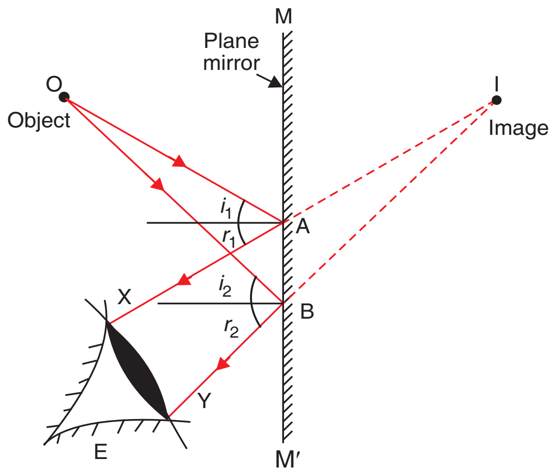


Figure 13. Formation of image in a plane mirror.

The two reflected rays *AX* and *BY* are diverging (moving away from one another), so they cannot meet on the left side. Let us produce the reflected rays *AX* and *BY* backwards (as shown by dotted lines in Figure 13). They meet at point *I* behind the mirror. Now, when the reflected rays *AX* and *BY* enter the eye of a person at position *E*, the eye sees the rays of light in the straight line direction in which the reflected rays enter it. So, the person looking into the mirror from position *E* sees the reflected rays as if they are coming from the point *I* behind the mirror (because *I* is the point of intersection of the reflected rays when produced backwards to the right side). Thus, point *I* is the image of the object *O* formed by the plane mirror. For example, if our face is at position *O* in front of the plane mirror, then we will see the image of our face in the mirror at point *I*.

Please note that **the image formed by a plane mirror can be seen only by looking into the mirror.** So, if a screen is placed at position *I*, no image would be formed on it because the light rays do not actually pass through the point *I*, they only appear to do so. **An image of this type, which cannot be received on a screen, is known as a virtual image.** Another point to be noted is that the light rays shown by dotted lines behind the mirror are only imaginary light rays. There can be no real light rays behind a mirror because it has a silvered reflecting surface at its back (covered with a paint) which does not allow light rays to pass through it and go behind the mirror. So, there is no light coming to the person directly from the image point *I*. It is only the light reflected from the mirror which appears to be coming from the image point *I*.

Image of an Extended Object (or Finite Object)

We have just studied that a plane mirror forms a point image of a point object. But most of the actual objects are much bigger than a mere 'point' and they are called 'extended objects' or 'finite objects'. An extended object (or bigger object) can be considered to be made up of a very, very large number of point objects. So, the image of an extended object is a collection of the image points corresponding to the various points of the object. We will now describe how a plane mirror forms the image of an extended object. In our ray-diagrams, we will use an 'arrow pointing upwards' to represent an extended object (or finite object).

In Figure 14, an extended object *AB* (an arrow pointing upwards) is placed in front of a plane mirror *MM′*. In order to locate the image of arrow *AB* in the plane mirror, we will first find out the positions of images of its top point *A* and bottom point *B*. This can be done as follows :

(*i*) From point *A*, we draw an incident ray *AC* perpendicular to the mirror (see Figure 14). This will be reflected back along the same path. So, *CA* is the first reflected ray. We now draw another incident ray *AD* which strikes the mirror at point *D*. The ray *AD* is reflected along *DE*, making an angle of reflection (r_1) equal to the angle of incidence (i_1). Thus, *DE* is the second reflected ray here. We produce the two reflected rays *CA* and *DE* backwards by dotted lines. They meet at point *A′* (*A*–dash). So, *A′* is the virtual image of the top point *A* of the object.

(*ii*) From point *B*, we draw an incident ray *BF* perpendicular to the mirror. This will be reflected back along the same path, giving the reflected ray *FB*. Another incident ray *BG* is reflected along *GH* making the angle of reflection (r_2) equal to the angle of incidence (i_2). We produce the two reflected rays *FB* and *GH* backwards by dotted lines. They meet at point *B′* (*B*–dash). So, *B′* is the virtual image of the bottom point *B* of the object.

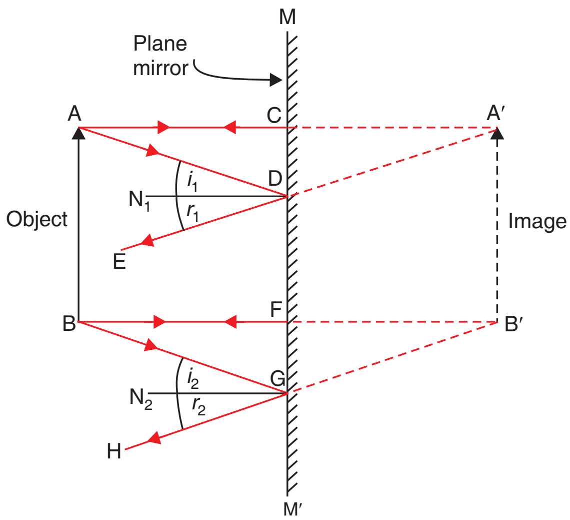


Figure 14. The formation of image of an extended object (here an arrow *AB*) in a plane mirror.

In this way we have located the images of the top point *A* and bottom point *B* of the object. Now, each point of the object (or arrow) between *A* and *B* will give a point image which will lie between the points *A′* and *B′*. So, to get the complete image of object *AB*, we join the points *A′* and *B′* by a dotted line. Thus, *A′B′* (A–dash *B*–dash) is the complete image of the object *AB* which has been formed by the plane mirror (see Figure 14).

The image is virtual, erect (same side up as the object, because both the object and image have arrow-head at the top), and of the same size as the object. Please note that in Figure 14, the image *A′B′* has been drawn by dotted line just to show that it is a virtual image. Thus, **the nature of image formed by a plane mirror is virtual and erect.** And **the size of image formed by a plane mirror is equal to that of the object.** The image is at the same distance behind the plane mirror as the object (arrow) is in front of the mirror.

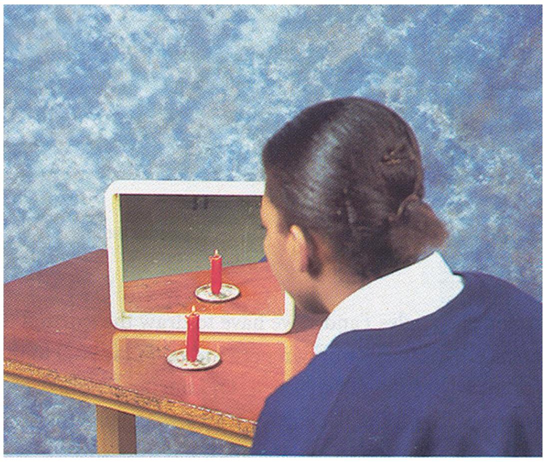


Figure 15. The image of candle in the plane mirror is the same distance behind the mirror as the candle is in front of the mirror.

The Position of Image Formed in a Plane Mirror

The image formed in a plane mirror is at the same distance behind the mirror as the object is in front of the mirror (see Figure 15). In other words, the image and object are at equal distances from a plane mirror but they are on the opposite sides of the plane mirror. For example, if an object is placed at a distance of 5 cm in front of a plane mirror, then its image will also be formed at a distance of 5 cm behind the mirror. And the total distance between the object and its image will be 5 + 5 = 10 cm. That is, the object will be at a distance of 10 cm from its image.

Lateral Inversion

If we stand in front of a big plane mirror, we see the image of our body in it. Though our image appears to be just as we are, but there is a difference. This is because if we lift our right hand, then our image lifts its left hand. And if we lift our left hand, then the image appears to lift its right hand (see Figure 16). This means that **the right side of our body becomes left side in the image; whereas the left side of our body becomes right side in the image**. It appears as if our image has been 'reversed sideways' with respect to our body. This effect of reversing the sides of an object and its image is called *lateral inversion*. And we say that the image formed in a plane mirror is laterally inverted. In other words, the image formed in a plane mirror is 'sideways reversed' with respect to the object. We can now define lateral inversion as follows :

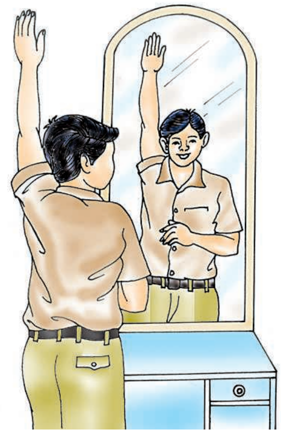
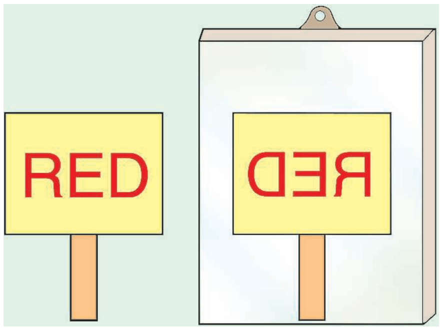


Figure 16. Our left hand appears to be right hand in the mirror image.

When an object is placed in front of a plane mirror, then the right side of object appears to become the left side of image; and the left side of object appears to become the right side of image. This change of sides of an 'object' and its 'mirror image' is called lateral inversion. The phenomenon of lateral inversion will become clear from the following example. Suppose we have a placard having the word RED written on it [see Figure 17(*a*)]. When we hold this placard in front of a plane mirror, the image of word RED appears to be like ꓷƎЯ [see Figure 17(*b*)]. Please note that the object (placard) has the letter R on its left side but the image has this letter in reversed form Я on its right side. Similarly, the image of letter E appears to be reversed like Ǝ. And the letter D on the right side of the object (placard) is on the left side of the image in the reversed form as ꓷ. Thus, all the letters written on the placard are reversed from left to right. We say that the image is laterally inverted. This is an example of lateral inversion. **The phenomenon of lateral inversion is due to the reflection of light.**



(*a*) Object (*b*) Laterally inverted image (as seen in plane mirror)

Figure 17. Diagram to show lateral inversion.

From the above discussion we conclude that **the image formed in a plane mirror is laterally inverted (or sideways reversed) with respect to the object.** It is due to lateral inversion that the image of our right hand appears to be our left hand. So, when we sit in front of a plane mirror and write with our right hand, it appears in the mirror that we are writing with the left hand. And it is also due to lateral inversion that the parting in our hair on the right appears to be on the left when seen in a mirror. The word AMBULANCE on the hospital vans is written in the form of its mirror image as ƎƆNA⅃UᙠMA (see Figure 18). This is because when we are driving our car and see the hospital van coming from behind in our rear-view mirror, then we will get the laterally inverted image of ƎƆNA⅃UᙠMA and read it as AMBULANCE. Since an ambulance carries seriously ill patients, we can make way for it to pass through and reach the hospital quickly. We are now in a position to give all the **characteristics of an image formed by a plane mirror.**

Figure 18. An ambulance. Please note the word AMBULANCE written in the form of its mirror image.

1. The image formed in a plane mirror is virtual. It cannot be received on a screen.

2. The image formed in a plane mirror is erect. It is the same side up as the object.
3. The image in a plane mirror is of the same size as the object.
4. The image formed by a plane mirror is at the same distance behind the mirror as the object is in front of the mirror.
5. The image formed in a plane mirror is laterally inverted (or sideways reversed).

Uses of Plane Mirrors

(*i*) Plane mirrors are used to see ourselves. The mirrors on our dressing table and in bathrooms are plane mirrors.

(*ii*) Plane mirrors are fixed on the inside walls of certain shops (like jewellery shops) to make them look bigger.

(*iii*) Plane mirrors are fitted at blind turns of some busy roads so that drivers can see the vehicles coming from the other side and prevent accidents.

(*iv*) Plane mirrors are used in making periscopes.

We will now solve some problems based on plane mirrors.

Sample Problem 1. An incident ray makes an angle of 35° with the surface of a plane mirror. What is the angle of reflection ?

Solution. In order to find out the angle of reflection, we should first know the angle of incidence. In this case, the incident ray makes an angle of 35° with the surface of the mirror (see Figure 19), so the angle of incidence is not 35°. The angle of incidence is the angle between incident ray and normal. So, in this case, the angle of incidence will be 90° – 35°= 55°. Since the angle of incidence is 55 degrees, therefore, the angle of reflection is also 55 degrees. This is shown clearly in Figure 19.

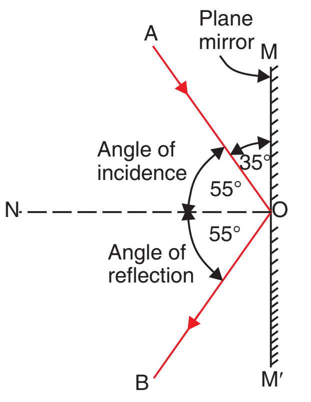


Figure 19.

Sample Problem 2. David is observing his image in a plane mirror. The distance between the mirror and his image is 4 m. If he moves 1 m towards the mirror, then the distance between David and his image will be :

(*a*) 3 m (*b*) 5 m (*c*) 6 m (*d*) 8 m

Solution. (*i*) In this problem, David is the object. Initially, the distance between the mirror and David's image is 4 m. Since the distance of object from plane mirror is equal to distance of image from plane mirror, therefore, the distance of David (which is object), from the plane mirror is also 4 m (see Figure 20).

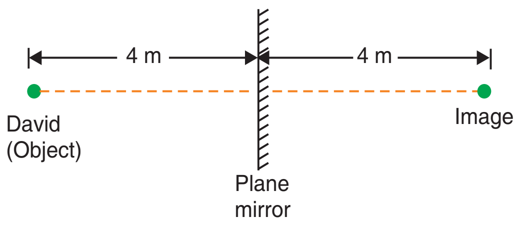


Figure 20.

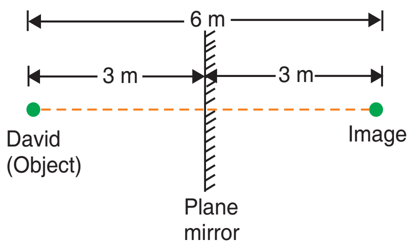


Figure 21.

(*ii*) David moves 1 m towards the mirror. This means that the distance of David from mirror will be 4 – 1 = 3 m. Since the image is formed at the same distance behind the mirror as the object is in front of it, therefore, the distance of image from mirror in this case will also be 3 m (see Figure 21)

Now, Distance of David from mirror = 3 m (in front)
And, Distance of image from mirror = 3 m (at the back)
So, Distance between David and his image = 3 m + 3 m
= 6 m

Thus, the correct option is : (*c*) 6 m.

Sample Problem 3. The rear view mirror of a car is a plane mirror. A driver is reversing his car at a speed of 2 m/s. The driver sees in his rear view mirror, the image of a truck parked behind his car. The speed at which the image of the truck appears to approach the driver will be :

(*a*) 1 m/s (*b*) 2 m/s (*c*) 4 m/s (*d*) 8 m/s

Solution. In a plane mirror, the object and its image always remain at the same distance from the mirror. So, when the car reverses at a speed of 2 m/s, then the image will also appear to move towards the mirror at the same speed of 2 m/s. So, the speed at which the image of truck appears to approach the car driver will be 2 m/s + 2 m/s = 4 m/s. Thus, the correct option will be : (*c*) 4 m/s.

Before we go further and discuss spherical mirrors, **please answer the following questions :**

Very Short Answer Type Questions

1. What happens when a ray of light falls normally (or perpendicularly) on the surface of a plane mirror ?

2. A ray of light is incident on a plane mirror at an angle of 30°. What is the angle of reflection ?

3. A ray of light strikes a plane mirror at an angle of 40° to the mirror surface. What will be the angle of reflection ?

4. A ray of light is incident normally on a plane mirror. What will be the :

(*a*) angle of incidence ?

(*b*) angle of reflection ?

5. What type of image is formed :

(*a*) in a plane mirror ?

(*b*) on a cinema screen ?

6. What kind of mirror is required for obtaining a virtual image of the same size as the object ?

7. What is the name of the phenomenon in which the right side of an object appears to be the left side of the image in a plane mirror ?

8. Name the phenomenon responsible for the following effect :

When we sit in front of a plane mirror and write with our right hand, it appears in the mirror that we are writing with the left hand.

9. If an object is placed at a distance of 10 cm in from of a plane mirror, how far would it be from its image ?

10. Which property of light makes a pencil cast a shadow when it is held in front of a light source ?

11. The image seen in a plane mirror cannot be formed on a screen. What name is given to this type of image ?

12. Fill in the following blank with a suitable word :

When light is reflected, the angles of incidence and reflection are.......... .

13. State whether the following statement is true or false :

A student says that we can see an object because light from our eyes is reflected back by the object.

14. Where is the image when you look at something in a mirror ?

15. A ray of light strikes a plane mirror such that its angle of incidence is 30°. What angle does the reflected ray make with the mirror surface ?

Short Answer Type Questions

16. What is the difference between a real image and a virtual image ? Give one example of each type of image.

17. The letter F is placed in front of a plane mirror :

(*a*) How would its image look like when seen in a plane mirror ?

(*b*) What is the name of the phenomenon involved ?

18. What is lateral inversion ? Explain by giving a suitable example.

19. Write the word AMBULANCE as it would appear when reflected in a plane mirror. Why is it sometimes written in this way (as its mirror image) on the front of an ambulance ?

20. What are the important differences between looking at a photograph of your face and looking at yourself in a plane mirror ?

21. (*a*) A wall reflects light and a mirror also reflects light. What difference is there in the way they reflect light ?
(*b*) Which type of reflection of light leads to the formation of images ?

22. What is the difference between regular reflection of light and diffuse reflection of light ? What type of reflection of light takes place from :
(*a*) a cinema screen (*b*) a plane mirror (*c*) a cardboard (*d*) still water surface of a lake

23. What can you see in a completely dark room ? If you switch on an electric bulb in this dark room as a light source, explain how you could now see :
(*a*) the electric bulb.
(*b*) a piece of white paper.

24. (*a*) A boy with a mouth 5 cm wide stands 2 m away from a plane mirror. Where is his image and how wide is the image of his mouth ?
(*b*) The boy walks towards the mirror at a speed of 1 m/s. At what speed does his image approach him ?

25. (*a*) An extended object in the form of an arrow pointing upward has been placed in front of a plane mirror. Draw a labelled ray-diagram to show the formation of its image.
(*b*) State the uses of plane mirrors.

Long Answer Type Questions

26. What is meant by 'reflection of light' ? Define the following terms used in the study of reflection of light by drawing a labelled ray-diagram :
(*a*) Incident ray (*b*) Point of incidence (*c*) Normal
(*d*) Reflected ray (*e*) Angle of incidence (*f*) Angle of reflection

27. State and explain the laws of reflection of light at a plane surface (like a plane mirror), with the help of a labelled ray-diagram. Mark the angles of 'incidence' and 'reflection' clearly on the diagram. If the angle of reflection is 47.5°, what will be the angle of incidence ?

28. With the help of a labelled ray-diagram, describe how a plane mirror forms an image of a point source of light placed in front of it. State the characteristics of the image formed in a plane mirror.

29. (*a*) Explain why, though both a plane mirror and a sheet of paper reflect light but we can see the image of our face in a plane mirror but not in a sheet of paper.
(*b*) The image in a plane mirror is virtual and laterally inverted. What does this statement mean ?
(*c*) Write all the capital letters of the alphabet which look the same in a plane mirror.

Multiple Choice Questions (MCQs)

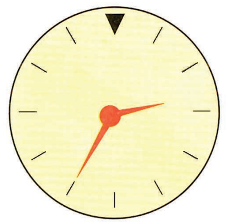
30. The angle of reflection is equal to the angle of incidence :
(*a*) always (*b*) sometimes (*c*) under special conditions (*d*) never

31. The angle between an incident ray and the plane mirror is 30°. The total angle between the incident ray and reflected ray will be :
(*a*) 30° (*b*) 60° (*c*) 90° (*d*) 120°

32. A ray of light is incident on a plane mirror making an angle of 90° with the mirror surface. The angle of reflection for this ray of light will be :
(*a*) 45° (*b*) 90° (*c*) 0° (*d*) 60°

33. The image of an object formed by a plane mirror is :
(*a*) virtual (*b*) real (*c*) diminished (*d*) upside-down

34. The image formed by a plane mirror is :
(*a*) virtual, behind the mirror and enlarged.
(*b*) virtual, behind the mirror and of the same size as the object.
(*c*) real, at the surface of the mirror and enlarged.
(*d*) real, behind the mirror and of the same size as the object.



35. The figure given alongside shows the image of a clock as seen in a plane mirror. The correct time is :
(*a*) 2.25 (*b*) 2.35 (*c*) 6.45 (*d*) 9.25

Questions Based on High Order Thinking Skills (HOTS)

36. A man stands 10 m in front of a large plane mirror. How far must he walk before he is 5 m away from his image ?

37. An object is placed 20 cm in front of a plane mirror. The mirror is moved 2 cm towards the object. The distance between the positions of the original and final images seen in the mirror is :

(*a*) 2 cm (*b*) 4 cm (*c*) 10 cm (*d*) 22 cm

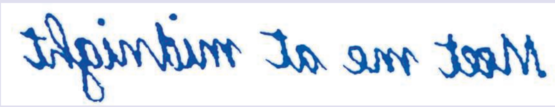
38. A man sits in an optician's chair, looking into a plane mirror which is 2 m away from him and views the image of a chart which faces the mirror and is 50 cm behind his head. How far away from his eyes does the chart appear to be ?

39. A ray of light strikes a plane mirror *PQ* at an angle of incidence of 30°, is reflected from the plane mirror and then strikes a second plane mirror *QR* placed at right angles to the first mirror. The angle of reflection at the second mirror is :

(*a*) 30° (*b*) 45° (*c*) 60° (*d*) 90°

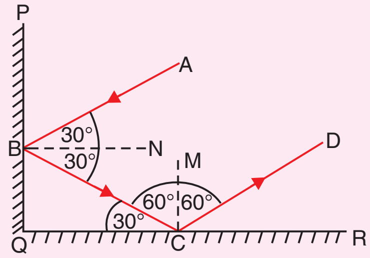
Draw a ray-diagram to illustrate your answer.

40. Explain how to read the following message which was found on some blotting paper :



ANSWERS

2. 30° **3.** 50° **4.** (*a*) 0° (*b*) 0° **6.** Plane mirror **7.** Lateral inversion **8.** Lateral inversion **9.** 20 cm **10.** Light travels in straight lines **11.** Virtual image **12.** equal **13.** False **14.** Behind the mirror **15.** 60° **17.** (*a*) ꟻ (*b*) Lateral inversion **24.** (*a*) 2 m behind the plane mirror ; 5 cm wide (*b*) 2 m/s **27.** 47.5° **29.** (*c*) A, H, I, M, O, T, U, V, W, X, Y **30.** (*a*) **31.** (*d*) **32.** (*c*) **33.** (*a*) **34.** (*b*) **35.** (*d*) **36.** 7.5 m **37.** (*b*) **38.** 4.5 m **39.** (*c*) 60°



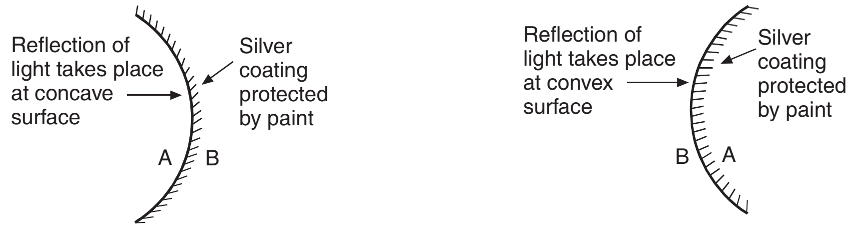
40. The impression on blotting paper is the mirror image of the written message ; Hold the written message in front of a mirror to read it.

REFLECTION OF LIGHT FROM CURVED SURFACES : SPHERICAL MIRRORS

So far we have discussed the reflection of light from plane surfaces like that of a plane mirror. **When a parallel beam of light rays falls on a plane mirror, it is reflected as a parallel beam.** So, a plane mirror changes only the direction of incident light rays, it does not 'converge' or 'diverge' the parallel rays of light (To bring the parallel rays of light '*closer together*' is called '*to converge*' the light rays whereas '*to spread out*' the parallel rays of light is called '*to diverge*' the light rays). **We will now describe the spherical mirrors which can converge or diverge the parallel rays of light which fall on them**. Please note that the spherical mirrors have a curve-like surface, so they are also known as curved mirrors. We will first define the spherical mirrors and then study the reflection of light from these spherical mirrors.

A spherical mirror is that mirror whose reflecting surface is the part of a hollow sphere of glass. The spherical mirrors are of two types : Concave mirrors, and Convex mirrors.

(*i*) A concave mirror is that spherical mirror in which the reflection of light takes place at the concave surface (or bent-in surface). A concave mirror is shown in Figure 22(*a*), in which the concave reflecting surface has been marked *A*. The other surface *B* in Figure 22(*a*), having short, oblique lines is the non-reflecting surface. The inner shining surface of a steel spoon is an example of concave mirror (see Figure 23). In our ray-diagrams, we use only the side-view of a concave mirror as shown in Figure 22(*a*). If, however, we look at a concave mirror from the front, it appears to be like a piece of thin round glass whose front surface is shining and bent inward whereas back surface is covered with a paint and bulging outward.



(*a*) A concave mirror (*b*) A convex mirror

Figure 22.

***(ii)* A convex mirror is that spherical mirror in which the reflection of light takes place at the convex surface (or bulging-out surface).** A convex mirror is shown in Figure 22(*b*), in which the convex reflecting surface has been marked *B*. The other surface *A* in Figure 22(*b*), having short, oblique lines is the non-reflecting surface. The back-side of a shining steel spoon is an example of convex mirror (see Figure 23). In our ray diagrams, we use only the side-view of a convex mirror as shown in Figure 22(*b*). If, however, we look at a convex mirror from the front, it appears like a piece of thin, round glass whose front shining surface is bulging outward but the back surface covered with paint is bent inward. **A spherical mirror (concave mirror or convex mirror) works on the reflection of light**. We will now understand the meaning of some new terms such as centre of curvature, radius of curvature, pole, and principal axis, which are used in the study of spherical mirrors.

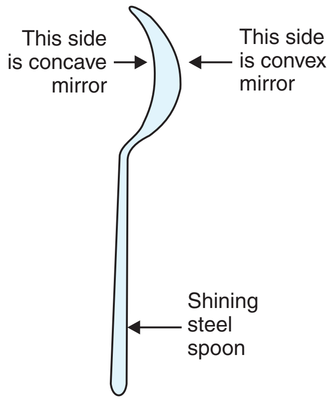
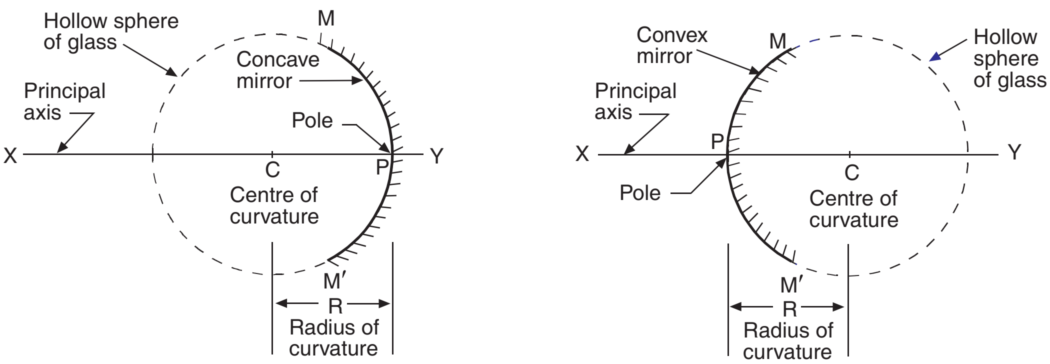


Figure 23. The front side of a shining steel spoon is a concave mirror whereas its back side is a convex mirror.

Centre of Curvature, Radius of Curvature, Pole and Principal Axis of a Spherical Mirror

The centre of curvature of a spherical mirror is the centre of the hollow sphere of glass of which the mirror is a part. The centre of curvature of a mirror is represented by the letter *C*. In Figure 24(*a*), *C* is the centre of curvature of the concave mirror and in Figure 24(*b*), *C* is the centre of curvature of the convex mirror. The centre of curvature is not a part of the mirror. It lies outside the reflecting surface of the mirror. It should be noted that **the centre of curvature of a concave mirror is in front of it but the centre of curvature of a convex mirror is behind it.**

The radius of curvature of a spherical mirror is the radius of the hollow sphere of glass of which the mirror is a part. In Figure 24(*a*), the distance *CP* is the radius of curvature of the concave mirror and in Figure 24(*b*), the distance *CP* is the radius of curvature of the convex mirror. The radius of curvature of a mirror is represented by the letter *R*.



(*a*) (*b*)

Figure 24. Diagrams to show how a concave mirror and a convex mirror can be considered to be the part of a hollow sphere of glass.

The centre of a spherical mirror is called its pole. In other words, the middle point of a spherical mirror is called its pole. In Figure 24(*a*), *P* is the pole of the concave mirror and in Figure 24(*b*), *P* is the pole of the convex mirror. The pole of a spherical mirror lies on the surface of the mirror.

The straight line passing through the centre of curvature and pole of a spherical mirror is called its principal axis. In Figure 24(*a*), *C* is the centre of curvature of the concave mirror and *P* is the pole of the concave mirror, so the line *XY*, passing through *C* and *P* is the principal axis of the concave mirror. Similarly, in Figure 24(*b*), *XY* is the principal axis of the convex mirror. The principal axis is normal (or perpendicular) to the mirror at its pole.

That portion of a mirror from which the reflection of light actually takes place is called the aperture of the mirror. The aperture of a spherical mirror is represented by the diameter of its reflecting surface. In Figure 24, the distance *MM′* is the aperture of the mirror. In fact, *the aperture of a mirror represents the size of the mirror.*

Principal Focus and Focal Length of a Concave Mirror

The principal focus of a concave mirror is a point on its principal axis to which all the light rays which are parallel and close to the axis, converge after reflection from the concave mirror. Look at Figure 25 in which a parallel beam of light rays is falling on a concave mirror *MM′*. In Figure 25, point *F* is the principal focus of the concave mirror because all the parallel rays of light converge at this point after getting reflected from the concave mirror. Since all the reflected light rays actually pass through the focus (*F*) of a concave mirror, therefore, **a concave mirror has a real focus. The focus of a concave mirror is in front of the mirror**. Since a concave mirror converges a parallel beam of light rays, it is also called a converging mirror. **The focal length of a concave mirror is the distance between its pole and principal focus.** In Figure 25, *P* is the pole of the concave mirror and *F* is the principal focus, so the distance *PF* is the focal length of this concave mirror. The focal length of a mirror is denoted by the letter *f*.

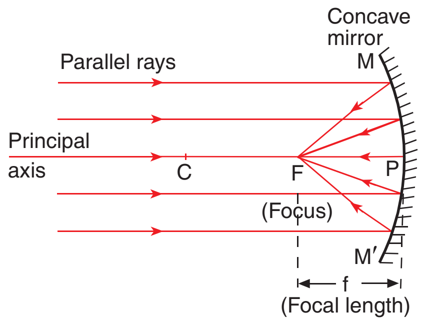


Figure 25. A concave mirror converges (brings closer) a beam of parallel rays of light.

We will now describe how an image of the sun can be formed by a concave mirror. The sun is at a far off distance from us, so the sunlight rays reaching us are parallel rays. **An image of the sun can be produced by a concave mirror at its focus** (see Figure 26). This can be done by performing a simple experiment as follows. We take a concave mirror and point it towards the sun. Hold a piece of paper in front of the concave mirror in such a way that the sunlight reflected by concave mirror falls on the paper (see Figure 26). A small patch of bright reflected light will appear on the paper. Adjust the distance of paper from the concave mirror in such a way that the sharpest point of bright light is obtained. This sharp point of light on paper is the image of sun formed by the concave mirror (see Figure 26). This image of the sun is formed at the focus of concave mirror (where the paper is held by us). If we keep this piece of paper in this position for a few minutes, the paper would start burning at the point of sun's image and a hole will be formed in it. This is because the concave mirror converges (or concentrates) a lot of sun's rays to a small point on paper. The heat energy of these concentrated sun rays burns the paper. Please note that the image of the sun formed by the concave mirror is real because it can be received on screen (such as a sheet of paper).

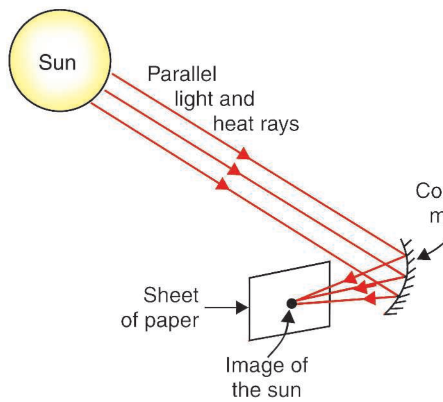


Figure 26. A concave mirror forms a real image of the sun.

Since the sun's image is formed at the focus of the concave mirror, therefore, the distance of sun's image (or paper) from the concave mirror gives us an approximate value of the focal length of the concave mirror.

Principal Focus and Focal Length of a Convex Mirror

The principal focus of a convex mirror is a point on its principal axis from which a beam of light rays, initially parallel to the axis, appears to diverge after being reflected from the convex mirror. In Figure 27, a parallel beam of light rays is incident on a convex mirror *MM′*. Each ray of light is reflected by the convex mirror, and the reflected rays diverge (spread out) from the mirror surface. Let us produce all the reflected rays backwards (as shown by dotted lines) so that they appear to meet at a point *F* behind the convex mirror. Now, to a person looking into the mirror from the left side, all the reflected rays appear to be coming (or diverging) from the same point *F* behind the convex mirror. This point *F* is the principal focus of the convex mirror. It should be noted that the reflected rays do not actually pass through the focus (*F*) of a convex mirror, therefore, **a convex mirror has virtual focus**. Another point to be noted is that **the focus of a convex mirror is situated behind the mirror**. The focal length of a convex mirror is the distance from the pole *P* to its principal focus *F*. Thus, in Figure 27, the distance *PF* is the focal length of the convex mirror.

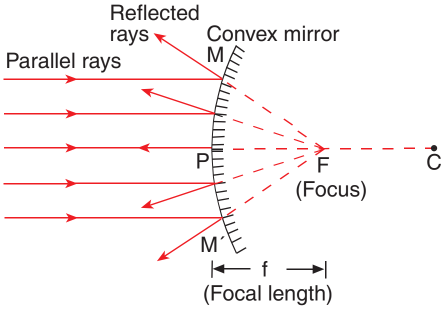


Figure 27. A convex mirror diverges (spreads out) a beam of parallel rays of light.

A plane mirror neither converges parallel rays of light nor diverges them. The focal length of a plane mirror can be considered to be 'infinite' or 'infinity' (which means very, very great or limitless).

Relation between Radius of Curvature and Focal Length of a Spherical Mirror

For a spherical mirror having small aperture, the principal focus (*F*) lies exactly mid-way between the pole (*P*) and centre of curvature (*C*) (see Figures 26 and 27). So, **the focal length of a spherical mirror (a concave mirror or a convex mirror) is equal to half of its radius of curvature.** If *f* is the focal length of a spherical mirror and *R* is its radius of curvature, then :

$$f = \frac{R}{2}$$

Let us solve one problem now.

Sample Problem. If the radius of curvature of a spherical mirror is 20 cm, what is its focal length ?

(NCERT Book Question)

Solution. We know that : $f = \frac{R}{2}$

Here, Focal length, f = ? (To be calculated)

And, Radius of curvature, R = 20 cm

So, $f = \frac{20}{2}$ cm

= 10 cm

Thus, the focal length of this spherical mirror is 10 cm.

We are now in a position to **answer the following questions :**

Very Short Answer Type Questions

1. Name the spherical mirror which has :
   (*a*) virtual principal focus.
   (*b*) real principal focus.
2. Out of convex mirror and concave mirror, whose focus is situated behind the mirror ?
3. Find the focal length of a concave mirror whose radius of curvature is 32 cm.
4. If the focal length of a convex mirror is 25 cm, what is its radius of curvature ?

5. Fill in the following blanks with suitable words :
   (*a*) Parallel rays of light are reflected by a concave mirror to a point called the ....
   (*b*) The focal length of a concave mirror is the distance from the ....to the mirror.
   (*c*) A concave mirror............rays of light whereas a convex mirror..........rays of light.
   (*d*) For a convex mirror, parallel rays of light appear to diverge from a point called the.......... .

Short Answer Type Questions

6. What is a spherical mirror ? Distinguish between a concave mirror and a convex mirror.
7. Name the two types of spherical mirrors. What type of mirror is represented by the :
   (*a*) back side of a shining steel spoon ?
   (*b*) front side of a shining steel spoon ?
8. What is the relation between the focal length and radius of curvature of a spherical mirror (concave mirror or convex mirror) ? Calculate the focal length of a spherical mirror whose radius of curvature is 25 cm.
9. Explain with a suitable diagram, how a concave mirror converges a parallel beam of light rays. Mark clearly the pole, focus and centre of curvature of concave mirror in this diagram.
10. Describe with a suitable diagram, how a convex mirror diverges a parallel beam of light rays. Mark clearly the pole, focus and centre of curvature of convex mirror in this diagram.

Long Answer type Questions

11. Define (*a*) centre of curvature (*b*) radius of curvature (*c*) pole (*d*) principal axis, and (*e*) aperture, of a spherical mirror with the help of a labelled diagram.
12. (*a*) Define (*i*) principal focus of a concave mirror, and (*ii*) focal length of a concave mirror.
    (*b*) Draw diagram to represent the action of a concave mirror on a beam of parallel light rays. Mark on this diagram principal axis, focus F, centre of curvature C, pole P and focal length *f*, of the concave mirror.
13. (*a*) What is meant by (*i*) principal focus of a convex mirror, and (*ii*) focal length of a convex mirror ?
    (*b*) Draw diagram to show the action of convex mirror on a beam of parallel light rays. Mark on this diagram principal axis, focus F, centre of curvature C, pole P and focal length *f*, of the convex mirror.

Multiple Choice Questions (MCQs)

14. In a convex spherical mirror, reflection of light takes place at :
    (*a*) a flat surface (*b*) a bent-in surface (*c*) a bulging-out surface (*d*) an uneven surface
15. A diverging mirror is :
    (*a*) a plane mirror (*b*) a convex mirror (*c*) a concave mirror (*d*) a shaving mirror
16. If R is the radius of curvature of a spherical mirror and f is its focal length, then :
    (*a*) $R = f$ (*b*) $R = 2f$ (*c*) $R = \frac{f}{2}$ (*d*) $R = 3f$
17. The focal length of a spherical mirror of radius of curvature 30 cm is :
    (*a*) 10 cm (*b*) 15 cm (*c*) 20 cm (*d*) 30 cm
18. If the focal length of a spherical mirror is 12.5 less cm, its radius of curvature will be :
    (*a*) 25 cm (*b*) 15 cm (*c*) 20 cm (*d*) 35 cm

Questions Based on High Order Thinking Skills (HOTS)

19. A communications satellite in orbit sends a parallel beam of signals down to earth. If these signals obey the same laws of reflection as light and are to be focussed onto a small receiving aerial, what should be the best shape of the metal 'dish' used to collect them ?
20. When a spherical mirror is held towards the sun and its sharp image is formed on a piece of carbon paper for some time, a hole is burnt in the carbon paper.
    (*a*) What is the nature of spherical mirror ?
    (*b*) Why is a hole burnt in the carbon paper ?
    (*c*) At which point of the spherical mirror the carbon paper is placed ?
    (*d*) What name is given to the distance between spherical mirror and carbon paper ?
    (*e*) What is the advantage of using a carbon paper rather than a white paper ?

ANSWERS

1. (*a*) Convex mirror (*b*) Concave mirror **2.** Convex mirror **3.** 16 cm **4.** 50 cm **5.** (*a*) principal focus (*b*) principal focus (*c*) converges ; diverges (*d*) principal focus **8.** 12.5 cm **14.** (*c*) **15.** (*b*) **16.** (*b*) **17.** (*b*) **18.** (*a*) **19.** Concave metal dish : It will collect the parallel beam of satellite signals at its focus where receiving aerial is fixed. **20.** (*a*) Concave mirror (*b*) A lot of sun's heat rays are concentrated at the point of sun's image which burn the hole in carbon paper (*c*) At the focus (*d*) Focal length (*e*) A black carbon paper absorbs more heat rays and hence burns a hole more easily (than a white paper).

RULES FOR OBTAINING IMAGES FORMED BY CONCAVE MIRRORS

When an object is placed in front of a concave mirror, an image is formed. **The image is formed at that point where at least two reflected rays intersect (or appear to intersect).** Now, to find out the position of an image formed by a concave mirror, we will use only those two rays of light (starting from the object), whose paths, after reflection from the mirror, are known to us and easy to draw. The following rays of light are usually used to locate the images formed by concave mirrors. We can call them rules for obtaining images in concave mirrors.

Rule 1. **A ray of light which is parallel to the principal axis of a concave mirror, passes through its focus after reflection from the mirror.** This is shown in Figure 28. Here, we have a concave mirror *M* and its principal axis is *XP*. The centre of curvature is *C* and its focus is *F*. Now, a ray of light *AB* is parallel to the principal axis of the mirror. It strikes the mirror at point *B* and gets reflected. After reflection its path changes and it passes through the focus *F* and goes in the direction *BY* (see Figure 28).

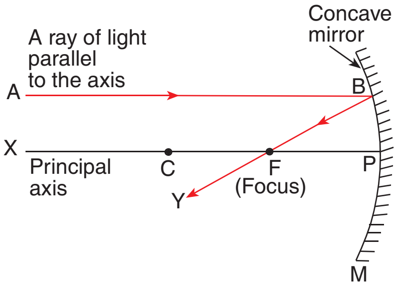


Figure 28.

Rule 2. **A ray of light passing through the centre of curvature of a concave mirror is reflected back along the same path** (because it strikes the mirror normally or perpendicularly). This is shown in Figure 29. A ray of light *AD* is passing through the centre of curvature *C* of the concave mirror. It falls normally (or perpendicularly) on the mirror at point *D* and gets reflected back along the same path *DA*. It should be noted that we have put two arrow-heads on the line *AD* which point in the opposite directions. *The arrow pointing from left to right indicates the direction of incident ray and the arrow pointing from right to left indicates the direction of reflected ray* (see Figure 29). The ray of light passing through the centre of curvature of a concave mirror is reflected back along the same path because it strikes the concave mirror at right angles (90°) to its surface due to which the angle of incidence and angle of reflection both are 0°.

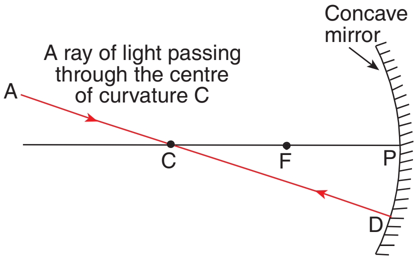


Figure 29.

Rule 3. **A ray of light passing through the focus of a concave mirror becomes parallel to the principal axis after reflection.** This rule is just the reverse case of the first rule and it is shown in Figure 30. Here, the incident ray *AE* is passing through the focus *F* of the concave mirror. It strikes the mirror surface at point *E* and gets reflected. After reflection, it becomes parallel to the axis and goes in the direction *EG*.

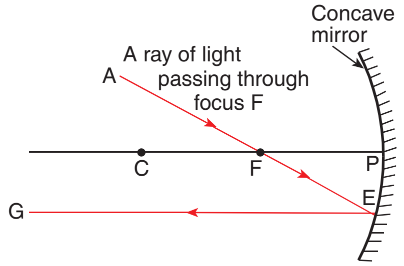


Figure 30.

Rule 4. **A ray of light which is incident at the pole of a concave mirror is reflected back making the same angle with the principal axis.** This is shown in Figure 31. Here a ray of light *AP* is incident at the pole *P* of the concave mirror making an angle of incidence *i* with the principal axis. It gets reflected along the direction *PH* such that the angle of reflection (*r*) is equal to the angle of incidence (*i*).

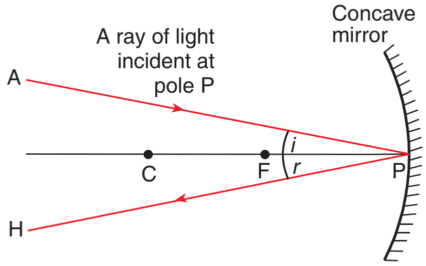


Figure 31.

Please note that if a ray of light is incident on a concave mirror along its principal axis, then it is reflected back along the same path (because it will be normal to the mirror surface). The angle of incidence as well as the angle of reflection for such a ray of light will be zero.

FORMATION OF DIFFERENT TYPES OF IMAGES BY A CONCAVE MIRROR

The type of image formed by a concave mirror depends on the position of object in front of the mirror. We can place the object at different positions (or different distances) from a concave mirror to get different types of images. For example, we can place the object :

(*i*) between the pole (*P*) and focus (*F*) (see Figure 32),
(*ii*) at the focus (*F*),
(*iii*) between focus (*F*) and centre of curvature (*C*),
(*iv*) at the centre of curvature (*C*),
(*v*) beyond the centre of curvature (*C*), and
(*vi*) at far-off distance called infinity (This distance cannot be shown in the Figure).

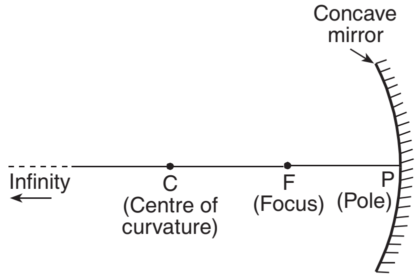


Figure 32.

Please note that in all our ray-diagrams the object, an arrow *AB* pointing upwards, will be placed on the principal axis. So, a ray of light coming from the bottom *B* of the object always travels along the principal axis and gets reflected back along the same path. We, however, do not put arrows on the principal axis to show this ray of light.

We will now draw the ray-diagrams to show the images formed by a concave mirror for the different positions of an object. We will consider all the six positions of the object, one by one.

Case 1. Image formed by a concave mirror when the object is placed between pole and focus of the mirror (Object between P and F)

In Figure 33, we have an object *AB* placed between the pole (*P*) and focus (*F*) of a concave mirror, that is, the object is within the focus of the concave mirror. To find out the position and nature of the image, starting from *A*, we draw a ray *AD* parallel to the axis (see Figure 33). This ray gets reflected at *D* and then passes through the focus *F*. A second ray of light *AE* passing through the centre of curvature *C* strikes the mirror normally (or perpendicularly) at point *E* and gets reflected back along the same path.

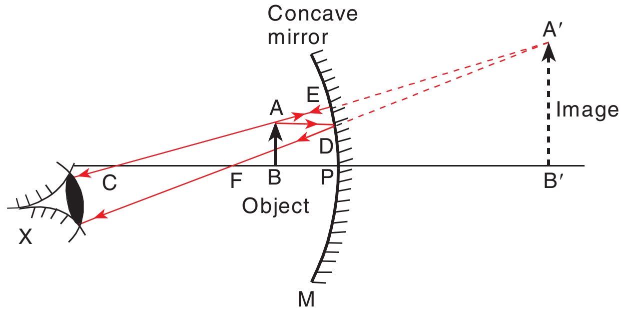


Figure 33. Formation of image by a concave mirror when the object is placed between its pole (P) and focus (F).

Now, the two reflected rays *DF* and *EC* are diverging rays and, therefore, do not intersect each other on the left side. The reflected rays *DF* and *EC* are produced backwards (as shown by dotted lines). On producing backwards, they appear to intersect at point *A′* behind the concave mirror. Thus, *A′* is the virtual image of point *A* of the object. To get the complete image of the object we draw *A′B′* perpendicular to the axis from point *A′*. Thus *A′B′* is the image of the object *AB* formed by the concave mirror. Now, an eye at position *X*, sees the reflected rays as if they have come from points *A′B′* behind the mirror. Since there is no actual intersection of the reflected rays, so the image *A′B′* is a virtual image. This image can be seen only by looking into the concave mirror, it cannot be obtained on a screen. We can see from Figure 33 that the image is same side up as object (both of them have arrow-head at the top), so it is an erect image. And if we compare the size of the object *AB* and its image *A′B′*, the image appears to be bigger in size than the object. Thus, it is an enlarged image or magnified image. From the above discussion we conclude that : **When an object is placed between the pole (*P*) and focus (*F*) of a concave mirror, the image formed is :**

(*i*) behind the mirror,
(*ii*) virtual and erect, and
(*iii*) larger than the object (or magnified).

It is clear from the above discussion that to obtain a magnified and erect image with a concave mirror, the object should be placed between the pole and focus of the concave mirror, that is, the object should be placed within the focus (or focal length) of the concave mirror. For example, if the focal length of a concave mirror is 10 cm, then its focus (*F*) will be at a distance of 10 cm from the pole of the mirror. So, to obtain a magnified and erect image with this concave mirror, we will have to place the object at a distance of less than 10 cm so that it remains between the pole and focus. Thus, if we place the object at a distance of, say 8 cm, from this concave mirror, the object will be within the focus and a magnified, virtual and erect image will be formed behind the concave mirror (which can be seen by looking into the concave mirror).

If we hold a matchstick (as object) within the focus of a concave mirror, then a magnified, virtual and erect image of the matchstick is seen on looking into the concave mirror [as shown in Figure 34(*a*)]. This

(*a*) A concave mirror can be used to magnify objects. Here it is magnifying a matchstick kept close to it

(*b*) A concave mirror being used as a make-up mirror. It is magnifying a part of the face here.

(*c*) Dentist's mirror is a small concave mirror fitted in a frame with a long handle. It gives a magnified image of tooth.

Figure 34.

also explains the use of a concave mirror as a shaving mirror. When the face is placed close to a concave mirror (so that the face is within its focus) the concave mirror produces a magnified (large) and erect image of the face. Since a large image of the face is seen in the concave mirror, it becomes easier to make a smooth shave. Thus, **while using a concave mirror as a shaving mirror, the face should be close to the concave mirror.** For the same reason, concave mirrors are also used as make-up mirrors by women for putting on make-up (such as painting eye-lashes) [see Figure 34(*b*)]. In order to use a concave mirror as a make-up mirror, the face is held close to the concave mirror so that it lies within the focus of concave mirror. Dentists use concave mirrors to see the large image of the teeth for examining the teeth of a person (see Figure 34(*c*)]. For this purpose, the dentist holds a small concave mirror in such a way that the tooth lies within its focus. A magnified image of the tooth is then seen by the dentist in the concave mirror. Since the tooth looks much bigger, it becomes easy to examine the defect in the tooth.

Case 2. When the object is placed at the focus of a concave mirror (Object at F)

In Figure 35, the object *AB* has been placed at the focus (*F*) of the concave mirror. Now, the parallel ray of light *AD* (coming from the top of the object) gets reflected at *D* and passes through the focus *F*, giving us the reflected ray *DX*. A second ray of light *AE* passing through the centre of curvature *C*, is reflected back along the same path giving us another reflected ray *EY*. We find that the reflected rays *DX* and *EY* are parallel to one another. These parallel rays will intersect (or meet) at a far off distance to

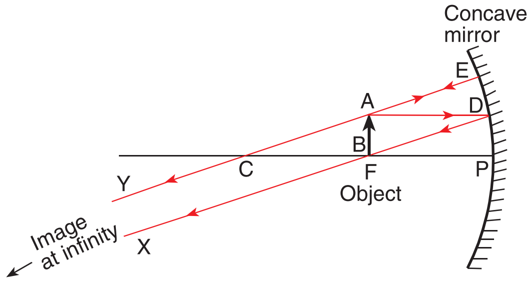


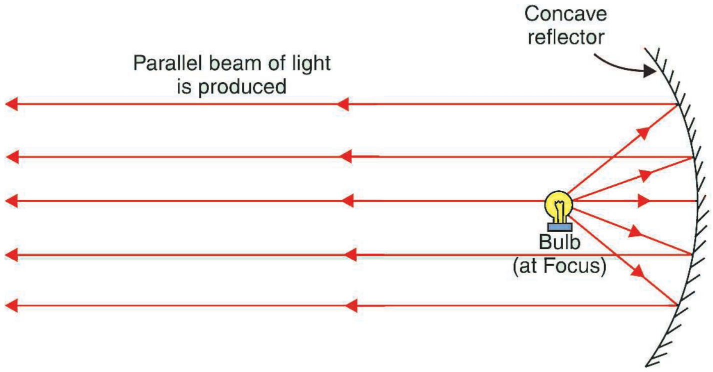
Figure 35. Formation of image by a concave mirror when the object is placed at its focus (F).

form an image 'at infinity'. And since the image is formed at infinity, it is not possible to show it in our diagram. From this discussion we conclude that : **When an object is placed at the focus of a concave mirror, the image formed is :**

(*i*) **at infinity,**
(*ii*) **real and inverted,** and
(*iii*) **highly magnified (or highly enlarged).**

Suppose we have a concave mirror of focal length 10 cm, then its focus (*F*) will be at a distance of 10 cm from it. So, by saying that an object is placed at the focus of this concave mirror, we will mean that the object is placed at a distance of 10 cm from the concave mirror. In this case, the concave mirror converts the diverging rays of light coming from the object into a parallel beam of light rays (which form image at infinity).

When a lighted bulb is placed at the focus of a concave mirror reflector, the diverging light rays of the bulb are collected by the concave reflector and then reflected to produce a strong, parallel-sided beam of light [see Figure 36(*a*)]. This explains the use of concave reflectors in torches, car head-lights, and search lights to produce a strong beam of light (which travels a considerable distance in the darkness of night).



(*a*) When a lighted bulb is placed at the focus of a concave reflector, a parallel beam of light is produced.

(*b*) This picture shows the concave reflector of a torch.

Figure 36.

Case 3. When the object is placed between focus and centre of curvature (Object between F and C)

In Figure 37, the object *AB* has been placed between the focus *F* and centre of curvature C of a concave mirror. Now, a ray of light *AD* parallel to the principal axis gets reflected at point *D* and then passes through the focus *F*. A second ray of light *AE* passing through the centre of curvature C falls normally on the mirror surface at *E* and returns along the same path. Thus, we have two reflected rays *DF* and *EC* which are converging in the downward direction. If we extend these rays further in the downward direction, they actually intersect at point *A'*. Thus *A'* is the real image of point *A* of the object. To get the complete image we draw *A'B'* perpendicular to the axis from point *A'*. Thus, *A'B'* is the real image of the object *AB* and it can be received on a screen. For example, if we take a lighted candle as the object then the image of its wick will be formed on a white screen placed at the image position. If we look at the image *A'B'*, we find that it is wrong side up having arrow-head at its bottom. So, we say that the image is inverted. The size of image is larger than the object, so the image is magnified, and

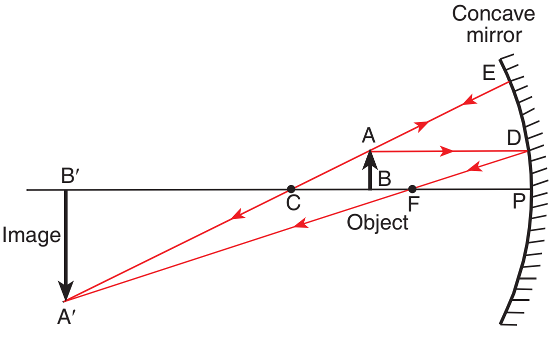


Figure 37. Formation of image by a concave mirror when the object is placed between focus (F) and centre of curvature (C).

it has been formed beyond the centre of curvature of the mirror. From the above discussion we conclude that : **When an object is placed between the focus (*F*) and centre of curvature (*C*) of a concave mirror, the image formed is :**

(*i*) **beyond the centre of curvature,**
(*ii*) **real and inverted,** and
(*iii*) **larger than the object (or magnified).**

Please remember that **a real image is always inverted,** and **a virtual image is always erect.** Suppose we have a concave mirror of focal length 10 cm. Then its focus (*F*) will be at a distance of 10 cm and centre of curvature (*C*) will be at a distance of 2 × 10 = 20 cm from it. Now, by saying that the object is placed between the focus and centre of curvature of this concave mirror, we mean that the object is at any distance between 10 cm and 20 cm from the concave mirror. For example, it may be at a distance of say, 15 cm from the concave mirror. And by saying that the image is formed beyond centre of curvature, we mean that it is at a distance greater than 20 cm from this concave mirror.

Case 4. When the object is placed at the centre of curvature of a concave mirror (Object at C)

In Figure 38, the object *AB* has been placed at the centre of curvature *C* of the concave mirror. A ray of light *AD* which is parallel to the principal axis passes through the focus *F* after reflection. Now, the second ray of light that we usually use is the one passing through the centre of curvature *C*. But in this case the object itself is placed at the centre of curvature, so we cannot use this ray of light to locate the image. Here we will use rule No. 3 of image formation which says that "A ray of light passing through the focus of a concave mirror becomes parallel to the principal axis after reflection". So, we now take the ray *AE* passing through the focus *F*. It strikes the mirror at point *E* and gets reflected in the direction *EA′* parallel to the principal axis.

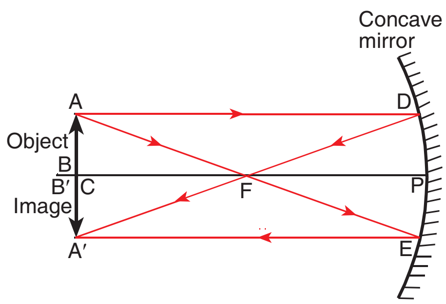


Figure 38. Formation of image by a concave mirror when the object is placed at the centre of curvature (C).

The reflected rays *DA′* and *EA′* meet at point *A′*, so *A′* is the real image of point *A* of the object. To get the complete image, we draw *A′B′* perpendicular to the principal axis. Thus, *A′B′* is the real image of the object *AB* (Note that *B* and *B′* is just the same point). The image is of the same size as the object, it is real, inverted and formed at the centre of curvature, where the object itself is placed. From this discussion we conclude that : **When an object is placed at the centre of curvature (*C*) of a concave mirror, the image formed is :**

(*i*) **at the centre of curvature (*C*),**
(*ii*) **real and inverted,** and
(*iii*) **same size as the object.**

Suppose we have a concave mirror of focal length 10 cm, then its focus (*F*) will be at a distance of 10 cm and its centre of curvature (*C*) will be at a distance of 2 × 10 = 20 cm. So, by saying that the object is at the centre of curvature, we mean that the object is at a distance of 20 cm from this concave mirror. And by saying that the image is formed at the centre of curvature, we mean that the image is also formed at a distance of 20 cm from the concave mirror.

Case 5. When the object is beyond the centre of curvature of the concave mirror (Object beyond C)

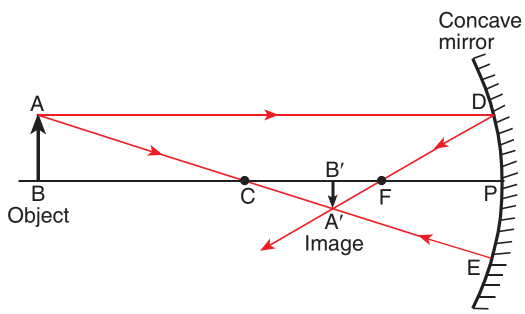


Figure 39. Formation of image by a concave mirror when the object is placed beyond the centre of curvature C.

In Figure 39, the object *AB* has been placed beyond the centre of curvature *C* of the concave mirror. A ray of light *AD* which is parallel to the principal axis, passes through the focus *F* after reflection. A second ray of light *AE* passing through the centre of curvature falls normally on the mirror surface at *E* and returns along the same path. The two reflected rays intersect at *A′*. Thus, *A′* is the real image of point *A* of the object. To get the complete image, we draw *A′B′* perpendicular to the axis. Thus, *A′B′* is the complete image of the object *AB*. It is clear from Figure 39 that the image *A′B′* is formed between the focus (*F*) and centre of curvature (*C*). The image is real and inverted. It is smaller in size than the object *AB*, so we call it a diminished image. From the above discussion we conclude that : **When an object is placed beyond the centre of curvature (*C*) of a concave mirror, the image formed is :**

(*i*) between the focus and centre of curvature,
(*ii*) real and inverted, and
(*iii*) smaller than the object (or diminished).

Suppose we have a concave mirror of focal length 10 cm, then its focus (*F*) will be at a distance of 10 cm and its centre of curvature (*C*) will be at a distance of 2 × 10 = 20 cm from it. Now, by saying that an object is placed beyond the centre of curvature of this concave mirror, we mean that the object is placed at a distance greater than 20 cm (say, 25 cm) from the concave mirror. And by saying that the image is formed between focus and centre of curvature, we mean that the image is formed at a distance between 10 cm and 20 cm.

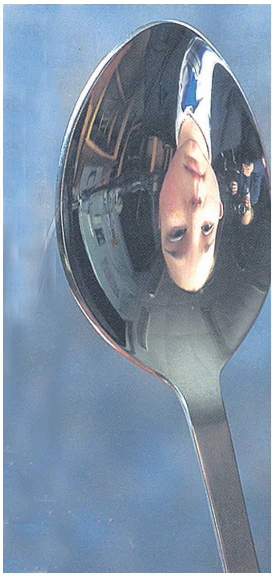


Figure 40. The formation of a real, inverted and diminished image of face in the front side (concave surface) of a shining steel spoon.

We know that the front side of a shining steel spoon is a kind of concave mirror. So, if we keep our face at a fairly good distance from the front side of a shining steel spoon (so that it is beyond its centre of curvature), we will see a real, inverted and smaller image (diminished image) of our face in the spoon (as shown in Figure 40).

Case 6. When the Object is at Infinity

When the object is at a very large distance, we say that the object is at infinity. In Figure 41 we have a concave mirror *M*. Suppose an object (an arrow pointing upwards) has been placed at infinity in front of the concave mirror (Since the object is very far off, it cannot be shown in the diagram). Because the object *AB* is very far off, the two rays *AD* and *AP* coming from its top point *A* are parallel to one-another but at an angle to the principal axis as shown in Figure 41. These parallel rays get reflected at points *D* and *P* and then intersect at point *A′* in the focal plane of the mirror. Thus, *A′* is the real image of the top point *A* of the object. To get the full image of the object, we draw *A′B′* perpendicular to the principal axis from *A′*. Thus, *A′B′* is the image of the object *AB* placed at infinity. We find that image *A′B′* is formed at the focus (*F*) of the concave mirror.

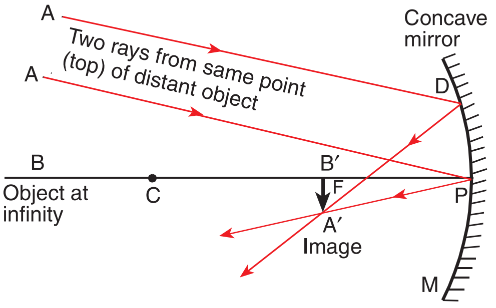


Figure 41. Formation of image by a concave mirror when the object is at a considerable distance (or infinity).

It is real, inverted and much smaller than the object or highly diminished. From the above discussion we conclude that : **When an object is at infinity from a concave mirror, the image formed is :**

(*i*) at the focus (*F*),
(*ii*) real and inverted, and
(*iii*) much smaller than the object (or highly diminished).

It should be noted that this case is just opposite of case No. 2 which we have already discussed. There we studied that **"when the object is at focus of concave mirror, the image is formed at infinity"** and here we have seen that **"when the object is at infinity, the image is formed at the focus of concave mirror".** This means that a concave mirror can concentrate all the parallel rays of light to its focus.

Suppose we have a concave mirror of focal length 10 cm, then its focus (*F*) will be at a distance of 10 cm from it. Now, by saying that the object is at infinity, we mean that the object is at a distance which is many, many times its focal length : it may be 1000 cm, 10,000 cm or even more. And by saying that the image is formed at the focus of this concave mirror, we mean that the image is formed at a distance of 10 cm from the pole of this concave mirror.

Please note that when the object kept at infinity in front of a concave mirror is assumed to be a big arrow pointing upwards, then its image is formed at focus according to the ray-diagram shown in Figure 41. If, however, the object kept at infinity in front of a concave mirror is round in shape (like the sun), then its image is formed at the focus according to the ray-diagram shown in Figure 25 on page 177.

The fact that when a parallel beam of light rays falls on a concave mirror, the concave mirror concentrates all the light at its focus, explains the use of concave mirror as a doctor's head-mirror. **A concave mirror is used as a "head-mirror" by the doctors to concentrate light coming from a lamp on to the body part of a patient (like ear, nose, throat, etc.) to be examined.** This is done as follows : A concave mirror is fixed to the front part of a doctor's head with the help of a strap [as shown in Figure 42(*a*)]. When the beam of light coming from a lamp falls on the doctor's concave head-mirror, the mirror focusses this light on to the body part of the patient. The body part gets illuminated brightly with this light due to which the doctor can look into the body part (like ear, nose, throat, etc.) very clearly.

(*a*) The doctor's head-mirror is a concave mirror

(*b*) The metal 'dish' of dish antenna of television is concave.

Figure 42.

The concave 'metal dishes' are used in dish antennas (or dish aerials) of televisions to receive TV signals from the very distant communications satellites which are high up in the sky [see Figure 42(*b*)]. The dish is a concave reflector. The dish collects a large amount of parallel beams of TV signals coming from the far off satellite and converges them to its focus. The antenna (or signal detector) is fixed in front of the concave dish at its focus. Since the antenna is fixed at the focus of dish, it receives the strongest possible TV signals from the satellite which make our television work. The TV signals coming from satellite can be made even more stronger by using a bigger dish in the dish antenna. Please note that though the TV signals coming from the satellite are not light rays, they obey the laws of reflection of light.

How to find out the Focal Length of a Concave Mirror Quickly but Approximately

The fact that "when the object is at a considerable distance (or at infinity) from a concave mirror, then its image is formed at the focus" can be used to find out the focal length of a concave mirror quickly but approximately. We focus a distant object (several metres away) like a window or tree on a screen by using a concave mirror whose focal length is to be determined (see Figure 43). The sharp image of window or tree will be formed at the focus of the concave mirror. That is, the distance of image (or screen) from the

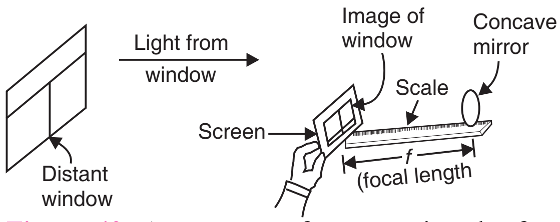


Figure 43. Arrangement for measuring the focal length of a concave mirror quickly but approximately.

concave mirror will be equal to the focal length of concave mirror. This distance can be measured with a scale. It will give us the approximate focal length of the concave mirror. And before we conclude this discussion, here is a summary of the images formed by a concave mirror.

Summary of the Images Formed by a Concave Mirror

Position of object	*Position of image*	*Size of image*	*Nature of image*
1. Within focus (between pole *P* and focus *F*)	Behind the mirror	Enlarged	Virtual and erect
2. At focus (*F*)	At infinity	Highly enlarged	Real and inverted
3. Between *F* and *C*	Beyond *C*	Enlarged	Real and inverted
4. At *C*	At *C*	Equal to object	Real and inverted
5. Beyond *C*	Between *F* and *C*	Diminished	Real and inverted
6. At infinity	At focus (*F*)	Highly diminished	Real and inverted

Uses of Concave Mirrors

(*i*) Concave mirrors are used as shaving mirrors to see a large image of the face. This is because when the face is held within the focus of a concave mirror, then an enlarged image of the face is seen in the concave mirror. This helps in making a smooth shave. For the same reason, **concave mirrors are used as make-up mirrors.**

(*ii*) Concave mirrors are used by dentists to see the large images of the teeth of patients. This is because when a tooth is within the focus of a concave mirror, then an enlarged image of the tooth is seen in the concave mirror. Due to this, it becomes easier to locate the defect in the tooth. The concave mirrors used by dentists are very small in size. They are fitted in a frame with a long handle.

(*iii*) Concave mirrors are used as reflectors in torches, vehicle head-lights and search lights to get powerful beams of light. This is because when a lighted bulb is placed at the focus of a concave reflector, then the concave reflector produces a powerful beam of parallel light rays. This helps us see things up to a considerable distance in the darkness of night. **Concave reflectors are also used in room heaters.** The concave reflectors of room heaters direct heat rays into the whole room.

(*iv*) Concave mirrors are used as doctor's head-mirrors to focus light coming from a lamp on to the body parts of a patient (such as eye, ear, nose, throat, etc.) to be examined by the doctor.

(*v*) Concave dishes are used in TV dish antennas to receive TV signals from the distant communications satellites. The concave dish collects a lot of TV signals and focusses them on to an antenna (or aerial) fixed at its focus, so as to produce strong signals to run the television.

(*vi*) Large concave mirrors are used in the field of solar energy to focus sun's rays for heating solar furnaces. This can be explained as follows : The solar furnace is placed at the focus of a large concave reflector. The concave reflector focuses the sun's heat rays on the furnace due to which the solar furnace gets very hot. Even steel can be melted in this solar furnace.

Let us solve some problems now.

Sample Problem 1. We wish to obtain an erect image of an object using a concave mirror of focal length 15 cm. What should be the range of distance of the object from the mirror ? What is the nature of the image ? Is the image larger or smaller than the object ? Draw a ray-diagram to show the image formation in this case. **(NCERT Book Question)**

Solution. In order to obtain an erect image of an object with a concave mirror, the object should be at a distance less than its focal length. Here the focal length of concave mirror is 15 cm. So to obtain an erect image of the object by using this concave mirror, the object should be placed at any distance which is less than 15 cm from the mirror. The nature of image will be virtual. The image will be larger than the object (For ray-diagram, see Figure 33 on page 181).

Sample Problem 2. The image formed by a concave mirror is seen to be virtual, erect and larger than the object. The position of the object must then be :

(*i*) between the focus and centre of curvature.
(*ii*) at the centre of curvature.
(*iii*) beyond the centre of curvature.
(*iv*) between the pole of the mirror and its focus.

Choose the correct alternative. **(NCERT Book Question)**

Solution. The correct alternative is (*iv*) : between the pole of the mirror and its focus.

Sample Problem 3. A concave mirror has a focal length of 10 cm. Where should an object be placed in front of this concave mirror so as to obtain an image which is real, inverted and same size as the object ?

Solution. When the image formed by a concave mirror is real, inverted and of the same size as the object, then the object must be placed at its centre of curvature (*C*). Now, the centre of curvature of a concave mirror is at a distance of 'twice the focal length' or '2*f*'. Here,

Focal length, $f = 10$ cm

So, $2f = 2 \times 10$ cm

$= 20$ cm

Thus, the object should be placed at a distance of 20 cm in front of this concave mirror.

Sample Problem 4. An object is placed at the following distances from a concave mirror of focal length 10 cm :

(*a*) 8 cm (*b*) 15 cm (*c*) 20 cm (*d*) 25 cm

Which position of the object will produce :

(*i*) a diminished real image ?
(*ii*) a magnified real image ?
(*iii*) a magnified virtual image ?
(*iv*) an image of the same size as the object ?

Solution. In this case the focal length of concave mirror is 10 cm. This means that the focus (*F*) of this concave mirror is at a distance of 10 cm from the mirror and its centre of curvature (*C*) is at a distance of $2 \times 10 = 20$ cm from the mirror.

(*i*) A diminished real image is formed by a concave mirror when the object is beyond C. Here *C* is at 20 cm. So, the diminished real image will be formed when the object is at a distance greater than 20 cm, which in this problem is 25 cm. So, the position of object for a diminished real image is **25 cm**.

(*ii*) A magnified real image is formed by a concave mirror when the object is between *F* and *C*. Here *F* is at 10 cm and *C* is at 20 cm. So, the magnified real image will be formed when the object is at a distance between 10 cm and 20 cm, which in this problem is 15 cm. So, the position of object for a magnified real image is **15 cm.**

(*iii*) A magnified virtual image is formed by a concave mirror when the object is within focus (*F*) at a distance less than focal length or less than 10 cm, which in this problem is 8 cm. So, the position of object for a magnified virtual image is **8 cm.**

(*iv*) An image of the same size as object is formed by a concave mirror when the object is at centre of curvature (*C*). Here *C* is at 20 cm. So, the image of same size as the object will be formed when the object is at 20 cm from the concave mirror. Thus, the position of object for an image of same size as the object is **20 cm.**

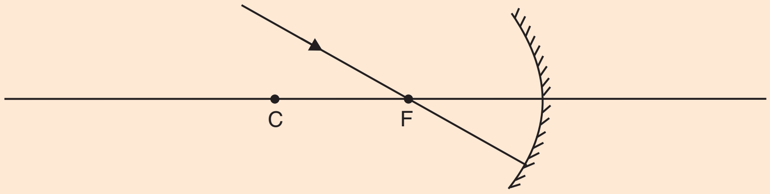
Please note that we have given so many details in answering the above question just to make you understand clearly. There is, however, no need to give so many details in the examination. In the examination, the answer to the above question can just be written as :

(*i*) 25 cm (*ii*) 15 cm (*iii*) 8 cm (*iv*) 20 cm

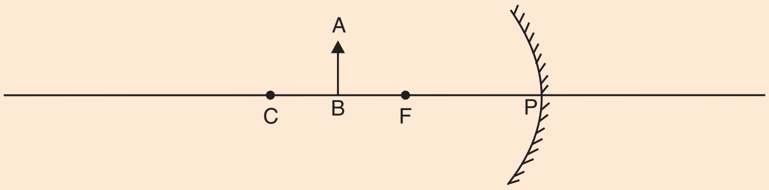
Before we go further and discuss the sign convention for spherical mirrors, **please answer the following questions :**

Very Short Answer Type Questions

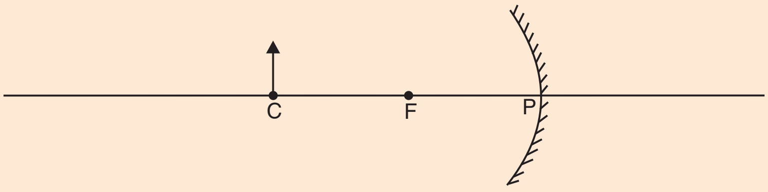
1. For what position of an object, a concave mirror forms a real image equal in size to the object ?
2. Where should an object be placed in front of the concave mirror so as to obtain its virtual, erect and magnified image ?
3. For which positions of the object does a concave mirror produce an inverted, magnified and real image ?
4. If an object is placed at the focus of a concave mirror, where is the image formed ?
5. If an object is at infinity (very large distance) in front of a concave mirror, where is the image formed ?
6. For what position of an object, a real and diminished image is formed by a concave mirror ?
7. Copy this figure in your answer book and show the direction of the light ray after reflection :



8. Draw the following diagram in your answer book and show the formation of image of the object AB with the help of suitable rays :



9. Draw the following diagram in your answer book and show the formation of image with the help of suitable rays :



10. Which type of mirror could be used as a dentist's mirror ?

Short Answer Type Questions

11. Which kind of mirror is used in the headlights of a car ? Why is it used for this purpose ?
12. Explain why, a ray of light passing through the centre of curvature of a concave mirror gets reflected back along the same path.
13. What is the minimum number of rays required for locating the image formed by a concave mirror for an object ? Draw a ray diagram to show the formation of a virtual image by a concave mirror.
14. With the help of a ray diagram, determine the position, nature and size of the image formed of an object placed at the centre of curvature of a concave mirror.
15. Describe with the help of a diagram, the nature, size and position of the image formed when an object is placed beyond the centre of curvature of a concave mirror.
16. If an object is placed at a distance of 8 cm from a concave mirror of focal length 10 cm, discuss the nature of the image formed by drawing the ray diagram.
17. Draw a ray diagram showing how a concave mirror can be used to produce a real, inverted and diminished image of an object.

18. Which mirror is used as a torch reflector ? Draw a labelled diagram to show how a torch reflector can be used to produce a parallel beam of light. Where is the bulb placed in relation to the torch reflector ?

19. State where an object must be placed so that the image formed by a concave mirror is :

(*a*) erect and virtual.

(*b*) at infinity.

(*c*) the same size as the object.

20. With the help of a labelled ray diagram, describe how a converging mirror can be used to give an enlarged upright image of an object.

21. Make labelled ray diagrams to illustrate the formation of :

(*a*) a real image by a converging mirror.

(*b*) a virtual image by a converging mirror.

Mark clearly the pole, focus, centre of curvature and position of object in each case.

22. Briefly describe how you would find the focal length of a concave mirror quickly but approximately.

23. Which type of mirror is used in a solar furnace ? Support your answer with reason.

24. Name the type of mirror used by dentists. How does it help ?

25. Explain why, concave mirrors are used as shaving mirrors.

26. Give two uses of concave mirrors. Explain why you would choose concave mirrors for these uses.

Long Answer Type Questions

27. (*a*) Draw ray-diagrams to show the formation of images when the object is placed in front of a concave mirror (converging mirror) :

(*i*) between its pole and focus

(*ii*) between its centre of curvature and focus

Describe the nature, size and position of the image formed in each case.

(*b*) State one use of concave mirror based on the formation of image as in case (*i*) above.

28. (*a*) Give two circumstances in which a concave mirror can form a magnified image of an object placed in front of it. Illustrate your answer by drawing labelled ray diagrams for both.

(*b*) Which one of these circumstances enables a concave mirror to be used as a shaving mirror ?

Multiple Choice Questions (MCQs)

29. The real image formed by a concave mirror is larger than the object when the object is :

(*a*) at a distance equal to radius of curvature
(*b*) at a distance less than the focal length
(*c*) between focus and centre of curvature
(*d*) at a distance greater than radius of curvature

30. The real image formed by a concave mirror is smaller than the object if the object is :

(*a*) between centre of curvature and focus
(*b*) at a distance greater than radius of curvature
(*c*) at a distance equal to radius of curvature
(*d*) at a distance equal to focal length

31. The image formed by a concave mirror is virtual, erect and magnified. The position of object is :

(*a*) at focus
(*b*) between focus and centre of curvature
(*c*) at pole
(*d*) between pole and focus

32. The image formed by a concave mirror is real, inverted and of the same size as the object. The position of the object must then be :

(*a*) at the focus
(*b*) between the centre of curvature and focus
(*c*) at the centre of curvature
(*d*) beyond the centre of curvature

33. The image formed by a concave mirror is real, inverted and highly diminished (much smaller than the object). The object must be :

(*a*) between pole and focus
(*b*) at focus
(*c*) at the centre of curvature
(*d*) at infinity

34. The angle of incidence for a ray of light passing through the centre of curvature of a concave mirror is :

(*a*) 45° (*b*) 90° (*c*) 0° (*d*) 180°

35. In the concave reflector of a torch, the bulb is placed :
(*a*) between the pole and focus of reflector (*b*) at the focus of reflector
(*c*) between focus and centre of curvature of reflector (*d*) at the centre of curvature of reflector

36. The focal length of a small concave mirror is 2.5 cm. In order to use this concave mirror as a dentist's mirror, the distance of tooth from the mirror should be :
(*a*) 2.5 cm (*b*) 1.5 cm (*c*) 4.5 cm (*d*) 3.5 cm

Questions Based on High Order Thinking Skills (HOTS)

37. An object is 100 mm in front of a concave mirror which produces an upright image (erect image). The radius of curvature of the mirror is :
(*a*) less than 100 mm (*b*) between 100 mm and 200 mm
(*c*) exactly 200 mm (*d*) more than 200 mm

38. A virtual, erect and magnified image of an object is to be produced with a concave mirror of focal length 12 cm. Which of the following object distance should be chosen for this purpose ?
(*i*) 10 cm (*ii*) 15 cm (*iii*) 20 cm
Give reasons for your choice.

39. A concave mirror has a focal length of 25 cm. At which of the following distance should a person hold his face from this concave mirror so that it may act as a shaving mirror ?
(*a*) 45 cm (*b*) 20 cm (*c*) 25 cm (*d*) 30 cm
Give reason for your choice.

40. An object is placed at the following distances from a concave mirror of focal length 15 cm, turn by turn :
(*a*) 35 cm (*b*) 30 cm (*c*) 20 cm (*d*) 10 cm
Which position of the object will produce :
(*i*) a magnified real image ?
(*ii*) a magnified virtual image ?
(*iii*) a diminished real image ?
(*iv*) an image of same size as the object ?

ANSWERS

1. At the centre of curvature **2.** Between pole and focus **3.** Between focus and centre of curvature **4.** At infinity **5.** At focus **6.** Beyond centre of curvature **12.** It falls normally (perpendicularly) on the mirror surface; The angle of incidence is 0° and the angle of reflection is also 0° **13.** Two rays **16.** Virtual, erect and magnified **29.** (*c*) **30.** (*b*) **31.** (*d*) **32.** (*c*) **33.** (*d*) **34.** (*c*) **35.** (*b*) **36.** (*b*) **37.** (*d*) **38.** 10 cm ; Because it is less than focal length **39.** 20 cm **40.** (*i*) 20 cm (*ii*) 10 cm (*iii*) 35 cm (*iv*) 30 cm.

SIGN CONVENTION FOR SPHERICAL MIRRORS

These days New Cartesian Sign Convention is used for measuring the various distances in the ray-diagrams of spherical mirrors (concave mirrors and convex mirrors). According to the New Cartesian Sign Convention :

(*i*) All the distances are measured from *pole* of the mirror as origin.
(*ii*) Distances measured in the *same* direction as that of incident light are taken as *positive*.
(*iii*) Distances measured *against* the direction of incident light are taken as *negative.*
(*iv*) Distances measured *upward* and perpendicular to the principal axis are taken as *positive*.
(*v*) Distances measured *downward* and perpendicular to the principal axis are taken as *negative.*

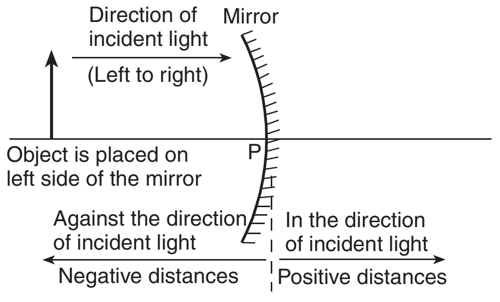


Figure 44. Sign convention for mirrors.

The New Cartesian Sign Convention for mirrors is shown in Figure 44. **The object is always placed on the left side of the mirror** (as shown in Figure 44) so that the direction of incident light is from *left* to *right*. Since the incident light always goes from left to right, **all the distances measured from the pole (*P*) of mirror to the right side will be considered positive** (because they will be in the same direction as the incident light). On the other hand, **all the distances measured from pole (*P*) of mirror to the left side will be negative** (because they are measured against the direction of incident light).

Some Important Conclusions

According to the sign convention, the distances towards the left of the mirror are negative. Since an object is always placed to the left side of a mirror, therefore, **the object distance *(u)* is always negative.**

The images formed by a concave mirror can be either behind the mirror (virtual) or in front of the mirror (real). So, the image distance (*v*) for a concave mirror can be either positive or negative depending on the position of the image. **If an image is formed behind a concave mirror (to the right side), the image distance *(v)* is positive** but **if the image is formed in front of the mirror (on the left side), then the image distance will be negative.**

In a convex mirror, the image is always formed on the right hand side (behind the mirror), so **the image distance *(v)* for a convex mirror will be always positive.**

The focus of concave mirror is in front of the mirror on the left side, so **the focal length of a concave mirror is considered negative** (and written with a minus sign, say, –10 cm). On the other hand, the focus of a convex mirror is behind the mirror on the right side, so **the focal length of a convex mirror is positive** (and written with a plus sign, say +20 cm or just 20 cm).

We will now discuss the signs for the heights of objects and images. An object is always placed above the principal axis in the upward direction, so **the height of an object is always considered positive.** On the other hand, an image can be formed above the principal axis or below the principal axis. **If an image is formed above the principal axis, its height is taken as positive** and **if an image is formed below the principal axis, then its height is taken as negative.** Now, we know that all the virtual images are erect and are formed above the principal axis, so **the height of all the virtual and erect images is considered positive.** On the other hand, all the real images are inverted and they are formed below the principal axis, so **the height of all the real and inverted images is taken as negative.** We are now in a position to **answer the following questions :**

Very Short Answer Type Questions

1. According to the "New Cartesian Sign Convention" for mirrors, what sign has been given to the focal length of :
(*i*) a concave mirror ?
(*ii*) a convex mirror ?

2. Which type of mirror has :
(*a*) positive focal length ?
(*b*) negative focal length ?

3. What is the nature of a mirror having a focal length of, +10 cm ?

4. What kind of mirror can have a focal length of, – 20 cm ?

5. Complete the following sentence :
All the distances are measured from the .... of a spherical mirror.

6. What sign (+ve or –ve) has been given to the following on the basis of Cartesian Sign Convention ?
(*a*) Height of a real image.
(*b*) Height of a virtual image.

Short Answer Type Questions

7. Describe the New Cartesian Sign Convention used in optics. Draw a labelled diagram to illustrate this sign convention.

8. Giving reasons, state the 'signs' (positive or negative) which can be given to the following :
   (*a*) object distance (u) for a concave mirror or convex mirror
   (*b*) image distances (v) for a concave mirror
   (*c*) image distances (v) for a convex mirror

Multiple Choice Questions (MCQs)

9. According to New Cartesian Sign Convention :
   (*a*) focal length of concave mirror is positive and that of convex mirror is negative
   (*b*) focal length of both concave and convex mirrors is positive
   (*c*) focal length of both concave and convex mirrors is negative
   (*d*) focal length of concave mirror is negative and that of convex mirror is positive
10. One of the following does not apply to a concave mirror. This is :
   (*a*) focal length is negative
   (*b*) image distance can be positive or negative
   (*c*) image distance is always positive
   (*d*) height of image can be positive or negative

ANSWERS

3. Convex mirror **4.** Concave mirror **5.** pole **9.** (*d*) **10.** (*c*)

MIRROR FORMULA

The distance of an object from the pole of a mirror is known as object distance. Object distance is denoted by the letter u. The distance of image from the pole of a mirror is known as image distance. Image distance is denoted by the letter v. The distance of focus from the pole of a mirror is known as focal length. Focal length is denoted by the letter f. There is a relationship between the object distance, image distance and focal length of a spherical mirror (concave mirror or convex mirror). This relationship is given by the mirror formula.

A formula which gives the relationship between image distance (v), object distance (u) and focal length (f) of a spherical mirror is known as the mirror formula. The mirror formula can be written as :

$$\frac{1}{Image\ distance} + \frac{1}{Object\ distance} = \frac{1}{Focal\ length}$$

or

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

where v = distance of image from mirror
u = distance of object from mirror
and f = focal length of the mirror

The mirror formula has three values in it. If any two values are known, the third value can be calculated. The known values should be put in this formula with their proper signs but no sign should be given to the unknown value to be calculated. Its proper sign will come by itself by calculations. The proper signs of the known values of u, v or f can be found by using New Cartesian Sign Convention for spherical mirrors. Another point to be noted is that the mirror formula can be applied to both type of spherical mirrors : concave mirrors as well as convex mirrors. By using this mirror formula, we can find out the position and nature of the images formed by concave mirrors and convex mirrors. Before we do that, we will discuss the 'magnification' produced by spherical mirrors.

Linear Magnification Produced by Mirrors

The size of image formed by a spherical mirror depends on the position of the object from the mirror. The image formed by a spherical mirror can be bigger than the object, equal to the object or smaller than the object. The size of the image relative to the object is given by the linear magnification. This is discussed on the next page.

The ratio of the height of image to the height of object is known as linear magnification. That is,

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

or $\boldsymbol{m = \frac{h_2}{h_1}}$

where m = magnification

h_2 = height of image

and h_1 = height of object

In our ray-diagrams, the object is always placed above the principal axis, so **the height (h_1) of the object will always be positive**. We also know that a virtual image is always formed above the principal axis, therefore, **the height (h_2) of a virtual image will be positive**. But a real image is formed below the principal axis, so **the height (h_2) of a real image will be negative** because it is measured in the downward direction. From this discussion we conclude that though the height of object h_1 is always positive, the height h_2 of the image can be either positive or negative.

Now, for a virtual image h_2 is positive and h_1 is also positive, so the magnification $\left(\frac{h_2}{h_1}\right)$ of a virtual (and erect) image is always positive. In other words, **if the magnification has a plus sign, then the image is virtual and erect.** For a real image, h_2 is negative and h_1 is positive, so the magnification $\left(\frac{h_2}{h_1}\right)$ for a real (and inverted) image is always negative. In other words, **if the magnification has a minus sign, then the image is real and inverted.**

Since a concave mirror can produce virtual images as well as real images, the magnification produced by a concave mirror can be either positive or negative. A convex mirror, however, forms only virtual images, so the magnification produced by a convex mirror is always positive. Another point to be noted is that if the magnification m has a value greater than 1 then the image is bigger than the object, that is, the image is magnified or enlarged. And if the magnification m is exactly 1, then the image is of the same size as the object. But if the magnification is less than 1 then the image is smaller than the object (or diminished).

A concave mirror can form images which are smaller than the object, equal to the object or bigger than the object, therefore, the linear magnification (or just magnification) (m) produced by a concave mirror can be less than 1, equal to 1 or more than 1. On the other hand, a convex mirror forms images which are always smaller than the object, so the linear magnification (m) produced by a convex mirror is always less than 1. A plane mirror forms images which are always of the same size as the object, therefore, the magnification (m) produced by a plane mirror is always 1.

If we know the height (or size) of the object and that of the image, then we can calculate the magnification by using the formula given above. Many times, however, we do not know their heights, so we will now write another formula for calculating the magnification produced by a spherical mirror in terms of "object distance" and "image distance".

The linear magnification produced by a mirror is equal to the ratio of the image distance to the object distance, with a minus sign. That is,

$$\text{Magnification} = -\frac{\text{Image distance}}{\text{Object distance}}$$

or $\boldsymbol{m = -\frac{v}{u}}$

where m = magnification

v = image distance

and u = object distance

Thus, if we know the image distance v and the object distance u, then the magnification m can be calculated.

So, now we have two formulae for calculating the magnification :

$$m = \frac{h_2}{h_1} \qquad \text{and} \qquad m = -\frac{v}{u}$$

We will use these two formulae to solve numerical problems. We can also combine these two formulae to get another formula :

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

This will also be used in solving problems.

Numerical Problems Based on Concave Mirrors

We will now solve some numerical problems based on concave mirrors by using the mirror formula and the magnification formulae. Here are some examples.

Sample Problem 1. Find the size, nature and position of image formed when an object of size 1 cm is placed at a distance of 15 cm from a concave mirror of focal length 10 cm.

Solution. Here we have been given the object distance and focal length, so first of all we will find out the image distance which will give us the position of image.

(*i*) Position of image

Here, Object distance, u = – 15 cm (To the left of mirror)

Image distance, v = ? (To be calculated)

And, Focal length, f = – 10 cm (It is concave mirror)

Now, putting these values in the mirror formula :

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

we get :

$$\frac{1}{v} + \frac{1}{-15} = \frac{1}{-10}$$

or

$$\frac{1}{v} - \frac{1}{15} = -\frac{1}{10}$$

or

$$\frac{1}{v} = -\frac{1}{10} + \frac{1}{15}$$

$$\frac{1}{v} = \frac{-3+2}{30}$$

$$\frac{1}{v} = -\frac{1}{30}$$

So, Image distance, v = – 30 cm

Thus, the position of image is 30 cm to the left side of mirror or 30 cm in front of mirror (Minus sign shows the left side of mirror).

(*ii*) Nature of image. Since the image is formed in front of the concave mirror, its nature will be "Real and Inverted".

(*iii*) Size of image. To find the size of image, we will have to calculate the magnification first. The magnification produced by a mirror is given by :

$$m = -\frac{v}{u}$$

Here, Image distance, v = – 30 cm

Object distance, u = – 15 cm

So, $m = -\frac{(-30)}{(-15)}$

$m = -\frac{30}{15}$

Magnification, $m = -2$

We also have another formula for magnification, which is :

$$m = \frac{h_2}{h_1}$$

Here, Magnification, $m = -2$ (Found above)

Height of image, $h_2 = ?$ (To be calculated)

Height of object, $h_1 = 1$ cm (Given)

Now, putting these values in the above magnification formula, we get :

$$-2 = \frac{h_2}{1}$$

So, Height of image, $h_2 = -2 \times 1$

$= -2$ cm

Thus, the size of image is 2 cm long. The minus sign here shows that the image is formed below the principal axis. That is, it is a real and inverted image.

Sample Problem 2. An object 2 cm high is placed at a distance of 16 cm from a concave mirror which produces a real image 3 cm high.

(*i*) What is the focal length of the mirror ?

(*ii*) Find the position of the image.

Solution. (*i*) **Calculation of position of image**

The height of object is 2 cm and that of real image is 3 cm. So, we will first calculate the magnification by using the formula :

$$m = \frac{h_2}{h_1}$$

Please note that an object is always placed above the axis, so the height of object is always taken as positive and written with a plus sign. A real image is formed below the axis. So, the height of a real image is taken as negative and written with a minus sign.

Here, Height of real image, $h_2 = -3$ cm

Height of object, $h_1 = +2$ cm

So, putting these values in the above magnification formula, we get :

Magnification, $m = \frac{-3}{+2}$

or $m = -1.5$

Now, we have another magnification formula for mirrors, which is :

$$m = -\frac{v}{u}$$

Here, Magnification, $m = -1.5$ (Found above)

Image distance, $v = ?$ (To be calculated)

and Object distance, $u = -16$ cm (To the left of mirror)

So, putting these values in the above formula, we get :

$$-1.5 = -\frac{v}{(-16)}$$

or $-1.5 = \frac{v}{16}$

So, $v = -1.5 \times 16$

or $v = -24$ cm

Thus, the position of image is 24 cm in front of the mirror, to the left side of mirror (The minus sign shows that the image is on the left side of the mirror).

(*ii*) Calculation of focal length

Here, Object distance, $u = -16$ cm

Image distance, $v = -24$ cm

Focal length, $f = ?$ (To be calculated)

Now, putting these values in the mirror formula :

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

we get :

$$\frac{1}{-24} + \frac{1}{-16} = \frac{1}{f}$$

or

$$-\frac{1}{24} - \frac{1}{16} = \frac{1}{f}$$

$$\frac{-2-3}{48} = \frac{1}{f}$$

$$-\frac{5}{48} = \frac{1}{f}$$

$$f = -\frac{48}{5}$$

So, Focal length, $f = -9.6$ cm

Sample Problem 3. A concave mirror produces three times magnified (enlarged) real image of an object placed at 10 cm in front of it. Where is the image located ? **(NCERT Book Question)**

Solution. In this problem we have been given magnification (m) and object distance (u). We are to find out the image distance (v). Now,

Magnification, $m = -3$ (Image is real)

Object distance, $u = -10$ cm (To the left of mirror)

And, Image distance, $v = ?$ (To be calculated)

Putting these values in the magnification formula for a mirror :

$$m = -\frac{v}{u}$$

we get :

$$-3 = -\frac{v}{-10}$$

$$-3 \times -10 = -v$$

$$v = -30 \text{ cm}$$

Thus, the image is located at a distance of 30 cm in front of the mirror (on its left side).

Sample Problem 4. The magnification produced by a plane mirror is +1. What does this mean ? **(NCERT Book Question)**

Answer. The plus sign (+) of the magnification shows that the image is virtual and erect. And the value 1 for magnification shows that the image is exactly of the same size as the object. So, the magnification of +1 produced by a plane mirror means that the image formed in a plane mirror is virtual and erect, and of the same size as the object.

Sample Problem 5. What is the nature of the image formed by a concave mirror if the magnification produced by the mirror is +3 ?

Answer. If the magnification has a plus sign (+), then the image is virtual and erect. In this case, the magnification has a plus sign (it is +3), therefore, the nature of this image is virtual and erect.

Sample Problem 6. What is the nature of the image formed by a concave mirror if the magnification produced by the mirror is, – 0.75 ?

Answer. If the magnification has a minus sign (–), then the image is real and inverted. In this case, the magnification has a minus sign (it is, – 0.75), so the nature of image is real and inverted.

Before we go further and discuss the images formed by convex mirrors, **please answer the following questions and problems yourself :**

Very Short Answer Type Questions

1. If the magnification of a body of size 1 m is 2, what is the size of the image ?

2. What is the position of the image when an object is placed at a distance of 20 cm from a concave mirror of focal length 20 cm ?

3. What is the nature of image formed by a concave mirror if the magnification produced by the mirror is (*a*) + 4, and (*b*) – 2 ?

4. State the relation between object distance, image distance and focal length of a spherical mirror (concave mirror or convex mirror).

5. Write the mirror formula. Give the meaning of each symbol which occurs in it.

6. What is the ratio of the height of an image to the height of an object known as ?

7. Define linear magnification produced by a mirror.

8. Write down a formula for the magnification produced by a concave mirror.

(*a*) in terms of height of object and height of image

(*b*) in terms of object distance and image distance

9. Describe the nature of image formed when the object is placed at a distance of 20 cm from a concave mirror of focal length 10 cm.

10. Fill in the following blanks with suitable words :

(*a*) If the magnification has a plus sign, then image is..............and............

(*b*) If the magnification has a minus sign, then the image is...........and............

Short Answer Type Questions

11. An object is placed at a distance of 10 cm from a concave mirror of focal length 20 cm.

(*a*) Draw a ray diagram for the formation of image.

(*b*) Calculate the image distance.

(*c*) State two characteristics of the image formed.

12. If an object of 10 cm height is placed at a distance of 36 cm from a concave mirror of focal length 12 cm, find the position, nature and height of the image.

13. At what distance from a concave mirror of focal length 10 cm should an object 2 cm long be placed in order to get an erect image 6 cm tall ?

14. When an object is placed at a distance of 15 cm from a concave mirror, its image is formed at 10 cm in front of the mirror. Calculate the focal length of the mirror.

15. An object 3 cm high is placed at a distance of 8 cm from a concave mirror which produces a virtual image 4.5 cm high :

(*i*) What is the focal length of the mirror ?

(*ii*) What is the position of image ?

(*iii*) Draw a ray-diagram to show the formation of image.

16. A converging mirror forms a real image of height 4 cm of an object of height 1 cm placed 20 cm away from the mirror :

(*i*) Calculate the image distance.

(*ii*) What is the focal length of the mirror ?

17. An object of size 7.0 cm is placed at 27 cm in front of a concave mirror of focal length 18 cm. At what distance from the mirror should a screen be placed so that a sharp focussed image can be obtained ? Find the size and nature of image.

[**Hint.** Find the value of image distance (v) first. The screen should be placed from the mirror at a distance equal to image distance].

18. An object 3 cm high is placed at a distance of 10 cm in front of a converging mirror of focal length 20 cm. Find the position, nature and size of the image formed.

19. A concave mirror has a focal length of 4 cm and an object 2 cm tall is placed 9 cm away from it. Find the nature, position and size of the image formed.

20. When an object is placed 20 cm from a concave mirror, a real image magnified three times is formed. Find :

(*a*) the focal length of the mirror.

(*b*) Where must the object be placed to give a virtual image three times the height of the object ?

21. A dentist's mirror has a radius of curvature of 3 cm. How far must it be placed from a small dental cavity to give a virtual image of the cavity that is magnified five times ?

22. A large concave mirror has a radius of curvature of 1.5 m. A person stands 10 m in front of the mirror. Where is the person's image ?

23. An object of 5.0 cm size is placed at a distance of 20.0 cm from a converging mirror of focal length 15.0 cm. At what distance from the mirror should a screen be placed to get the sharp image ? Also calculate the size of the image.

24. A concave mirror produces three times enlarged virtual image of an object placed at 10 cm in front of it. Calculate the radius of curvature of the mirror.

25. A bright object 50 mm high stands on the axis of a concave mirror of focal length 100 mm and at a distance of 300 mm from the concave mirror. How big will the image be ?

26. How far should an object be placed from the pole of a converging mirror of focal length 20 cm to form a real image of the size exactly $\frac{1}{4}$ th the size of the object ?

27. When an object is placed at a distance of 50 cm from a concave spherical mirror, the magnification produced is, $-\frac{1}{2}$. Where should the object be placed to get a magnification of, $-\frac{1}{5}$?

28. An object is placed (*a*) 20 cm, (*b*) 4 cm, in front of a concave mirror of focal length 12 cm. Find the nature and position of the image formed in each case.

29. A concave mirror produces a real image 1 cm tall of an object 2.5 mm tall placed 5 cm from the mirror. Find the position of the image and the focal length of the mirror.

30. A man holds a spherical shaving mirror of radius of curvature 60 cm, and focal length 30 cm, at a distance of 15 cm, from his nose. Find the position of image, and calculate the magnification.

Long Answer Type Question

31. (*a*) An object is placed just outside the principal focus of concave mirror. Draw a ray diagram to show how the image is formed, and describe its size, position and nature.

(*b*) If the object is moved further away from the mirror, what changes are there in the position and size of the image ?

(*c*) An object is 24 cm away from a concave mirror and its image is 16 cm from the mirror. Find the focal length and radius of curvature of the mirror, and the magnification of the image.

Multiple Choice Questions (MCQs)

32. Linear magnification produced by a concave mirror may be :

(*a*) less than 1 or equal to 1 (*b*) more than 1 or equal to 1
(*c*) less than 1, more than 1 or equal to 1 (*d*) less than 1 or more than 1

33. Magnification produced by a convex mirror is always :

(*a*) more than 1 (*b*) less than 1 (*c*) equal to 1 (*d*) more or less than 1

34. Magnification produced by a plane mirror is :

(*a*) less than one (*b*) greater than one (*c*) zero (*d*) equal to one

35. In order to obtain a magnification of, –2 (minus 2) with a concave mirror, the object should be placed :

(*a*) between pole and focus (*b*) between focus and centre of curvature
(*c*) at the centre of curvature (*d*) beyond the centre of curvature

36. A concave mirror produces a magnification of + 4. The object is placed :

(*a*) at the focus (*b*) between focus and centre of curvature
(*c*) between focus and pole (*d*) beyond the centre of curvature

37. If a magnification of, –1 (minus one) is to be obtained by using a converging mirror, then the object has to be placed :

(*a*) between pole and focus (*b*) at the centre of curvature

(*c*) beyond the centre of curvature (*d*) at infinity

38. In order to obtain a magnification of, – 0.6 (minus 0.6) with a concave mirror, the object must be placed :

(*a*) at the focus (*b*) between pole and focus

(*c*) between focus and centre of curvature (*d*) beyond the centre of curvature

39. An object is placed at a large distance in front of a concave mirror of radius of curvature 40 cm. The image will be formed in front of the mirror at a distance of :

(*a*) 20 cm (*b*) 30 cm (*c*) 40 cm (*d*) 50 cm

40. In order to obtain a magnification of, –1.5 with a concave mirror of focal length 16 cm, the object will have to be placed at a distance :

(*a*) between 6 cm and 16 cm (*b*) between 32 cm and 16 cm

(*c*) between 48 cm and 32 cm (*d*) beyond 64 cm

41. Linear magnification (*m*) produced by a rear view mirror fitted in vehicles :

(*a*) is equal to one (*b*) is less than one

(*c*) is more than one (*d*) can be more or less than one depending on the position of object

Questions Based on High Order Thinking Skills (HOTS)

42. Between which two points of concave mirror should an object be placed to obtain a magnification of :

(*a*) – 3 (*b*) + 2.5 (*c*) – 0.4

43. At what distance from a concave mirror of focal length 10 cm should an object be placed so that :

(*a*) its real image is formed 20 cm from the mirror ?

(*b*) its virtual image is formed 20 cm from the mirror ?

44. If a concave mirror has a focal length of 10 cm, find the two positions where an object can be placed to give, in each case, an image twice the height of the object.

45. A mirror forms an image which is 30 cm from an object and twice its height.

(*a*) Where must the mirror be situated ?

(*b*) What is the radius of curvature ?

(*c*) Is the mirror convex or concave ?

ANSWERS

1. 2 m **2.** At infinity **3.** (*a*) Virtual and erect (*b*) Real and inverted **6.** Magnification **9.** Real and inverted **10.** (*a*) virtual ; erect (*b*) real ; inverted **11.** (*b*) 20 cm (*c*) Virtual and erect ; Magnified **12.** $v = -18$ cm ; The position of image is 18 cm in front of concave mirror (to its left side); Real and inverted ; 5 cm **13.** $u = -6.66$ cm ; The object should be placed at a distance of 6.66 cm on the left side of concave mirror **14.** 6 cm **15.** (*i*) 24 cm (*ii*) 12 cm behind the concave mirror (on its right side) **16.** (*i*) 80 cm in front of the mirror (*ii*) 16 cm **17.** $v = -54$ cm ; The screen should be placed at a distance of 54 cm in front of the concave mirror ; 14.0 cm; Real and inverted **18.** $v = +20$ cm ; The image is formed at a distance of 20 cm behind the converging mirror; Virtual and erect ; 6 cm **19.** Real and inverted ; $v = -7.2$ cm : The image is formed at a distance of 7.2 cm in front of concave mirror ; 1.6 cm **20.** (*a*) 15 cm (*b*) 10 cm from the concave mirror ; **21.** 1.2 cm **22.** 0.81 m in front of the concave mirror **23.** 60 cm in front of the converging mirror ; 15.0 cm **24.** 30 cm **25.** 25 mm **26.** 100 cm **27.** 100 cm **28.** (*a*) $v = -30$ cm ; The image is formed at a distance of 30 cm in front of mirror (on its left side); Real and inverted (*b*) $v = +6$ cm ; The image is formed at a distance of 6 cm behind the mirror (on its right side); Virtual and erect **29.** $v = -20$ cm ; The image is formed 20 cm in front of the mirror ; 4 cm **30.** $v = +30$ cm ; The image is formed at a distance of 30 cm behind the mirror ; $m = +2$ **31.** (*c*) 9.6 cm ; 19.2 cm ; 0.66 **32.** (*c*) **33.** (*b*) **34.** (*d*) **35.** (*b*) **36.** (*c*) **37.** (*b*) **38.** (*d*) **39.** (*a*) **40.** (*b*) **41.** (*b*) **42.** (*a*) Between focus and centre of curvature (*b*) Between pole and focus (*c*) Beyond the centre of curvature **43.** (*a*) 20 cm (*b*) $\frac{20}{3}$ cm **44.** 15 cm ; 5 cm **45.** (*a*) 10 cm from the object (*b*) 40 cm (*c*) Concave mirror

RULES FOR OBTAINING IMAGES FORMED BY CONVEX MIRRORS

In order to construct ray-diagrams to find out the position, nature and size of the images formed by a convex mirror, we should remember the paths of the following rays of light. We can call them the rules for obtaining images in convex mirrors.

Rule 1. **A ray of light which is parallel to the principal axis of a convex mirror, appears to be coming from its focus after reflection from the mirror.** This is shown in Figure 45. In Figure 45, the ray of light *AB* is parallel to the principal axis *XP* of a convex mirror. The ray of light *AB* gets reflected at point *B* on the mirror and goes in the direction *BD*. To a person on the left side, the reflected ray *BD* appears to be coming from the focus *F* of the convex mirror situated behind the mirror (as shown by dotted line).

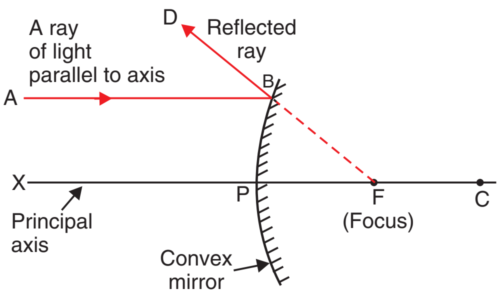


Figure 45.

Rule 2. **A ray of light going towards the centre of curvature of a convex mirror is reflected back along the same path.** This is shown in Figure 46. In Figure 46, the ray of light *AD* is going towards the centre of curvature *C* of a convex mirror. It strikes the mirror surface at point *D* and gets reflected back along the same path *DA*. To a person on the left side, the reflected ray *DA* appears to be coming from the centre of curvature *C* (as shown by dotted line behind the mirror). Please note that the ray *AD* gets reflected back along the same path because it falls normally (or perpendicularly) on the mirror surface at point *D*.

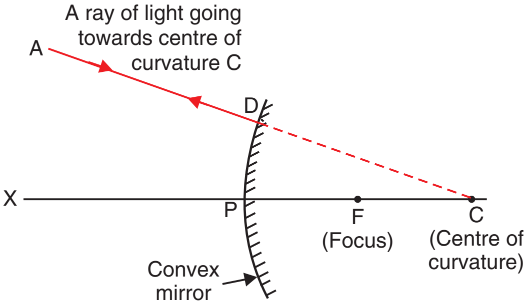


Figure 46.

Please note that if a ray of light is incident on a convex mirror along its principal axis, then it is reflected back along the same path (because it will be normal or perpendicular to the mirror surface). The angle of incidence as well as the angle of reflection for such a ray of light will be zero.

Rule 3. **A ray of light going towards the focus of a convex mirror becomes parallel to the principal axis after reflection.** This is just the reverse case of the first rule and it is shown in Figure 47. Here the incident ray of light *AE* is going towards the focus *F* of the convex mirror. It strikes the mirror surface at point *E* and gets reflected. After reflection, it becomes parallel to the principal axis and goes in the direction *EG* (see Figure 47).

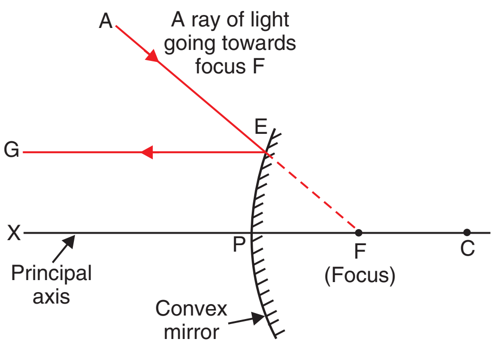


Figure 47.

Rule 4. **A ray of light which is incident at the pole of a convex mirror is reflected back making the same angle with the principal axis.** This is shown in Figure 48. Here a ray of light *AP* is incident on the pole *P* of the convex mirror making an angle of incidence *i* with the principal axis *XP*. It gets reflected along the direction *PH* making an equal angle of reflection *r* with the principal axis (see Figure 48).

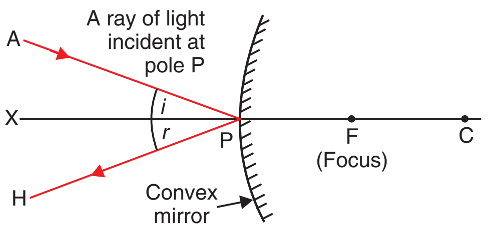


Figure 48.

It should be noted that a convex mirror has its focus and centre of curvature behind it. Since no real rays of light can go behind the convex mirror, all the rays shown behind the convex mirror are virtual (or unreal) and hence they have been represented by dotted lines. In fact, no actual rays can pass through the focus and centre of curvature of a convex mirror.

Please note that **whatever be the position of object in front of a convex mirror, the image formed by a convex mirror is always behind the mirror, it is virtual, erect and smaller than the object (or diminished).** When the distance of the object is changed from convex mirror, then only the position and size of the image changes. There are two main positions of an object in the case of a convex mirror from the point of view of position and size of image. The object can be :

(*i*) anywhere between pole (*P*) and infinity, and

(*ii*) at infinity.

We will discuss both these cases one by one. Let us first describe the formation of image by a convex mirror when the object is placed between pole (*P*) of the mirror and infinity.

FORMATION OF IMAGE BY A CONVEX MIRROR

In Figure 49, we have an object *AB* placed in front of a convex mirror *M* anywhere between pole *P* and infinity. A ray of light *AD*, parallel to the principal axis of the convex mirror, strikes the mirror at point *D*. Now, according to the first rule of image formation, this parallel ray of light should appear to be coming from focus *F* after reflection. So, we join the points *D* and *F* by a dotted line and produce the line *FD* towards the left in the direction *DX*. Now, *DX* gives us the reflected ray which appears to be coming from focus *F* of the convex mirror.

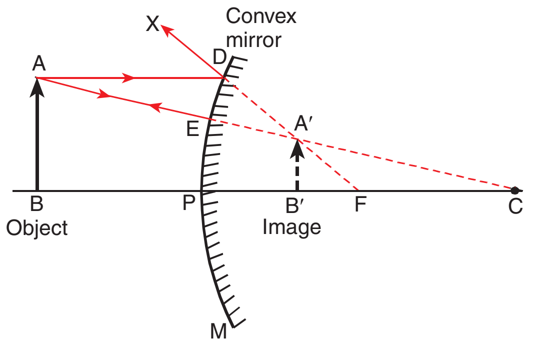


Figure 49. Formation of image by a convex mirror when the object is placed anywhere between the pole of mirror and infinity.

We have now to draw a second ray of light from the point *A* going towards the centre of curvature *C* of the convex mirror. For this we join the point *A* with point *C* by a line which cuts the mirror at point *E*. The line from *A* to *E* is a solid line and it represents a real ray of light but the line from *E* to *C* is a dotted line which represents a virtual ray of light. Now, *AE* represents a ray of light going towards the centre of curvature *C* of the convex mirror. According to the second rule of image formation, this ray is reflected along the same path *EA* but it appears to be coming from the centre of curvature *C.*

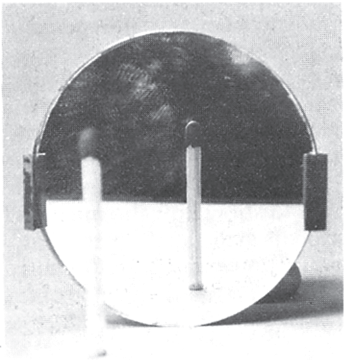
The two reflected rays *DX* and *EA* are diverging rays but they appear to intersect at point *A′* when produced backwards. Thus *A′* is the virtual image of point *A* of the object. To get the full image of the object, we draw the perpendicular *A′B′* to the axis from point *A′*. Thus *A′B′* is the virtual image of the object *AB*. It is clear from Figure 49 that the image is formed behind the convex mirror between the pole and the focus. It is virtual, erect and smaller than the object (or diminished). From the above discussion we conclude that : **When an object is placed anywhere between pole (*P*) and infinity in front of a convex mirror, the image formed is :**

(*i*) behind the mirror between pole (*P*) and focus (*F*),

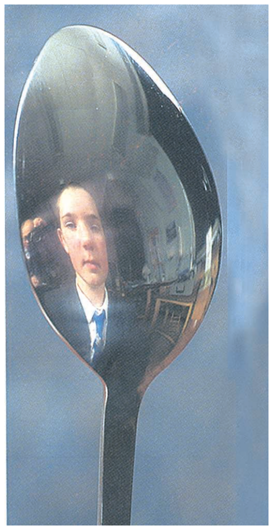
(*ii*) virtual and erect, and

(*iii*) diminished (smaller than the object).

If we hold a matchstick (as object) in front of a convex mirror, a virtual, erect and diminished (smaller) image of the matchstick is seen on looking into the convex mirror [see Figure 50(*a*)]. We know that the back side of a shining steel spoon (which is bulging outwards) is a kind of convex mirror. So, if we keep our face in front of the back side of a shining steel spoon we will see a virtual and erect image of the face which is smaller in size as compared to the face [see Figure 50 (*b*)].



(*a*) The image of matchstick in the convex mirror is virtual, erect and diminished (smaller in size).



(*b*) The image of face in the backside (convex surface) of a shining steel spoon is virtual, erect and diminished.

Figure 50.

If we move the object more and more away from the pole of the convex mirror, the image becomes smaller and smaller in size and moves away from the mirror towards its focus but it remains virtual and erect for all the positions of the object. And *when the object is at infinity, the image is formed at the focus*. This is discussed below.

When the Object is at Infinity

When the object is at a far-off distance, we say that the object is at infinity. In Figure 51, we have a convex mirror *M*. Suppose an object (an arrow pointing upwards) has been placed at infinity in front of the convex mirror (Since the object is very far-off, it cannot be shown in the diagram). Because the object *AB* is very far-off, the two rays *AD* and *AP* coming from its top point *A* are parallel to one another but at an angle to the principal axis as shown in Figure 51. The ray *AD* gets reflected in the direction *DX* and the ray *AP* gets reflected in the direction *PY*. When the diverging reflected rays *DX* and *PY* are produced backwards (as shown by dotted lines in Figure 51), they intersect at point *A′* in the focal plane of the convex mirror. Thus, *A′* is the virtual image of the top point *A* of the object. To get the full image of the object, we draw *A′B′* perpendicular to the axis. So, *A′B′* is the image of the object *AB* placed at infinity. We find that the image is formed at the focus (*F*) of the convex mirror behind the mirror. It is virtual, erect and highly diminished (much smaller than the object). From the above discussion we conclude that : **When an object is at infinity from a convex mirror, the image formed is :**

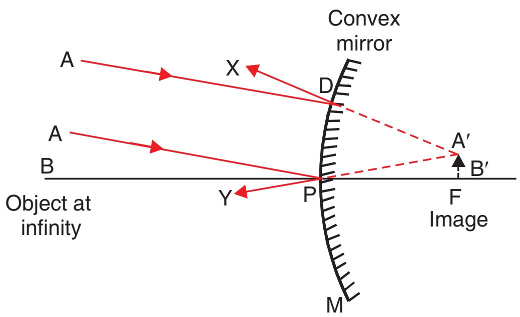


Figure 51. Formation of image by a convex mirror when the object is at infinity (large distance).

(*i*) behind the mirror at focus (*F*),
(*ii*) virtual and erect, and
(*iii*) highly diminished (much smaller than the object).

Since the image of a distant object formed by a convex mirror is highly diminished, we can see the full image of a tall building or tree even in a small convex mirror. Please note that when the object kept at infinity in front of a convex mirror is assumed to be a big arrow pointing upwards, then its image is formed at focus according to the ray-diagram shown in Figure 51. If, however, the object kept at infinity in front of a convex mirror is round in shape, then its image is formed at the focus according to the ray diagram shown in Figure 27 on page 178. And before we conclude this discussion, here is a summary of the images formed by a convex mirror.

Summary of the Images Formed by a Convex Mirror

Position of object	*Position of image*	*Size of image*	*Nature of image*
1. Anywhere between pole *P* and infinity	Behind the mirror between *P* and *F*	Diminished	Virtual and erect
2. At infinity	Behind the mirror at focus (*F*)	Highly diminished	Virtual and erect

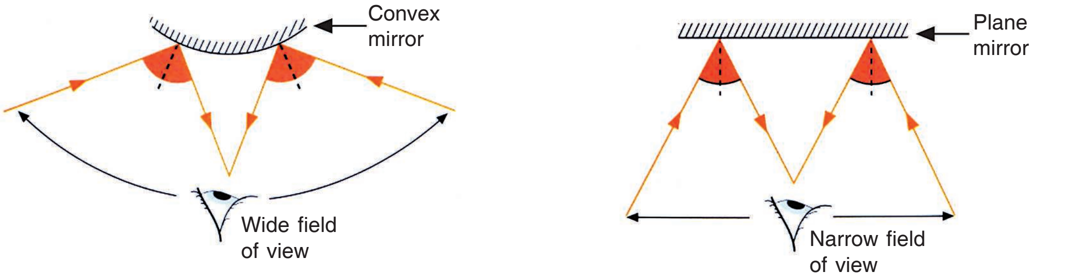
Uses of Convex Mirrors

(*i*) Convex mirrors are used as rear-view mirrors in vehicles (like cars, trucks and buses) to see the traffic at the rear side (or back side) (see Figure 52). A driver prefers to use a convex mirror as rear-view mirror because of two reasons :

(*a*) A convex mirror always produces an erect (right side up) image of the objects.

(*b*) The image formed in a convex mirror is highly diminished or much smaller than the object, due to which a convex mirror gives a wide field of view (of the traffic behind) [see Figure 53(*a*)]. A convex mirror enables a driver to view much larger area of the traffic behind him than would be possible with a plane mirror. A plane mirror gives a narrow field of view [see Figure 53(*b*)]. Due to this if a plane mirror is used as a rear-view mirror in vehicles, it will give the driver a much smaller view of the road and traffic behind. Rear-view mirrors are also known as driving mirrors or side-view mirrors or wing mirrors.

Figure 52. Convex mirror is used as a rear view mirror (or side view mirror) in vehicles.



(*a*) A convex mirror gives a wide field of view (or large field of view).

(*b*) A plane mirror gives a narrow field of view (or small field of view).

Figure 53.

Please note that **we cannot use a concave mirror as a rear-view mirror in motor vehicles.** This is because a concave mirror produces inverted images (upside down images) of distant objects. So, if we use a concave mirror as a rear view mirror in a car (bus or truck, etc.) we will see in the mirror that all the vehicles on the road (at the back side) are running upside down with their wheels up in the air. This will be really a very funny situation to watch.

(*ii*) Big convex mirrors are used as 'shop security mirrors' (see Figure 54). By installing a big convex mirror at a strategic point in the shop, the shop owner can keep an eye on the customers to look for thieves and shoplifters among them.

Figure 54. This picture shows a big convex mirror installed as a security mirror in a shop. A large number of goods displayed in the shop can be seen in this convex mirror.

How to Distinguish Between a Plane Mirror, a Concave Mirror and a Convex Mirror Without Touching Them

We can distinguish between these mirrors just by looking into them, that is, by bringing our face close to each mirror, turn by turn. All of them will produce an image of our face but of different types. **A plane mirror will produce an image of the same size** as our face and we will look our normal self. **A concave mirror will produce a magnified image** and our face will look much bigger (like that of a giant !). **A convex mirror will produce a diminished image** and our face will look much smaller (like that of a small child !). Let us answer one question now.

Sample Problem. No matter how far you stand from a mirror, your image appears erect. The mirror may be :

(*i*) plane (*ii*) concave (*iii*) convex (*iv*) either plane or convex

Choose the correct alternative. **(NCERT Book Question)**

Answer. The correct alternative is : (*iv*) either plane or convex.

We are now in a position to **answer the following questions :**

Very Short Answer Type Questions

1. What type of image/images are formed by :
   (*a*) a convex mirror ?
   (*b*) a concave mirror ?
2. Which mirror has a wider field of view ?
3. If you want to see an enlarged image of your face, state whether you will use a concave mirror or a convex mirror ?
4. Which mirror always produces a virtual, erect and diminished image of an object ?
5. An object is placed at a long distance in front of a convex mirror of radius of curvature 30 cm. State the position of its image.
6. Name the spherical mirror which can produce a real and diminished image of an object.
7. Name the spherical mirror which can produce a virtual and diminished image of an object.
8. One wants to see a magnified image of an object in a mirror. What type of mirror should one use ?
9. Name the mirror which can give :
   (*a*) an erect and enlarged image of an object.
   (*b*) an erect and diminished image of an object.
10. State whether the following statement is true or false :
    A diverging mirror is used as a rear-view mirror.
11. What type of mirror could be used :
    (*a*) as a shaving mirror ?
    (*b*) as a shop security mirror ?
12. Which type of mirror is usually used as a rear-view mirror in motor cars ?
13. What kind of mirrors are used in big shopping centres to watch the activities of the customers ?
14. A ray of light going towards the focus of a convex mirror becomes parallel to the principal axis after reflection from the mirror. Draw a labelled diagram to represent this situation.
15. Fill in the following blank with a suitable word :
    A ray of light which is parallel to the principal axis of a convex mirror, appears to be coming from...........after reflection from the mirror.

Short Answer Type Questions

16. Why does a driver prefer to use a convex mirror as a rear-view mirror in a vehicle ?
17. Why can you not use a concave mirror as a rear-view mirror in vehicles ?
18. Where would the image be formed by a convex mirror if the object is placed :

(*a*) between infinity and pole of the mirror ?

(*b*) at infinity ?

Draw labelled ray-diagrams to show the formation of image in both the cases.

19. The shiny outer surface of a hollow sphere of aluminium of radius 50 cm is to be used as a mirror :

(*a*) What will be the focal length of this mirror ?

(*b*) Which type of spherical mirror will it provide ?

(c) State whether this spherical mirror will diverge or converge light rays.

20. What is the advantage of using a convex mirror as a rear-view mirror in vehicles as compared to a plane mirror ? Illustrate your answer with the help of labelled diagrams.

21. Give two uses of a convex mirror. Explain why you would choose convex mirror for these uses.

22. What would your image look like if you stood close to a large :

(*a*) convex mirror ?

(*b*) concave mirror ?

Give reasons for your answer.

23. Which of the following are concave mirrors and which convex mirrors ?

Shaving mirrors, Car headlight mirror, Searchlight mirror, Driving mirror, Dentist's inspection mirror, Torch mirror, Staircase mirror in a double-decker bus, Make-up mirror, Solar furnace mirror, Satellite TV dish, Shop security mirror.

24. How will you distinguish between a plane mirror, a concave mirror and a convex mirror without touching them ?

25. If a driver has one convex and one plane rear-view mirror, how would the images in each mirror appear different ?

Long Answer Type Questions

26. (*a*) Draw a labelled ray diagram to show the formation of image of an object by a convex mirror. Mark clearly the pole, focus and centre of curvature on the diagram.

(*b*) What happens to the image when the object is moved away from the mirror gradually ?

(*c*) State three characteristics of the image formed by a convex mirror.

27. (*a*) Draw a labelled ray diagram to show the formation of image in a convex mirror when the object is at infinity. Mark clearly the pole and focus of the mirror in the diagram.

(*b*) State three characteristics of the image formed in this case.

(*c*) Draw diagram to show how a convex mirror can be used to give a large field of view.

Multiple Choice Questions (MCQs)

28. The image formed by a spherical mirror is virtual. The mirror will be :

(*a*) concave (*b*) convex (*c*) either concave or convex (*d*) metallic

29. Whatever be the position of the object, the image formed by a mirror is virtual, erect and smaller than the object. The mirror then must be :

(*a*) plane (*b*) concave (*c*) convex (*d*) either concave or convex

30. The mirror used by a dentist to examine the teeth of a person is :

(*a*) convex (*b*) concave (*c*) plane (*d*) any one of the above

31. If the image formed is always virtual, the mirror can be :

(*a*) concave or convex (*b*) concave or plane

(*c*) convex or plane (*d*) only convex

32. A concave mirror cannot be used as :

(*a*) a magnifying mirror (*b*) a torch reflector

(*c*) a dentist's mirror (*d*) a rear view mirror

33. A boy is standing in front of and close to a special mirror. He finds the image of his head bigger than normal, the middle part of his body of the same size, and his legs smaller than normal. The special mirror is made up of three types of mirrors in the following order from top downwards :

(*a*) Convex, Plane, Concave (*b*) Plane, Convex, Concave
(*c*) Concave, Plane, Convex (*d*) Convex, Concave, Plane

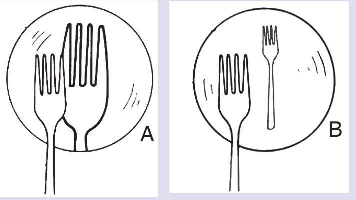
34. The mirror which can form a magnified image of an object is :
(*a*) convex mirror (*b*) plane mirror
(*c*) concave mirror (*d*) both convex and concave mirrors

35. A real image of an object is to be obtained. The mirror required for this purpose is :
(*a*) convex (*b*) concave (*c*) plane (*d*) either convex or concave

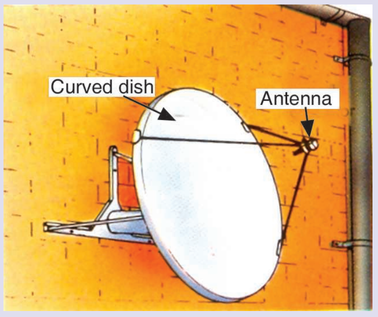
36. Consider two statements A and B given below :
A : real image is always inverted
B : virtual image is always erect
Out of these two statements :
(*a*) only A is true (*b*) only B is true (*c*) both A and B are true (*d*) none is true

Questions Based on High Order Thinking Skills (HOTS)

37. The diagrams show the appearance of a fork when placed in front of and close to two mirrors A and B, turn by turn.
(*a*) Which mirror is convex ?
(*b*) Which mirror is concave ?
Give reasons for your choice.



38. The diagram shows a dish antenna which is used to receive television signals from a satellite. The antenna (signal detector) is fixed in front of the curved dish.
(*a*) What is the purpose of the dish ?
(*b*) Should it be concave or convex ?
(*c*) Where should the antenna be positioned to receive the strongest possible signals ?
(*d*) Explain what change you would expect in the signals if a larger dish was used.



39. A man standing in front of a special mirror finds his image having a very small head, a fat body and legs of normal size. What is the shape of :
(*a*) top part of the mirror ?
(*b*) middle part of the mirror ?
(*c*) bottom part of the mirror ?
Give reasons for your choice.

40. Two big mirrors A and B are fitted side by side on a wall. A man is standing at such a distance from the wall that he can see the erect image of his face in both the mirrors. When the man starts walking towards the mirrors, he finds that the size of his face in mirror A goes on increasing but that in mirror B remains the same.
(*a*) mirror A is concave and mirror B is convex
(*b*) mirror A is plane and mirror B is concave
(*c*) mirror A is concave and mirror B is plane
(*d*) mirror A is convex and mirror B is concave

ANSWERS

1. (*a*) Virtual and erect (*b*) Virtual and erect ; Real and inverted **5.** At focus ; 15 cm behind convex mirror **9.** (*a*) Concave mirror (*b*) Convex mirror **10.** True **15.** focus **19.** (*a*) 25 cm (*b*) Convex mirror (*c*) Diverge light **28.** (*c*) **29.** (*c*) **30.** (*b*) **31.** (*c*) **32.** (*d*) **33.** (*c*) **34.** (*c*) **35.** (*b*) **36.** (*c*) **37.** (*a*) Mirror B is convex ; It forms a smaller image of fork (*b*) Mirror A is concave ; It forms a larger image of fork **38.** (*a*) To collect a large amount of TV signals from the satellite (*b*) Concave (*c*) At the focus of the dish (*d*) Stronger signals will be received **39.** (*a*) Convex (*b*) Concave (*c*) Plane **40.** (*c*)

NUMERICAL PROBLEMS BASED ON CONVEX MIRRORS

In order to solve the numerical problems based on convex mirrors, we should remember that the mirror formula for a convex mirror is the same as that for a concave mirror, which is :

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

where v = image distance
u = object distance
and f = focal length

Please note that since a convex mirror always forms an image behind the mirror (on the right side of the mirror), therefore, **the image distance (v) in the case of convex mirrors is always positive**. The object is always placed to the left of mirror, so the object distance (u) is always taken with a negative sign. The focus of a convex mirror is behind the mirror on its right side, therefore, **the focal length of a convex mirror is always taken as positive.**

The two magnification formulae for convex mirror are also just the same as that for a concave mirror. That is :

$$m = \frac{h_2}{h_1} \quad \text{and} \quad m = -\frac{v}{u}$$

where the symbols have their usual meaning. Let us now solve one numerical problem based on convex mirror.

Sample Problem. An object 5 cm high is placed at a distance of 10 cm from a convex mirror of radius of curvature 30 cm. Find the nature, position and size of the image.

Solution. Here, Object distance, u = – 10 cm (To left of mirror)
Image distance, v = ? (To be calculated)

And, Focal length, $f = \frac{\text{Radius of curvature}}{2}$

$= \frac{30}{2}$ cm

= + 15 cm (Convex mirror)

Putting these values in the mirror formula :

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

we get :

$$\frac{1}{v} + \frac{1}{-10} = \frac{1}{+15}$$

or

$$\frac{1}{v} - \frac{1}{10} = \frac{1}{15}$$

or

$$\frac{1}{v} = \frac{1}{15} + \frac{1}{10}$$

$$\frac{1}{v} = \frac{2+3}{30}$$

$$\frac{1}{v} = \frac{5}{30}$$

$$\frac{1}{v} = \frac{1}{6}$$

So, Image distance, v = + 6 cm

Thus, the position of image is 6 cm behind the convex mirror. Since the image is formed behind the convex mirror, its nature will be virtual and erect.

To find the size of image, we will calculate the magnification first.

Now, Magnification, $m = -\frac{v}{u}$

Here, Image distance, $v = +6$ cm
and Object distance, $u = -10$ cm

So, $$m = -\frac{(+6)}{(-10)}$$

$$m = \frac{6}{10}$$

Magnification, $m = 0.6$

We also have another formula for magnification, which is :

$$m = \frac{h_2}{h_1}$$

Here, Magnification, $m = +0.6$
Height of image, $h_2 = ?$ (To be calculated)
and Height of object, $h_1 = +5$ cm

So, $$+0.6 = \frac{h_2}{+5}$$

$$h_2 = 5 \times 0.6$$

Height of image, $h_2 = 3$ cm (or + 3 cm)

Thus, the size of image is 3 cm.

We are now in a position to **answer the following questions and problems :**

Short Answer Type Questions

1. An object is kept at a distance of 5 cm in front of a convex mirror of focal length 10 cm. Calculate the position and magnification of the image and state its nature.

2. An object is placed at a distance of 10 cm from a convex mirror of focal length 5 cm.
(*i*) Draw a ray-diagram showing the formation of image.
(*ii*) State two characteristics of the image formed.
(*iii*) Calculate the distance of the image from mirror.

3. An object is placed at a distance of 6 cm from a convex mirror of focal length 12 cm. Find the position and nature of the image.

4. An object placed 20 cm in front of a mirror is found to have an image 15 cm (*a*) in front of it, (*b*) behind the mirror. Find the focal length of the mirror and the kind of mirror in each case.

5. An arrow 2.5 cm high is placed at a distance of 25 cm from a diverging mirror of focal length 20 cm. Find the nature, position and size of the image formed.

6. A convex mirror used as a rear-view mirror in a car has a radius of curvature of 3 m. If a bus is located at a distance of 5 m from this mirror, find the position of image. What is the nature of the image ?

7. A diverging mirror of radius of curvature 40 cm forms an image which is half the height of the object. Find the object and image positions.

8. The radius of curvature of a convex mirror used as a rear view mirror in a moving car is 2.0 m. A truck is coming from behind it at a distance of 3.5 m. Calculate (*a*) position, and (*b*) size, of the image relative to the size of the truck. What will be the nature of the image ?

Long Answer Type Question

9. (*a*) Draw a diagram to represent a convex mirror. On this diagram mark principal axis, principal focus F and the centre of curvature C if the focal length of convex mirror is 3 cm.
(*b*) An object 1 cm tall is placed 30 cm in front of a convex mirror of focal length 20 cm. Find the size and position of the image formed by the convex mirror.

Questions Based on High Order Thinking Skills (HOTS)

10. A shop security mirror 5.0 m from certain items displayed in the shop produces one-tenth magnification.
(*a*) What is the type of mirror ?
(*b*) What is the radius of curvature of the mirror ?

11. An object is placed 15 cm from (*a*) a converging mirror, and (*b*) a diverging mirror, of radius of curvature 20 cm. Calculate the image position and magnification in each case.

12. An object 20 cm from a spherical mirror gives rise to a virtual image 15 cm behind the mirror. Determine the magnification of the image and the type of mirror used.

ANSWERS

1. 3.3 cm behind the convex mirror ; 0.66 ; Virtual and erect **2.** (*ii*) Virtual and erect ; Diminished (Smaller than the object) (*iii*) 3.3 cm behind the convex mirror **3.** 4 cm behind the mirror ; Virtual and erect **4.** (*a*) Concave mirror of focal length $\frac{60}{7}$ cm (*b*) Convex mirror of focal length 60 cm **5.** v = 11.1 cm ; The image is formed 11.1 cm behind the convex mirror ; Virtual and erect ; 1.1 cm tall **6.** 1.15 m behind the mirror ; Virtual and erect **7.** 20 cm ; 10 cm behind the mirror **8.** (*a*) 0.77 m behind the mirror (*b*) $\frac{1}{4.5}$; Virtual and erect **9.** 0.4 cm ; 12 cm behind the mirror **10.** (*a*) Convex mirror (*b*) $\frac{10}{9}$ m **11.** (*a*) v = –30 cm ; The image is formed 30 cm in front of converging mirror ; m = –2 (*b*) v = + 6 cm; The image is formed 6 cm behind the diverging mirror ; m = + 0.4 **12.** m = + 0.75 ; Convex mirror