Chapter

3

Reflection of light by different surfaces

In class 6, we have learnt about shadows and we carried out many experiments with light rays and also discussed the rectilinear propagation of light i.e., light travels in a straight line. In class 7 we learnt the laws of reflection.

Let us recall some of them.

– A source of light, an opaque object and a screen are needed to form a shadow.
– Light travels in a straight line.
– When light gets reflected from a surface, the angle of reflection is equal to the angle of incidence.
– The incident ray, the normal at the point of incidence and the reflected ray all lie in the same plane.

You must have observed shadows and images in your daily life. Sme questions might have come to your mind while observing these shadows or images.

- Why does our image appear thin or bulged out in some mirrors?
- Why is there right-left inversion (lateral inversion) when we look into a mirror?
- Can we focus sunlight at a point using a mirror instead of a magnifying glass?
- Why is the angle of reflection equal to the angle of incidence when a light ray gets reflected from a surface?
- Are the angle of reflection and angle of incidence also equal for reflection by curved surfaces?

In this lesson we are going to learn about reflection of light in detail so that we can answer the above questions. Let's start with some activities based on your previous knowledge.

Activity 1

Formation of image by a pinhole camera

Recall how an image forms in a pinhole camera that you have learnt in class 6. Draw a ray diagram of the formation of an image in a pinhole camera.

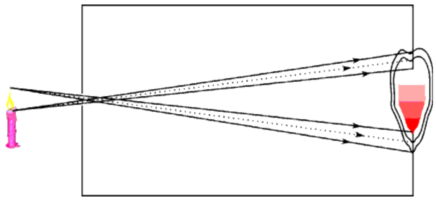


fig-1

What whould happen if we increase the size of the hole of the pinhole camera. Observe the flame of a candle with a pinhole camera making a big hole. Try to draw a ray diagram of the formation of an image in a pinhole camera with a big hole. Look at figure 1.

By observing the figure we can understand that the light rays coming from the top of the candle flame fall at different points on the screen. Similarly the rays coming from bottom of the candle flame also fall at different points on the screen. Thus we get blurred image on the screen due to the big hole of the camera as shown figure 1.

Think and discuss

- Does the explanation match your observation?
- What happens if the hole is much bigger i.e. equal to the size of the flame?
- If so, can we get an image of a flame on the screen of the pinhole camera? Why?
- What happens if we observe the same flame with the same pinhole camera from a long distance?

Think and answer. Do the experiment and check your answer.

Now think about reflection of light, and solve the task given below.

Activity 2

A smart crow is on a tree at point 'A' as shown in figure-2. Some grains are on the ground. If the crow wants to take a grain and reach the point 'B' on the other tree as early as possible(in least time), from where should the crow pick up the grain?

fig-2

With the mathematical knowledge you have about angles and triangles can you guess the path that the crow selects? If you can't, read the following.

The crow can pick the grain from any point on the ground but the condition is; selecting a point on the ground to reach point 'B' from point 'A' in least possible time. If we assume that the speed of the crow is constant the path that the crow selects should be the shortest. Let us find the shortest path.

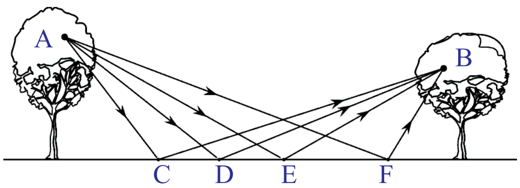


fig-3

Observe some of the paths in figure-3.

Which among the paths ACB, ADB, AEB and AFB is the shortest path?

To compare the lengths of these paths, we make duplicates of them as shown in figure-4.

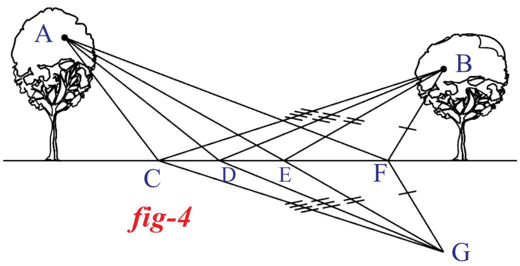


fig-4

In the figure, CB = CG. The length of path ACB = AC+CB = AC+CG = ACG. Thus the length of the path ACG is equal to the length of the path ACB. similarly ,

length of the path ADB = length of the path ADG

length of the path AEB = length of the path AEG

length of the path AFB = length of the path AFG

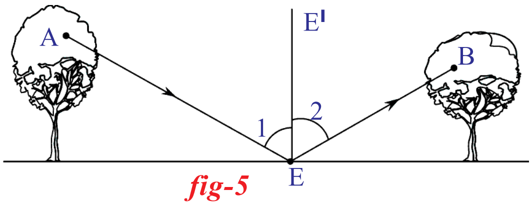


fig-5

If you observe Fig-4 carefully, you will notice that, among the paths ACG, ADG, AEG and AFG, the shortest path is AEG, because it is the straight line distance between points A and G. You can measure and check this using a scale. As AEG=AEB, path AEB is the shortest path to reach point B from point A. It would take the least time. So the smart crow will pick the grain from point E.

Observe the path AEB once again in figure-5.

If we draw a normal EE' at point E, we can easily find that angle AEE' (angle 1) is equal to angle $E'EB$ (angle 2).

Like the crow in the above situation, light also selects the path which takes the least time to travel. This principle was first given by ***Pierre de Fermat***, a French lawyer and an amateur mathematician.

It is also applicable to reflection of light. When light gets reflected from a surface, it selects the path that takes the least time. That is why the angle of incidence is equal to the angle of reflection as shown in figure-5.

Now, before a detailed discussion on reflection, perform a fun activity and refresh your previous knowledge.

Activity 3

Check your understanding of reflection

Look at figures 6a and 6b. Let us suppose that you have been given a plane mirror strip.

- What will you do to obtain figures that are shown in figure 6(b) using mirror strip and figure 6(a)?

Place the plane mirror strip on the figure shown in 6(a) in such a manner that you see one of the figures shown in figure-6b. The procedure is shown in figure-6c.

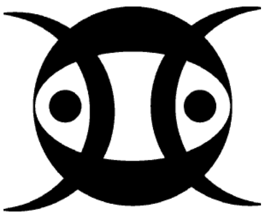


fig-6a

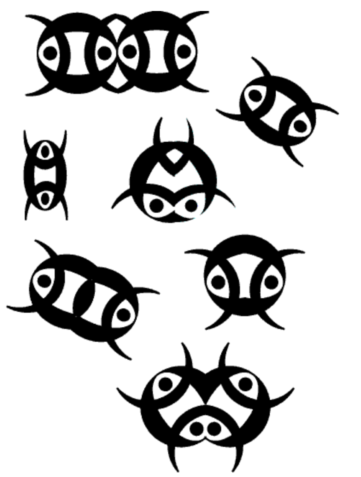


fig-6b

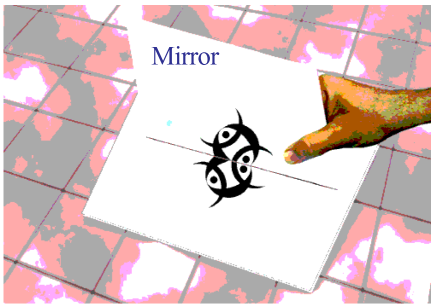


fig-6c

- Are you able to obtain all figures shown in 6(b)?

Take the help of your friends to complete the task.

Let us begin the detailed discussion on reflection of light by plane surfaces.

Reflection of light by plane mirrors

Lab Activity 1

Aim: Verification of laws of reflection

Required material: mirror strip, drawing board, white paper, pins, clamps, scale and pencil

Procedure: Take a drawing board and fix a white paper on it with the help of clamps. Draw a straight line AB at the centre of the paper and also a normal (ON) to AB at the point 'O'. Draw a straight line PQ making certain angle (angle i) with ON as shown in figure 7. Fix two pins at the points P and Q on the paper vertically. Observe the image P^l of the pin P and Q^l of the pin Q, in the mirror kept along the line AB. Fix two more pins R and S such that they are in the same line as that of P^l and Q^l. Join R, S and O as shown in figure-7.

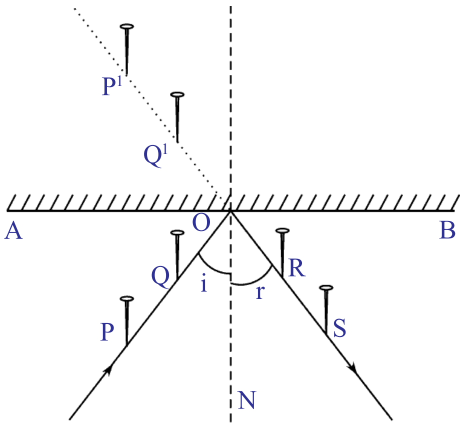


fig-7

Measure the angle between RS and ON (angle of reflection). You will find that angle of incidence = angle of reflection. Repeat the experiment for different angles of incidence and measure the corresponding angles of reflection (r).

- Is the angle of reflection equal to the angle of incidence in all cases ?

In which plane does the incident ray, reflected ray and the normal lie (2^{nd} law of reflection of light) ? Let us discuss this.

Plane of reflection

In the above activity, the incident ray is the ray which passes through the points P and Q touching the paper. The reflected ray is the ray which passes through the points R and S touching the same paper, and ON is the normal to the mirror at point O.

- Do the two rays and the normal lie in the same plane? If yes, which is that plane?

If the incident ray, reflected ray and normal are in the plane parallel to the plane of the paper, where will that plane be?

Assume that the heads of all pins pierced at points P,Q,R and S in the above activity are at the same height. The incident ray is the ray which passes through the heads of pins which are located at points P and Q, and reflected ray is the ray which passes through the heads of pins which are located at points R and S.

- Where will the normal be?
- In which plane will the incident ray, reflected ray and the normal lie?

The plane in which the incident ray, reflected ray and normal lie is the **plane of reflection**.

Assume that the heads of the pins which are located at the points P and Q are not of the same height.

- How will the incident ray be?
- How will the reflected ray be?

- How will the normal be?
- How will the plane of reflection be?

Arrange two pins with different heights. Arrange the incident ray, reflected ray and the normal with the help of spokes of a cycle. Then think of the plane of reflection.

- How does a mirror form the image of a pin or any object?

Let us discuss.

Formation of an image by a plane mirror

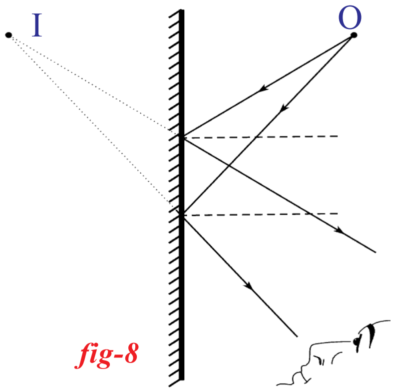


fig-8

Observe figure 8.

O is a point object. Some rays from O reach the mirror and get reflected. When we look into the mirror, the reflected rays seem to be coming from the point I. So point I is the image of point object O.

Observe the distances of object O and image I from the surface of the mirror and try to compare these distances by approximate estimation in figure 8. We find that these distances are equal.

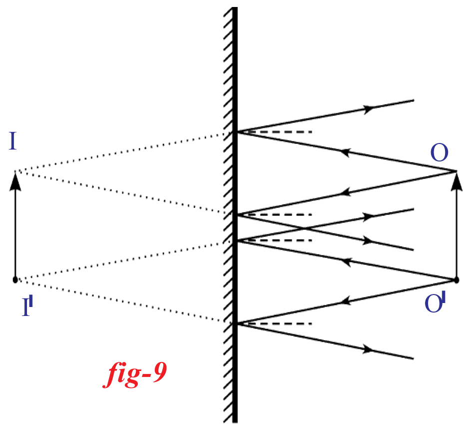


fig-9

Let us assume that an object (OO^I) is kept in front of a mirror as shown in figure 9. Draw a few incident rays from the object to the mirror and reflected rays from the mirror using laws of reflection. Your drawing may look like that shown in figure 9.

In the figure, the rays coming from the point O get reflected from the mirror and seem to be coming from the point I. So we say I is the image of O.

The rays coming from the point O^I get reflected from the mirror and seem to be coming from the point I^I. So we say I^I is the image of O^I.

The rays coming from the middle part of the O and O^I will form their own images between I and I^I.

Thus, II^I is the image of the object OO^I.

- What is the size of the image compared to the size of the object?

Let us discuss some of the characteristics like size, distance and right-left inversion of an image formed by a plane mirror.

Characteristics of an image formed by a plane mirror

Take an object, say pen or pencil. Put it in front of a plane mirror, touching the surface of the mirror.

- What do you say about the size of the image compared to the size of the object?

  Move the object towards your eye. What do you observe?

- Is the size of the image decreasing or increasing?

Figure 9 shows the formation of an image by a plane mirror. In that figure, you might have noticed that the size of the image is equal to the size of the object. Why does the size of the image seem to be decreased when you move the object towards your eye?

To understand this see figure 10, which shows how our eyes judge the size of an object.

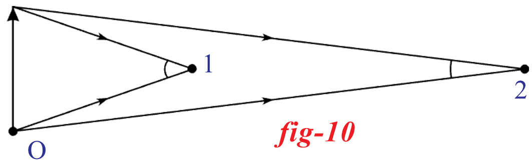


fig-10

Observers 1 and 2 are looking at the object which is at point O. It looks smaller to observer 2 than to observer 1, because the light rays coming from the object make a smaller angle at the eye of observer 2 who is at a larger distance compared to observer 1. The angle plays a role in judging the size of the object.

In the same way when we move the object from the mirror to our eye, the image in the mirror seems to move back in the mirror. Then the distance from the image to our eye increases. The angle made by image at our eye is smaller than the angle made by the object. That is why the image looks smaller than the object.

When you stand in front of a mirror you might have observed that the distance of your image in a plane mirror seems to be equal to the distance between the mirror and yourself. What you observe is generally true. You can verify this by observing figure-9.

You also might have observed the right-left inversion of your image in a plane mirror.

- Why does an image suffer lateral (right-left) inversion?

  See figure-11.

- What do you understand from the figure 11?

The light rays which come from our right ear get reflected from the plane mirror and reach our eye. Our brain feels that the ray (reflected ray) is coming from the inside of the mirror (shown by dotted line in the figure-11). That is why our right ear looks like left ear in the image.

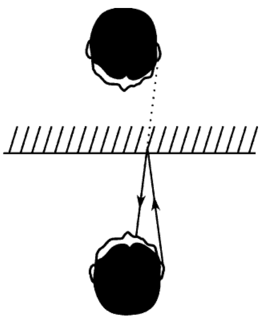
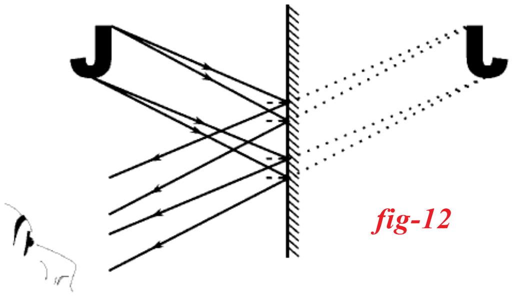


fig-11



Now observe the lateral inversion of a letter with a ray diagram in figure-12.

Think of the process of image formation by a plane mirror and explain lateral inversion by observing figure-12.

We now know how light reflects from plane surfaces. In class 7, we learnt about spherical mirrors and why they were called spherical mirrors.

We already did a simple activity to get an image with a concave mirror in class 7. Now we shall study the reflection of light by curved surfaces in detail.

Reflection of light by spherical mirrors

The first law of reflection tells us;

A light ray incident at an angle with the normal at the point of incidence will get reflected making equal angle with the normal.

This law is true for all surfaces, be it a plane surface or a curved one. The important words here are 'the angle made with normal at the point of incidence'. If for any surface one can decide the normal and find the incident angle, it is possible to deduce the angle made by the reflected ray. It is very easy to find a normal at any point on the plane surface but for a curved or uneven surface it is not straightforward.

Activity 4

Finding the normal to a curved surface

Take a small piece of thin foam or rubber (like the sole of a slipper). Put some pins along a straight line on the foam as shown in the figure -13a.

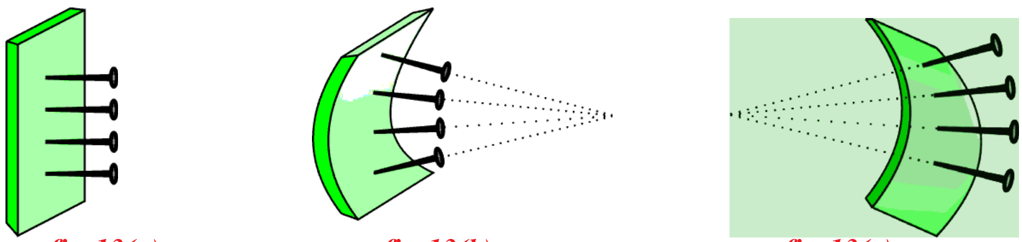


fig-13(a) fig-13(b) fig-13(c)

All these pins are perpendicular to the plane of foam. If the foam is considered as a mirror, each pin would represent the normal at that point. Any ray incident at the point where the pin makes contact with the surface will reflect with the same angle as the incident ray made with the pin-normal.

Now bend the foam piece inwards as shown in figure-13b, what happens to the pins?

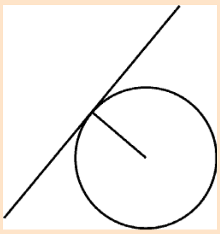
They still represent the normal at various points, but you will notice that all the pins tend to converge at a point (or intersect at a point).

If we bend the foam piece outwards, we will see that the pins seem to move away from each other or in other words they diverge as shown in figure-13c.

This gives us an idea of what is likely to happen with a spherical mirror. A concave mirror will be like the rubber sole bent inwards (fig-13b) and the convex mirror will be like the rubber sole bent out wards (fig-13c).

For a concave mirror, like these pins in figure-13b, all normals will converge towards a point. This point is called **centre of curvature(C)** of the mirror.

Recall a little bit of geometry: while learning about circles and tangents, you may have learnt that a radius is always perpendicular to the tangent to the circle drawn at the point.



This gives us a clue about how we can find normal to any point on a spherical mirror. All that we have to do is to draw a line from the point on the mirror to centre of the sphere.

It is much easier to imagine this in a two dimensional figure as shown in figure-14a. The concave mirror is actually a part of a big sphere. In order to find this centre point (centre of curvature) we have to think of the centre of the sphere to which the concave mirror belongs. The line drawn from C to any point on the mirror gives the normal at that point.

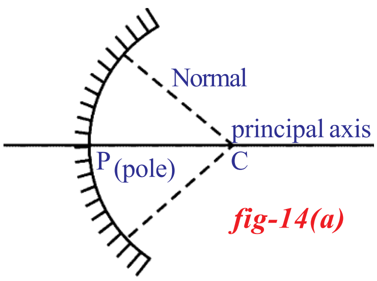


fig-14(a)

For the ray R, the incident angle is the angle it makes with the normal shown as **i** and the reflected angle is shown as **r** in figure-14b. We know by first law of reflection i = r.

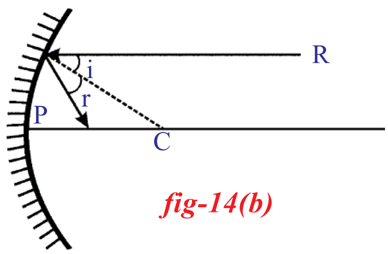


fig-14(b)

The mid point (Geometrical centre) of the mirror is called **pole (P)** of the mirror. The horizontal line shown in the figures which passes through the centre of curvature and pole is called **principal axis** of the mirror. The distance between P and C is **radius of curvature (R)** of the mirror.

Using the construction method described above, try to construct different reflected rays for any array of rays that are parallel to the principal axis. What is your conclusion?

Verifying your drawing with experiments

To verify this we must first find out some way of obtaining a beam of parallel rays. How do we do that?

First we need to create a situation in which one gets parallel rays of light.

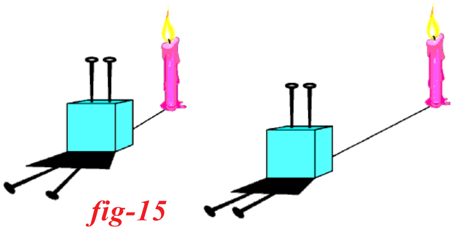


fig-15

In the figure-15 we have stuck two pins on a thermocole block. The pins are parallel to each other. As we see in the figure, when a source of light is kept very near, we see the shadows diverging (from the base of the pins). As we move the source away from the pins, the angle of divergence gets reduced. If we move the source far away we will get parallel shadows. But as we move the candle away, the light intensity becomes low. That means to get a beam of parallel rays the source should be at a long distance and it must be of sufficient intensity.

Where do we find one such source?

Yes, we have one easily available source, you probably have guessed it: The Sun.

Let us do an experiment with sun rays and a concave mirror.

Activity 5

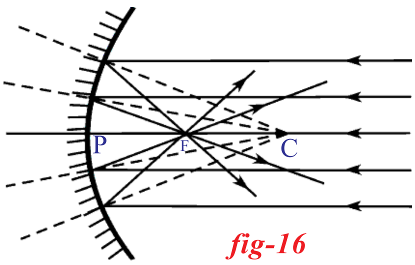


fig-16

Hold a concave mirror such that sunlight falls on it. Take a small paper and slowly move it in front of the mirror and find out the point where you get the smallest and brightest spot, which will be the image of the sun. (See to it that your paper is small so that it does not obstruct the incoming sun rays.)

The rays coming from the sun parallel to the principal axis of concave mirror converge to a point (see figure-16). This point is called **Focus or focal point (F)** of the concave mirror. Measure the distance of this spot from the pole of the mirror. This distance is the **focal length (f)** of the mirror. The radius of curvature will be twice this distance (R=2f).

Does this help you to verify the conclusions you arrived at, with your drawing?

- What happens if you hold the paper at a distance shorter than the focal length from the mirror and move it away?
- Does the image of the sun become smaller or bigger?

You will notice that the image of the sun first keeps on becoming small, beyond the focal point it keeps on becoming enlarged.

Note: while drawing a ray diagram sometimes it is not clear which is the reflecting side of the mirror. Hence we follow a convention of showing lines on the non-reflecting side(coated side).

Can you draw the same diagram for a convex mirror?

See figure-17. The parallel rays appear to diverge after reflection. If we extend the reflected rays backwards they meet at 'F' i.e. focus of the convex mirror.

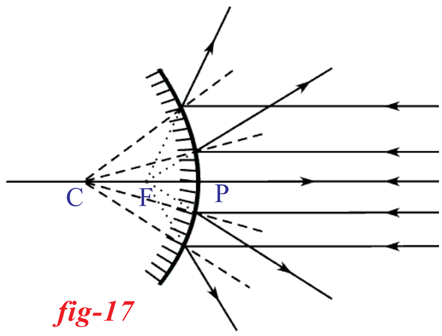


fig-17

Think and discuss

- See figure-17. A set of parallel rays are falling on a convex mirror. What conclusions can you draw from this?
- Will you get a point image if you place a paper at the focal point?

When parallel rays are incident on a concave mirror, on reflection they meet at the focus.

- Do we get an image with a concave mirror at the focus every time? Let us find out.

Lab Activity 2

Aim: Observing the types of images and measuring the object distance and image distance from the mirror.

Material required: A candle, paper, concave mirror (known focal length), V-stand, measuring tape or meter scale.

Procedure: Place the concave mirror on V-stand, a candle and meter scale as shown in figure-18.

Keep the candle at different distances from the mirror (10cm to 80cm) along the axis and by moving the paper (screen) find the position where you get the sharp image on paper. (Take care that flame is above the axis of mirror, paper is below the axis).

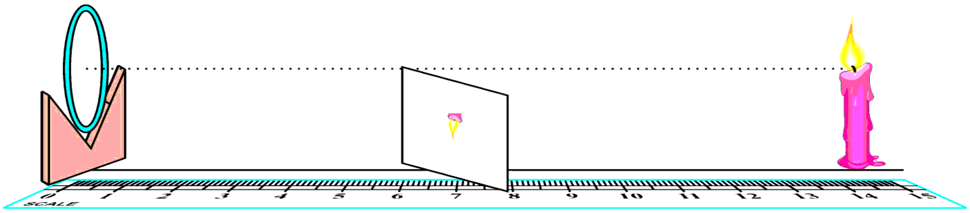


fig-18

Note down your observations in table-1.

Table-1

Observation no.	Distance of candle from mirror (object distance-u)	Distance of paper from mirror (image distance-v)	Enlarged/ diminished	Inverted or erect
1				
2				
3				
4				

Group your observations based on the type of image you see (e.g. Image is bigger and inverted). It is possible you may not get any image at some positions, note down that too!

Since we know the focal point and centre of curvature, we can reclassify our above observations as shown in table-2. What do you infer from this table?.

At this point we suggest that you make one more observation. You have been trying to get the image on a paper when the object is at different positions. At the same time also look into the mirror and note your observations about how the image appears.

- Is it inverted or erect, enlarged or diminished?

Table - 2

Position of the candle (object)	Position of the image	Enlarged/ diminished	Inverted or erect	Real or virtual
Between mirror & F				
At focal point				
Between F and C				
At centre of curvature				
Beyond C				

What do you infer from the table-2?

Let us try to draw ray diagrams with concave mirrors and compare them with your inferences.

Ray diagrams for concave mirror

In activity-5 we saw the ray diagram of sunrays parallel to the concave mirror and the image of the sun was very small at the focal point (See figure-16). Now we shall develop a technique to draw ray diagrams when an object is placed anywhere on the axis of the mirror and validate the above observations.

Here we will take at least two rays originating from the same point on the object but with different direction, see how they get reflected from the mirror and find out the point where they meet to form the image.

Let us take an example.

As shown in the figure-19, assume a concave mirror and a candle placed at some distance along the axis of the mirror.

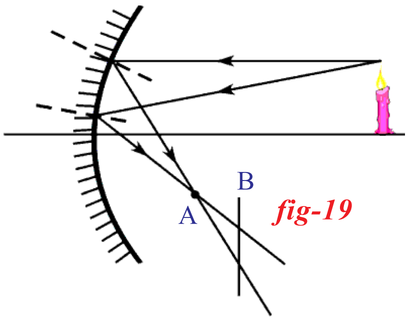


fig-19

The diagram shows two rays coming from the tip of the flame (object). The reflected rays are constructed based on the laws of reflection.They meet at point A. The tip of the flame of the reflected image will be at the point of intersection, A.

- Why only at point A?

If we hold the screen at any point before or beyond point A (for example at point B), we see that the rays will meet the screen at different points. Therefore, the image of the tip of the flame will be formed at different points due to these rays. If we draw more rays emanating from the same tip we will see that at point A they will meet but at point B they won't. So, the image of the tip of the flame will be sharp if we hold the screen at point A and will become blurred (due to overlaping of multiple images) when we move the paper slightly in any direction (forward or backward). Is this not something that you observed during the previous experiment with sun rays?

However, it is not going to be easy to evaluate the angle of reflection for any arbitrary ray, every time we will have to find the normal, measure the incident angle and construct a ray with equal angle on the other side. This would be a tedious task, can we find any other simpler method?

Yes, there are a few. Based on our discussion so far, we can identify some appropriate rays which we can take as representative rays to find the point 'A'.

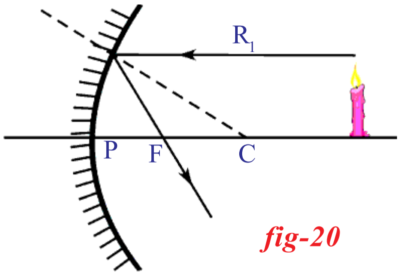


fig-20

We have seen that all rays that are parallel to the axis get reflected such that they pass through the focal point of the mirror. So, for drawing any diagram the most suitable ray to draw will be the one that comes from the object and goes parallel to the axis of the mirror. The reflected ray will be the line drawn from the point of incidence on the mirror and passes through the focal point of the mirror. To make it more convenient we will always take rays that come from the tip of the object. See the ray R_1 in figure-20.

The converse situation of previous one is also true; that is, a ray that passes through the focal point of the mirror will travel parallel to the axis after reflection.

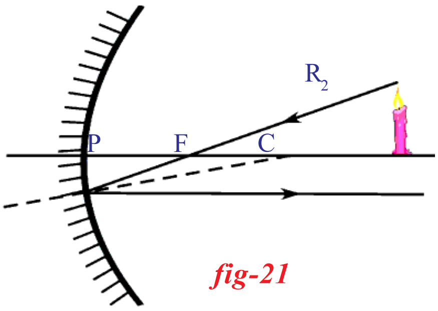


fig-21

This gives us our second ray. This will be the ray coming from the tip of the flame and going through the focal point and falling on the mirror. After reflection, this ray travels parallel to the axis. So we draw the reflected ray as a line parallel to the axis coming from the point where the incident ray meets the mirror. See R_2 in figure-21.

Using the rays R_1, R_2 and finding the point where they intersect we know the point where the image of the tip is formed.

There is one more ray which is convenient to draw.

We have seen earlier that any ray that is normal to the surface, on reflection, will travel along the same path but in the opposite direction. Which ray can such a one be for a spherical mirror?

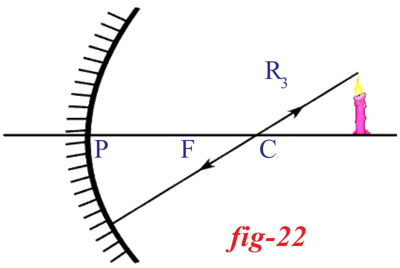


fig-22

We know that a line drawn from the centre of curvature to the mirror is perpendicular to the tangent at the point where the line meets the curve. So if we draw a ray coming from the tip of the object going through the centre of curvature to meet the mirror, it will get reflected along the same line. This ray is shown as R_3 in the figure-22. In general, a ray travelling along normal retraces its path.

Along with these three rays 'the ray which comes from the object and reaches the pole of the mirror' is also useful in drawing ray diagrams. For this ray, the principal axis is the normal.

If we have our object (candle) placed as shown in figure-23, we can draw the ray diagram to get the point of intersection A, of any two rays coming from the top of the object and point of intersection B, of any two rays coming from the botom of the object. We notice that point B is exactly at the same distance from mirror as point A. Hence the image is vertical and inverted.

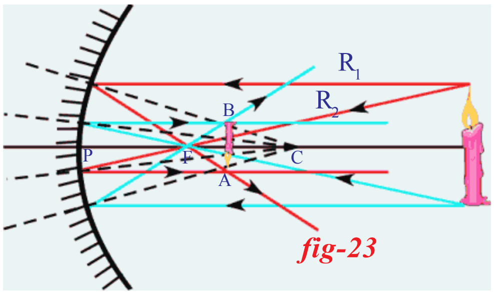


fig-23

- Where is the base of the candle expected to be in the image when the candle is placed on the axis of the mirror?

Since any ray coming from any point on the axis and travelling along the axis will get reflected on the axis itself, we can conclude that the base of the image is going to be on the axis. Using the knowledge, that if the object is placed vertically on the axis, the image is going to be vertical, all that we do is to draw a perpendicular from point A to the axis. The intersection point is the point where the base of the image of the candle is likely to be formed. See figure-24. Hence, as shown in the diagram the image will be inverted and diminished.

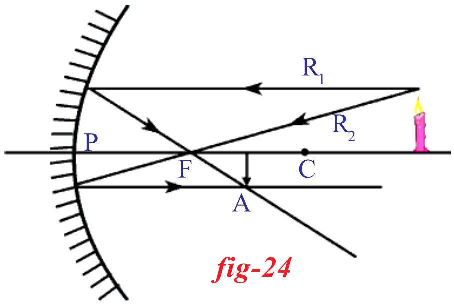


fig-24

Figure-24 is drawn for the case where the object is placed beyond the centre of curvature.

Does this conclusion match with your observations? (Lab Activity 2)

Draw similar diagrams for other cases and verify that they match with your observations.

- During the experiment, did you get any positions where you could not get an image on the screen?

Consider the case shown in the figure-25. The candle object (O) is placed at a distance less than the focal length of the mirror.

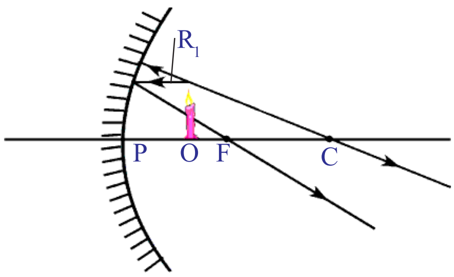


fig-25

The first ray (R_1) will start from tip of the object and run parallel to axis to get reflected so as to pass through the focal point. This one is easy to draw. The second ray that we chose for earlier ray diagrams is the ray coming from the tip of the object and going through the focal point but it is not possible as such a ray will not meet the mirror. So we must use the third ray, a ray coming from the tip of the object and going through the centre of curvature.

But that too does not seem to be possible. So we make a small change.

Instead of drawing a ray from the candle tip to centre of curvature, we consider a ray that comes from the tip and goes in such a direction that it would go through the centre of curvature if extended backwards. This ray is normal to the surface and so will be reflected along the same line in opposite direction and will go through centre of curvature.

We notice that the two reflected rays (figure-25) diverge and will not meet. While doing the experiments for a case such as this we were unable to find any place where we got a sharp image on the screen. This ray diagram tells us that since the reflected rays are diverging we will not get an image anywhere. So even if we had moved the screen much away from the mirror, we would not have found an image.

In such situations, however, we do see an image when we look in the mirror. Is it possible to explain this image with a ray diagram?

Remember what we did to find the image in a plane mirror. To decide the position of image we extended the reflected rays backwards till they met. We will do the same here. When we look in the mirror we are looking at these diverging reflected rays. They appear to be coming from one point. We can get this point by extending the rays backwards as shown in figure-26. The image does not really exist the way we saw in other cases, but it is visible to us.

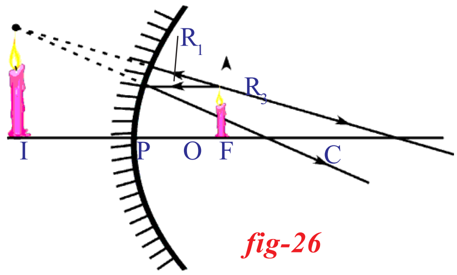


fig-26

As seen in the figure-26, the image will be erect and enlarged. Does this match with your observations?

This image that we got by extending the rays backwards is called a **virtual image.** We cannot get this on a screen like a **real image**.

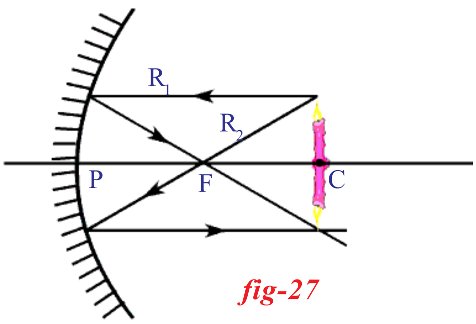


fig-27

The case in which the object is at the centre of curvature is another interesting situation. See figure-27.

From the ray diagram (figure-27) we conclude that the image of the object will be formed at the same distance as the object and it will be inverted and be of the same size. What is your observation?

Think and discuss

- How can one see an image formed on the object itself? Draw a ray diagram. Do the experiment.

From the ray diagrams and the observations you may have noticed some peculiar properties of concave mirrors. They enlarge the image when the object is held close to the mirror (less than the focal length). Also, the image is erect. This property is used at many places and most commonly in shaving mirrors and mirrors used by dentists.

Another property is the way that it can converge the rays to its focal point. This is extensively used in many places. Look at the shape of TV dish antennas.

If you look around you will see many curved surfaces but all surfaces are not concave, many of these are convex.

Have you observed the rare view mirrors of a car?

What type of surface do they have?

Have you observed images formed on the rear and window glasses of a car? What type of surfaces are these? See figure -28.

Can we draw ray diagrams for convex surfaces?

fig-28

Ray diagrams for convex mirrors

One can draw ray diagrams for a convex mirror too. The 'easy' rays that we identified earlier can be used in this case with small modification. Here there are three rules which describe these rays. The procedure for drawing the diagram is similar and is not repeated here.

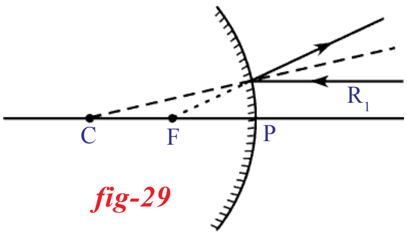


fig-29

Rule 1: A ray parallel to the axis, on meeting the convex mirror will get reflected so as to appear as if it is coming from the focal point. See figure-29.

Rule 2: This is converse of Rule 1. A ray travelling in the direction of the focal point, after reflection, will become parallel to the axis. See figure-30.

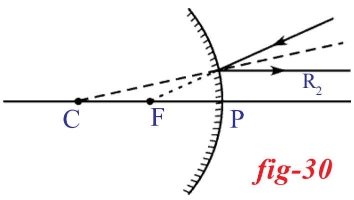


fig-30

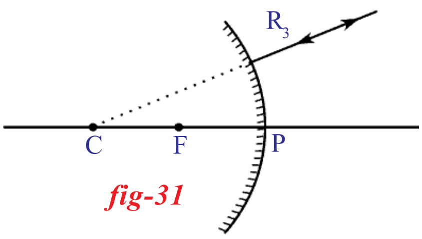


fig-31

Rule 3: A ray travelling in the direction of the centre of curvature will, on reflection, travel in the opposite direction and appears to be coming from the centre of curvature. See figure-31.

Using these rules, draw ray diagrams to show formation of images when an object is placed at different positions and note down your conclusions. Verify your results experimentally.

If necessary use another ray which comes from the object and reaches the pole of the mirror.

You may get the image at a particular distance when you place the object at a certain distance. Do you find any relation between the object distance(u) and the image distance(v)?

Derivation of formula for curved mirrors

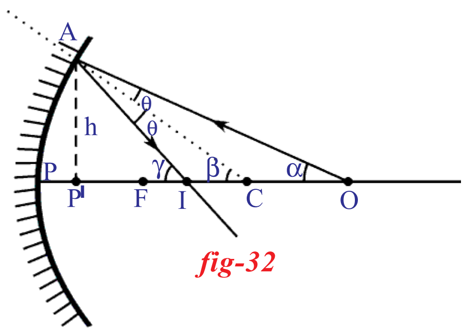


fig-32

Observe figure 32.

A ray coming from the point O which is on the principal axis of the mirror falls on the mirror at point A which is at height 'h' from the axis and after reflection, passes through point I which is also on the axis.

Here AC is the normal. The angle of incidence (angle OAC) and the angle of reflection (angle CAI) are equal and they are denoted by θ in the figure. Line segment AP^I is the perpendicular drawn to the axis from the point A. Now we can observe three right angled triangles namely, Triangle AOP^I, ACP^I and AIP^I.

Let the angles at the vertices O, C and I of three triangles be α, β and γ respectively as shown in figure 32.

In a triangle, sum of the interior angles is equal to the exterior angle.

From the triangle AOC; $\beta = \alpha + \theta$

$$\theta = \beta - \alpha$$

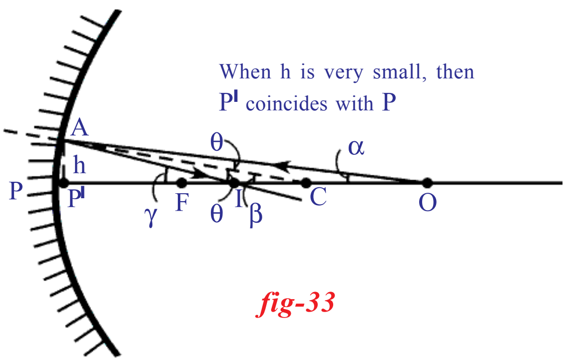


fig-33

From the triangle ACI; $\gamma = \beta + \theta$

By substituting $\theta = \beta - \alpha$ in the above equation, we get

$$\gamma = \beta + \beta - \alpha$$

$$2\beta = \alpha + \gamma \quad ....(1)$$

- What happens when 'h' becomes very small?

Observe figure 33.

When 'h' becomes very small,

1. P^I may coincide with point P, which is pole of the mirror.
   Then we can say $P^IO = PO$, $P^IC = PC$ and $P^II = PI$.

2. The angles α, β and γ become very small as shown in figure 33.

Let us calculate "Tan" values of the angles α, β and γ.

(In a right angled triangle, Tan value of acute angle is the ratio of the length of the opposite side to the length of the adjacent side of that acute angle)

Here P^I is assumed to coincide with P, then we have

$\tan \alpha = P^I A / P^I O = h / P^I O = h/PO$

$\tan \beta = P^I A / P^I C = h / P^I C = h/PC$

$\tan \gamma = P^I A / P^I I = h / P^I I = h/PI$

When an angle θ becomes very small i.e. close to zero, the value of numerator (length of the opposite side of the θ) becomes very small. You can observe this in figure 33. Then the value of Tan θ becomes very small i.e. close to zero. So the value of Tan θ is taken as θ. That is $\tan \theta \approx \theta$. Similarly here,

$\tan \alpha = \alpha = h/PO$

$\tan \beta = \beta = h/PC$

$\tan \gamma = \gamma = h/PI$

By substituting the values of α, β and γ in the equation- 1, we get:

$2\, h/PC = h/PO + h/PI$

$2/PC = 1/PO + 1/PI$ .... (2)

To take the values with correct sign (direction), follow the sign conventions given below.

Sign convention for the parameters related to the mirror equation

1. All distances should be measured from the pole.
2. The distances measured in the direction of incident light, to be taken positive and those measured in the direction opposite to incident light to be taken negative.
3. Height of object (H_o) and height of image (H_i) are positive if measured upwards from the axis and negative if measured downwards.

Substitute the values of PC, PO and PI in equation 2 according to the sign convection.

Radius of curvature $PC = -R$

Object distance $PO = -u$

Image distance $PI = -v$

$2/-R = 1/-u + 1/-v$

$2/R = 1/u + 1/v$

We know that, radius of curvature(R) = 2 (focal length) = 2f

So,

$2/2f = 1/u + 1/v$

$1/f = 1/u + 1/v$

This mirror formula should be used according to the sign convention in every situation.

Now let us understand magnification, i.e. the relation between the size of the object and the size of the image.

Magnification (m)

The image formed by a spherical mirror varies in size, here we discuss the variation in height only.

Observe figure 34.

A ray coming from O^I is incident at pole with an angle of incidence θ, and get reflected with same angle θ.

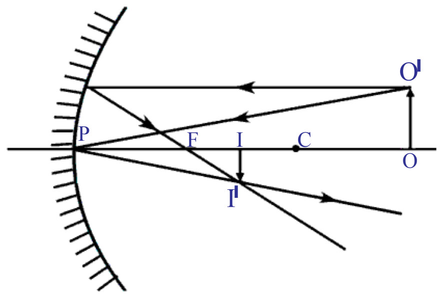


fig-34

From the triangle POO^I, $\tan\theta = OO^I/PO$ .....(1)

From the triangle PII^I, $\tan\theta = II^I/PI$ ....(2)

From 1 & 2 $OO^I/PO = II^I/PI$

⇨ $II^I/OO^I = PI/PO$ ....(3)

according to sign convention

$PO = -u$; $PI = -v$; $OO^I = h_0$; $II^I = -h_i$

Substuting the above values in equation (3).

$$-h_i / h_0 = -v/-u$$

$$\Rightarrow h_i / h_0 = -v/u$$

∴ Magnification **m** $= h_i / h_0 = -v/u$

We define the magnification,

m = height of image(h_i) /height of object (h_0)

In all cases it can be shown that

m = – image distance (v)/ object distance (u)

Calculate the magnifications with the information you have in table-2, for all the five cases.

Example

An object 4cm in size, is placed at 25cm infront of a concave mirror of focal length 15cm. At what distance from the mirror whould a screen be placed in order to obtain a sharp image?Find the nature and the size of the image.

Solution

Accordint to sign convention:

focal length (f) = –15cm

object distance (u) = –25cm

object height (h_o) = +4cm

image distance (v) = ?

image height (h_i) = ?

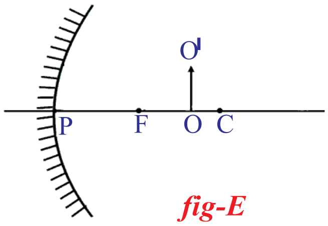


fig-E

Substitute teh above values in the equation

$1/f = 1/u + 1/v$

$1/–15 = 1/v + 1/–25$

$1/v = 1/25 – 1/15$

$1/v = – 2/75$

⇨ $v = –37.5cm$

So the screen should be placed at 37.5cm from the pole of the mirror. The image is real.

magnification $m = h_i / h_o = – v/u$

by substituting the above values $h_i/4 = –(–37.5) / (–25)$

$h_i = –(37.5 \times 4)/25$

$h_i = –6cm$

So, the image is inverted and enlarged.

We have learnt the phenomenon of reflection of light by curved mirrors. Let us make use of it in our daily life.

Making of solar cooker

You might have heard the story of **Archimedes** that he burned ships using mirrors.

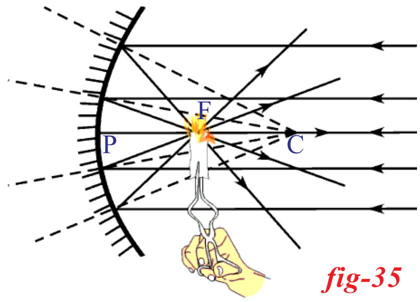


fig-35

Can we at least heat up a vessel using a mirror?

Let us try:

We already learnt that a concave mirror focuses parallel sun rays at the focal point of the mirror. So with a small concave mirror we can heat up and burn paper as shown in the figure-35. (Try this with convex mirror also. What do you observe?)

In the same way make a big concave mirror to heat up a vessel.

You might have observed the TV dish antenna. Make a wooden/ iron frame in in the shape of TV dish. Cut acrylic mirror sheets in to 8 or 12

fig-36

pieces in the shape of isosceles triangles with a height equal to the radius of your dish antenna. The bases of 8 or 12 triangles together make the circumference of the dish. Stick the triangle mirrors to the dish as shown in figure-36.

Your solar heater/cooker is ready.

Arrange it so that concave part faces sun. Find its focal point and place a vessel at that point. It will get heated. You can even cook rice in that vessel!

In practical applications (like in car-headlights), concave mirrors are of parabolic shape (see figure 37)

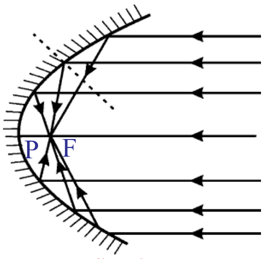


fig-37

Key words

angle of incidence, angle of reflection, normal, plane of reflection, lateral inversion, centre of curvature, radius of curvature, principal axis, pole, focus/focal point, focal length, object distance, image distance, virtual image, real image, magnification

What we have learnt

- **Fermat principle:** Light chooses the path which takes the least time to travel. It is also applicable to reflection of light.
- **Mirror formula:** $1/f = 1/u + 1/v$
- Magnification m = size of the image/ size of the object (or)
  m = – object distance/ image distance

Position of the candle (object)	Position of the image	Enlarged?/ diminished?	Inverted or erect	Real or virtual
Between mirror & F	Behind the mirror	Enlarged	Erect	Virtual
On focal point	At infinity	-	-	-
Between F and C	Beyond C	Enlarged	Inverted	Real
On centre of curvature	On C	Same size	Inverted	Real
Beyond C	Between F and C	Diminished	Inverted	Real

Improve your learning

1. State the laws of reflection of light. (AS1)
2. How do you find the focal length of a concave mirror? (AS1)
3. Where will the image form when we place an object, on the principal axis of a concave mirror at a point between focus and centre of curvature? (AS1)
4. Find the distance of the image when an object is placed on the principal axis at a distance of 10cm in front of a concave mirror whose radius of curvature is 8 cm. (AS1)
5. State the differences between convex and concave mirrors. (AS1)
6. Distinguish between real and virtual images. (AS1)
7. How do you get a virtual image using a concave mirror? (AS1)
8. What do you know about the terms given below related to spherical mirrors? (AS1)
   a) Pole b) Centre of curvature c) Focus
   d) Radius of curvature e) Focal length f) Principal axis
   g) Object distance h) Image distance i) Magnification
9. Write the rules for sign convention. (AS1)
10. The magnifaction produced by a plane mirror is +1. What does this mean? (AS1)
11. Imagine that spherical mirrors were not known to human beings. Guess the consequences. (AS2)
12. By observing steel vessels and different images in them; Surya, a third class student, asked his elder sister Vidya some questions. What may be those questions? (AS2)
13. How do you verify the 1st law of reflection of light with an experiment? (AS3)
14. How do you verify the 2nd law of reflection of light with an experiment? (AS3)
15. What do you infer from the experiment which you did with concave mirrors and measured the distance of object and distance of image? (AS3)
16. Find the plane of the reflection experimentally for the incident ray which passes through the heads of the pins pierced in front of the mirror. (AS3)
17. Collect information about the history of spherical mirrors in human civilization. Display it in your class room. (AS4)
18. Think about the objects which act as a concave or convex mirrors in your surroundings. Make a table and display it in your class room. (AS4)
19. How will our image be in concave and convex mirrors? Collect photographs and display in your class room. (AS4)
20. Draw and explain the process of formation of image with a pinhole camera? (AS5)
21. Draw suitable rays by which we can guess the position of the image formed by a concave mirror. (AS5)
22. Show the formation of image with a ray diagram when an object is placed on the principal axis of a concave mirror away from the centre of curvature. (AS5)
23. Make a solar heater/cooker and explain the process of making. (AS5)
24. To form the image on the object itself, how should we place the object in front of a concave mirror? Explain with a ray diagram. (AS5)
25. How do you appreaciate the role of spherical mirrors in daily life? (AS6)

26. How do you appreciate the use of reflection of light by a concave mirror in making of TV antenna dishes? (AS6)
27. Have you ever observed the image of the sky in rain water pools on earth? Explain the reflection of light in this context. (AS6)
28. Discuss the merits and demerits of using mirrors in building elevation. (AS7)
29. Why do we prefer a convex mirror as a rear-view mirror in the vehicles? (AS7)
30. A convex mirror with a radius of curvature of 3m is used as rear view in an automobile. If a bus is located at 5m from this mirror, find the position, nature and size of the imaze. (AS7)
31. An object is placed at a distance of 10cm from a convex mirror of focal length 15cm. Find the position and nature of the image. (AS7)

Fill in the blanks

1. The centre of sphere to which a sperical mirror belongs, is called ....
2. The geometric centre of the mirror is ....
3. The line which passes through the centre of curvature and pole is ....
4. The rays which are parallel to the principal axis of a concave mirror on reflection, meet at ....
5. The distance between pole and centre of curvature is ....
6. The distance between pole and focus is ....
7. The relation between focal length and radius of curvature is given by ....
8. The relation between the angle of incidence and angle of reflection is given by ....
9. Light selects the least time path to travel between two points. This principle was stated by ....
10. The equation of mirror formula is ....

Multiple choice questions

1. If an object is placed at C on the principal axis in front of a concave mirror, the position of the image is .... [ ]
   a) at infinity b) between F and C c) at C d) beyond C
2. We get a diminished image with a concave mirror when the object is placed .... [ ]
   a) at F b) between the pole and F c) at C d) beyond C
3. We get a virtual image in a concave mirror when the object is placed .... [ ]
   a) at F b) between the pole and F c) at C d) beyond C
4. Magnification m = ... [ ]
   a) v/u b) u/v c) h_o / h_i d) h_i / h_o
5. A ray which seems to be travelling through the focus of a convex mirror passes .... after reflection [ ]
   a) parallel to the axis b) along the same path in opposite direction
   c) through F d) through C