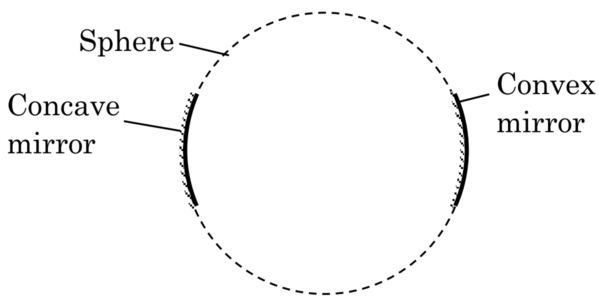
TOPIC: LIGHT
General Objective: The learner should be able to apply the principle of reflection to understand the behaviour of curved reflectors and use it in designing useful artifacts.

SUB-TOPIC: Reflection of light at curved surface

SPECIFIC OBJECTIVES
The learner should able to;
- Identify types of curved mirrors.
- Define the optical properties of curved mirrors.
- Draw a ray diagram to show the formation of caustic curve.
- Graphically construct ray diagrams on scale to form images using standard rays.
- Describe images formed by curved mirrors.
- Calculate linear magnification by curved mirrors.
- Carry out experiments to determine the focal length of a concave mirror.
- Describe some applications of curved mirror including parabolic mirrors.

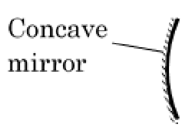
SPHERICAL MIRRORS/CURVED MIRRORS:

These mirrors are said to be spherical because each is part of a sphere

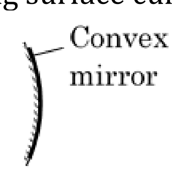


Curved reflecting surfaces are broadly classified as;
(a) Concave (converging) mirrors
(b) Convex (diverging) mirrors
(c) Parabolic mirrors.
They are categorized depending on their shapes.

(a) **Concave (converging) mirrors**
These are mirrors whose reflecting surface curves inwards.

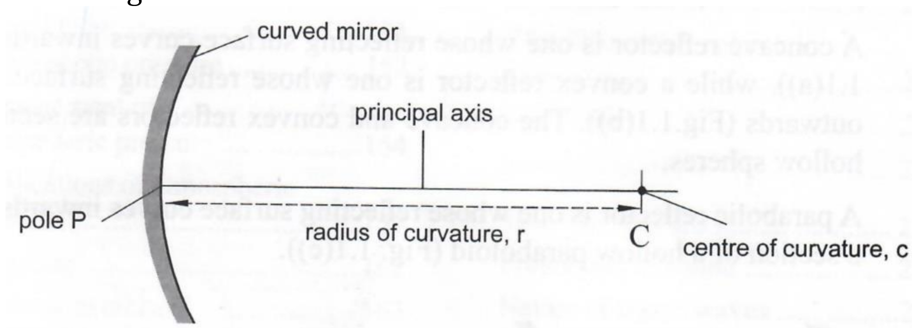


(b) Convex (diverging) mirrors
These are mirrors whose reflecting surface curves outwards.



TERMS USED IN CONCAVE AND CONVEX MIRRORS.

Imagine a parallel beam of light incident on each of such mirrors



P = pole
AB = aperture of the mirror
F = principal focus, F
CFP = principal axis
C = centre of curvature, C
FP = focal length. f
CP = radius of furniture, r

Definitions

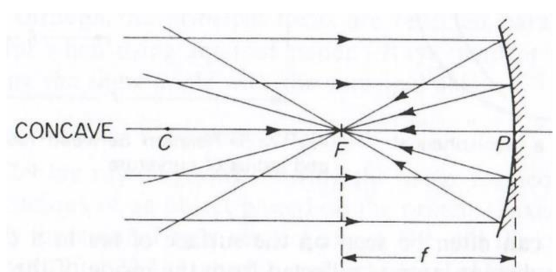
Pole, P
This is the central point of the curved mirror.

Centre of curvature, C
This is the centre of the sphere of which the mirror is part.

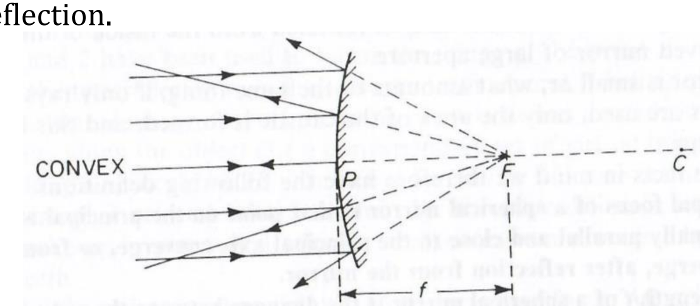
Principal axis
This is the line passing through the pole and centre of curvature.

Radius of curvature, r
This is the distance between the pole and centre of curvature.

Principal focus
For a **concave mirror** it is the point to which all rays originally parallel and close to the principal axis converge after reflection.



For a **convex mirror** it is the point from which all rays originally parallel and close to the principal axis **appear** to diverge after reflection.



In general, for a **curved mirror/ spherical mirror** it is the point to which all rays originally parallel and close to the principal axis converge after reflection or **appear** to diverge after reflection

Focal length, *f*
This is the distance between the pole and the principal focus.

Aperture of the mirror.
This is the length of the reflecting services of the mirror.

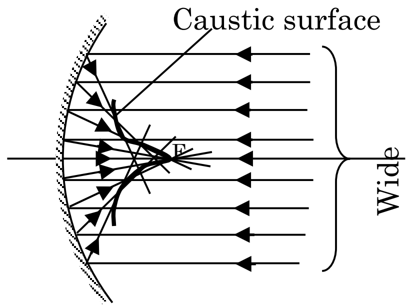
Relation between focal length and radius of curvature

$$\text{focal length} = \frac{\text{radius of curvature}}{2}$$

i.e. If f is the focal length and r the radius of curvature, then

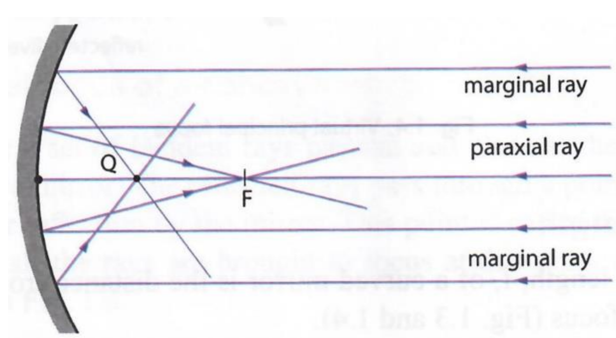
$$\mathbf{f = \frac{r}{2}}$$

Caustic surface/curve
When a wide beam of light parallel to the principal axis is incident on a concave mirror with a **wide aperture**, the reflected rays do not pass through a single point as a narrow beam does. The subsequent reflected rays meet at other point before the principal axis. The locus of such points forms a bright surface known as the **caustic surface/curve**.

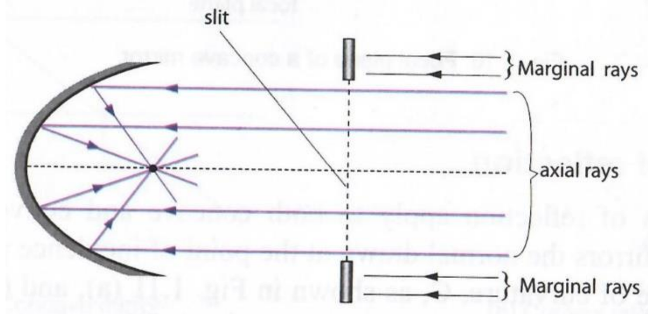


The formation of this caustic surface can be seen on the surface of a cup half full of tea, when light from one side is reflected on the tea by the curved surface of the curve. The reflected rays produce a curve of light instead of a sharp spot of light on the surface of the tea.

Causes of a caustic curve.
For a concave mirror, the incident rays parallel and close to the principle axis, called the **paraxial rays**, converge at the principal focus, F. However, the incident rays parallel but not close to the principle axis, called the marginal rays, are brought to focus at a different point say Q.
The incident ray between the paraxial and marginal rays will come focus between Q and F.



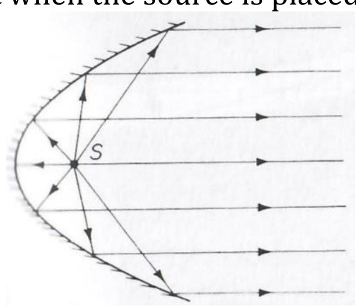
Correction.
This effect can be reduced by cutting off the marginal rays using a narrow slit. The slit should allow only paraxial rays, closer the principal axis.



It can also be corrected by using a **Parabolic reflector.**

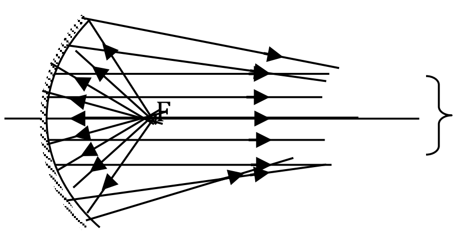
Parabolic reflector

This is a symmetrical concave reflector whose surface is parabolic.
It provides a wide parallel beam of light when the source is placed at its principal focus.



When a lamp/bulb is placed at the principle focus of a parabolic reflector, all rays from the lamp that strike the mirror at points close to and far from the principal axis will be reflected parallel to the principal axis. The intensity of the reflected beam remains undiminished as distance from the mirror increases. This accounts for the use of parabolic mirrors as search lights, headlamps of vehicles, reflector telescopes other than concave mirrors.

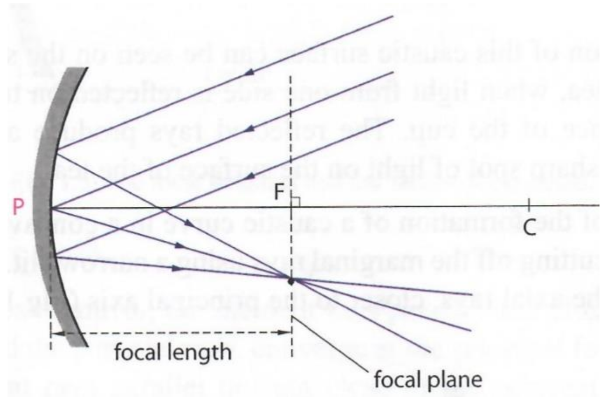
(ii) Spherical reflector e.g. concave reflector



Only a narrow beam is reflected parallel

When a lamp/bulb is placed at the principle focus of a parabolic reflector, only rays from the lamp that strike the mirror at points close to the principal axis will be reflected parallel to the principal axis and the rest will be reflected in different directions. The intensity of the reflected beam diminishes as distance from the mirror increases.

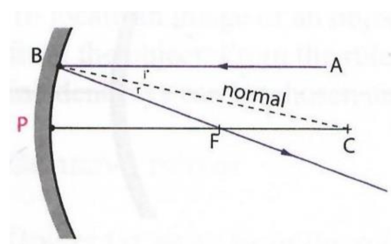
Focal plane
This is a plane which passes through the principal focus and is perpendicular to the principal axis.



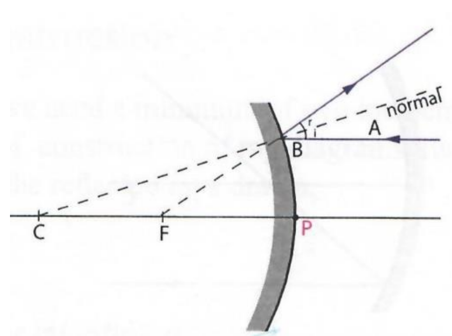
Laws of reflection in curved surfaces

The laws of reflection apply to both concave and convex mirrors. In curved mirrors the normal drawn at a point of incidence passes through the centre of curvature, C.

(a) In concave mirror



(b) In a convex mirror

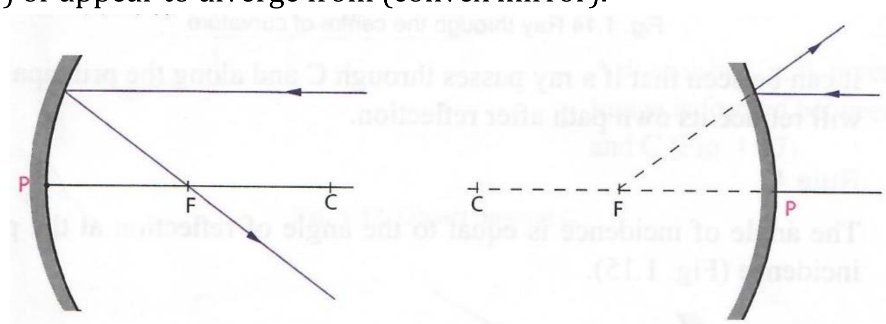


Images formed by curved mirrors

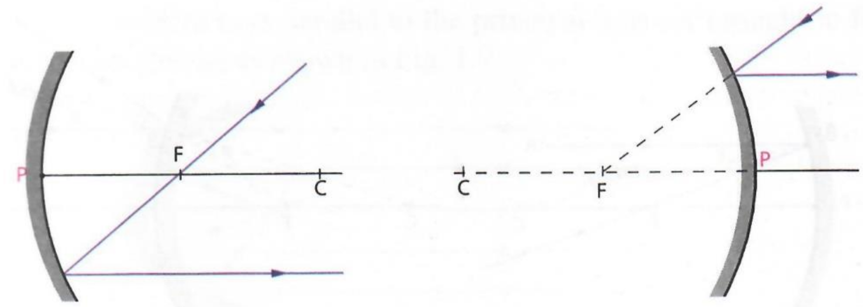
In a plane mirror, the image distance is always equal to the object distance. In curved mirrors, the image formed depends on the distance of the object from the mirror and the type of the mirror being used.

Ray diagrams are used to illustrate how and where the image is formed. The following standard rays will help in the construction of ray diagrams.

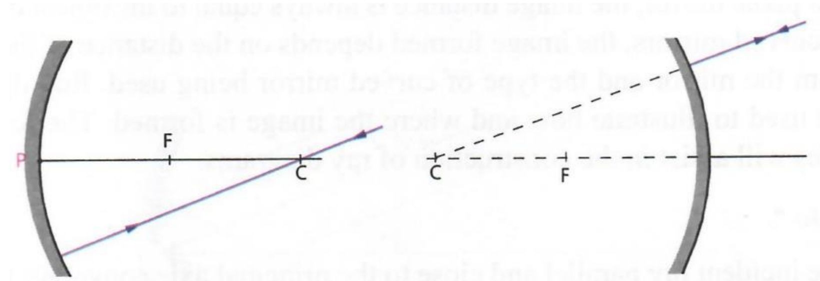
1. The incident rays parallel and close to the principal axis are reflected through the principal focus (concave mirror) or appear to diverge from (convex mirror).



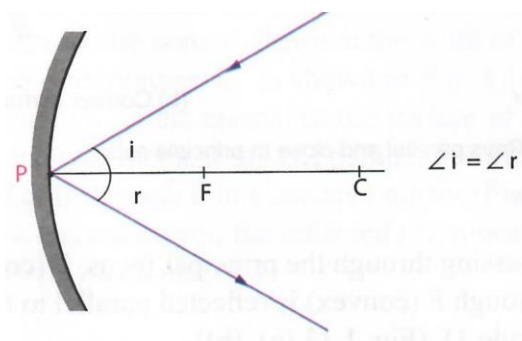
2. The incident ray passing through the principal focus, F (concave mirror) or appears to pass through F (convex) is reflected parallel to the principal axis. (converse of rule one).



3. A ray passing through the centre of curvature, C (concave) or appears to pass through the centre of curvature, C (convex mirror), is reflected back along its own path or it retraces its own path.



4. A ray incident at the pole is reflected at the same angle with the principal axis.



Terms used to describe images formed in Curved Mirrors

(i) Real - Formed by intersection of actual rays and can be obtained on screen.

(ii) Virtual - when not actual rays of light intersect after reflection

(iii) Inverted - Upside down

(iv) Diminished - Smaller than the object.

(v) Magnified - Bigger/larger than the object.

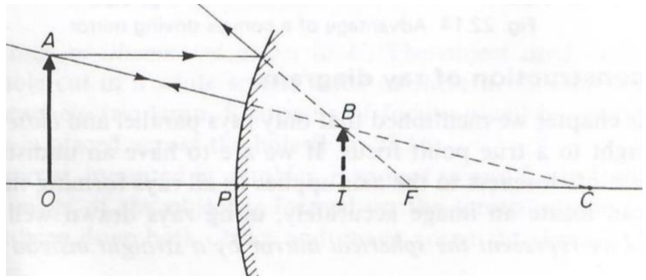
(vi) Erect - Upright

Locating images by construction.

To locate an image of an object we need a minimum of **two standard rays** from the object

Images formed by convex mirror.

The object is placed in front of the convex mirrors and at least two standard rays are used.



Whatever the position of the object, the image is:

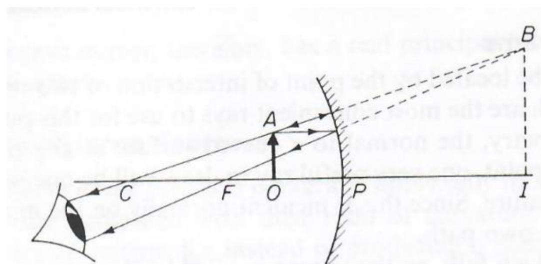
(i) between P and F

(ii) virtual

(iii) erect

(iv) diminished

Images formed by concave mirror.
Object placed between F and P



The image is:

(i) behind the mirror

(ii) virtual

(iii) erect

(iv) magnified

Object placed at F.

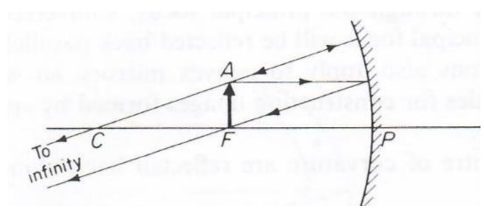
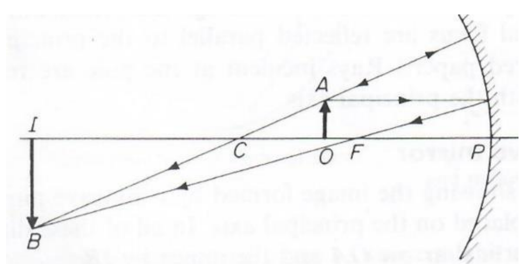


Image is at infinity

Object placed between F and C.



The image is:

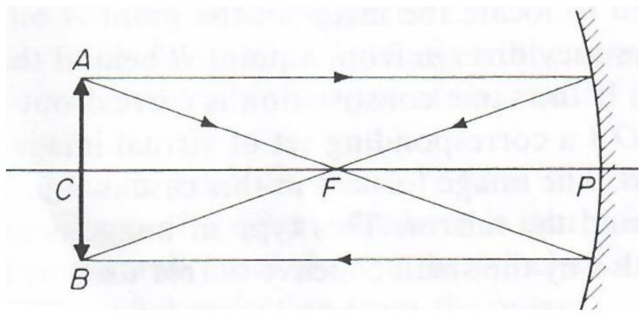
(i) beyond C

(ii) real

(iii) inverted

(iv) magnified

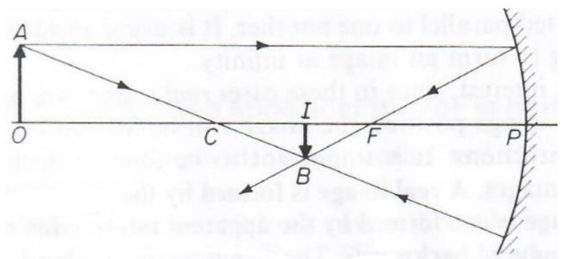
Object placed at C



The image is:

(i) at C
(ii) real
(iii) inverted
(iv) same size as object

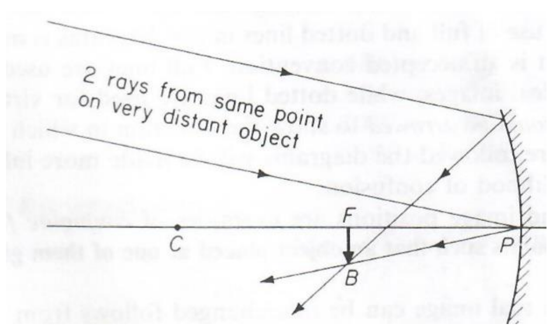
Object beyond C.



The image is

(i) between C and F
(ii) real
(iii) inverted
(iv) diminished

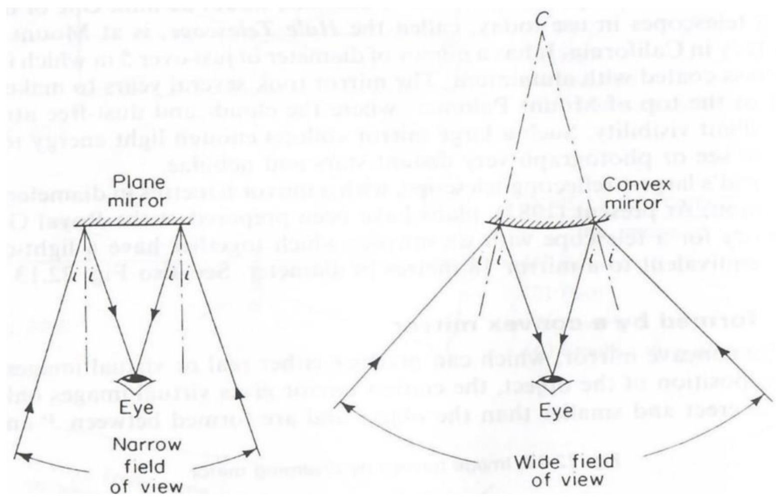
Object at infinity.



The image is

(i) at F
(ii) real
(iii) inverted
(iv) diminished

Compared to a plane mirror, a convex mirror of the same aperture has a **wider field of view**. See illustrations below. Because of this advantage and the characteristics of the images (upright and diminished) formed by a convex mirror, it is widely used as a driving aid on vehicles.



Graphical/accurate construction of ray diagrams on scale to form images using standard rays.
An image can be located accurately using rays drawn well away from the axis, provided the spherical mirror is represented by **a straight line** instead of **a curved line**.
The construction is best done on a squared paper using a suitable scale, for example; 1 cm represents 2cm, 5cm etc.

Examples

1. An object 3cm high is placed at right angles to principal axis of a concave mirror with focal length 7.5cm. If the object is 30cm from the pole, construct a ray diagram to obtain the position size and nature of image (use a scale 1cm : 3cm)

2. An object 4cm high is placed 2.4cm from concave mirror of focal length 8cm. Draw a ray diagram to find the position size and nature of image. Scale 1cm = 2cm

3. An object of height 10cm is placed at a distance 60cm from a convex mirror of focal length 20cm. by scale drawing, find the image position, height, nature and magnification (scale 1cm : 5cm)

4. A concave mirror has a focal length of 3.0cm and an object 1.0 cm tall is placed at 4.0cm from the pole of the mirror. By means of an accurate scale diagram, find the position of the image.

5. By means of an accurate graphical construction, determine the position, size and nature of the image of an object 5 cm tall, standing on the principal axis of a concave mirror of focal length 20 cm and 30 from the mirror.

6. An object 1cm tall is placed 30cm in front of a convex mirror of focal length 20cm so that it is perpendicular to, and has one end resting on the axis of the mirror. Find the size and the position of the image formed by the mirror.

7. A concave spherical mirror of radius of curvature 20cm forms an erect image 30cm from the mirror and 5cm high. Find the position and size of the object and show with a scale diagram how the image is formed.

8. An object 2cm long is placed 40cm in front of a concave mirror of focal length 15cm. find by means of a ray diagram, drawn to suitable scales, the size and position of the image.

9. An object is placed on the axis of a converging mirror of focal length 20cm. The image produced is inverted and has a magnification of 1.5. by scale drawing on graph paper determine the position of the object.

10. An object 4cm tall is placed 4cm in front of a concave mirror of focal length 12cm. By graphical construction, find the position and nature of the image formed. (5 marks)

11. An object 3 cm high is placed 15 cm in front of a concave mirror of focal length 10 cm. By graphical construction find the
    (i) image distance
    (ii) magnification

12. An object 2 cm high is placed 10 cm in front of a converging mirror of focal length 15 cm. By graphical construction find the magnification produced.

13. When an object is placed 20 cm in front of a converging mirror, a real image of the object is formed 60 cm from the mirror. Determine the magnification, and by graphical construction find the focal length of the mirror.

14. An object 5 cm high is placed 20 cm in front of a convex mirror of focal length 15 cm. By graphical construction find the
    (i) image distance
    (ii) magnification

MAGNIFICATION (LINEAR MAGNIFICATION)
This is the ratio of the height of the image to the height of the object.

It tells us the number of times an image is bigger than the object.

$$Linear\ magnification = \frac{height\ of\ the\ image}{height\ of\ the\ object}$$

$$M = \frac{h_I}{h_o}$$

Sometimes it becomes difficult to measure the height of the image or the object accurately. In such cases, magnification can be calculated in terms object distance, u and image distance, v.

$$Linear\ magnification = \frac{distance\ of\ the\ image}{distance\ of\ the\ object}$$

$$M = \frac{v}{u}$$

In summary;

$$\frac{h_I}{h_o} = \frac{v}{u}$$

Sign Convention
Real-is-Positive Convention
1. All distances are measured from the mirror as the origin.
2. Distances of real objects and images are positive.
3. Distances of virtual objects and images are negative.
4. Focal length, *f*, for concave mirror is positive and negative for convex mirror.

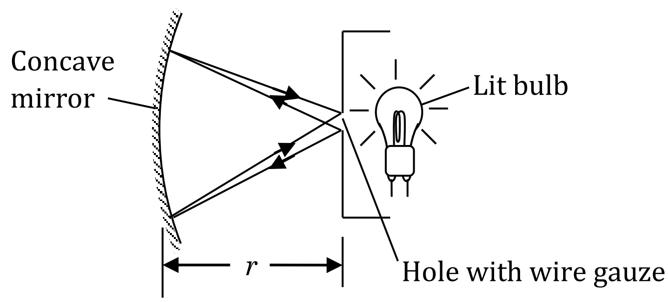
Examples

1. An object of height 2cm is placed 25cm in front of a concave mirror. A real image is formed 75cm from the mirror. Calculate the height of the image formed. (Ans = 6cm)

2. An object 40cm from a concave mirror produces a magnification of 1. Calculate the focal length of the mirror. (ans = 20cm)

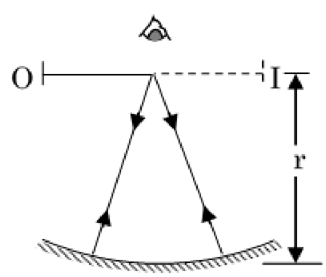
An experiment to determine the radius of Curvature (and Focal Length) of a Concave Mirror

(a) Using an illuminated object:



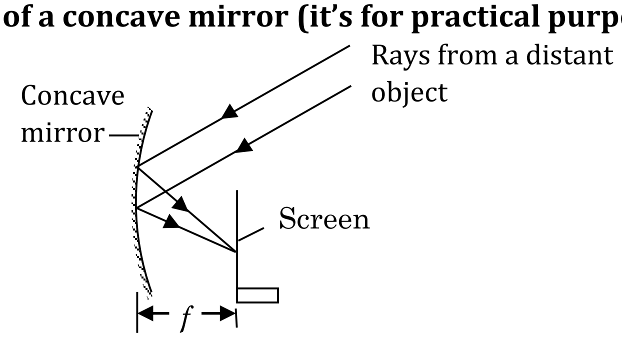
The concave mirror is placed facing the wire gauze fixed in a hole in a white screen.
The gauze is illuminated from behind.
The mirror is moved to and fro in front of the screen until a sharp image of the gauze is formed on the screen adjacent to the object.
The distance between the pole and the screen is measured. It is equal to the radius of curvature, **r**.
The focal length, **f** can be calculated from $f = \frac{r}{2}$.

(b) By method of no parallax



The mirror is placed on a bench, facing up.
A horizontal pin, **O** is held above the mirror with its tip on the axis of the mirror.
The pin, **O** is moved up or down until it coincides in position with its image, **I**.
The distance between the pin and the pole is measured and it is equal to the radius of curvature, **r**.
The focal length, **f** can be calculated from $\boldsymbol{f} = \frac{\boldsymbol{r}}{\boldsymbol{2}}$.

Estimation method for focal length of a concave mirror (it's for practical purposes mainly)



A sharp image of a distant object is focused on to a screen. The distance between the pole and the screen is measured and it is equal to the focal length.

Applications of Curved Mirrors
Curved mirrors are applied in various fields depending on the type of the mirror.

(a) Convex Mirror
Convex mirrors are used in:
(i) Locomotives as driving mirrors for seeing traffic behind.
(ii) They are used to observe the activities of customers in super markets.
(iii) They are used at securities.
(iv) They can be used as street light reflectors because they can spread the light over a bigger area

They are preferred to plane mirrors and concave mirrors for this purpose because of the following advantages.
- They form erect image.
- They have wider field of view.

However, despite the above advantages they have one disadvantage, that they do not give the correct distance of the vehicle behind as the image distance (v) is smaller than the object distance (u).

(b) **Concave Mirrors**
Concave mirrors are used as:

(i) **Cinema projectors.**
A concave mirror is placed behind a source of light. The light rays travelling in the backward direction which would, otherwise, have been lost, get reflected from the mirror and increase the intensity of light reaching the film or a transparent slide to be projected on a screen.

(ii) **Doctors**
Doctors who examine the ear, nose and throat of persons (ENT specialists) use a concave mirror fitted with a bulb at its principal focus. Light from the bulb is made to fall upon the concave mirror and the reflected light, as a narrow sharp beam, incident upon the area to be examined.

Doctor's ophthalmoscope also uses the same principle as above. The reflected light is directed into the 'pupil' of the patient's eye to be examined.

(iii) **Parabolic mirrors.**
Concave parabolic mirrors are used in search lights where a powerful luminous source of light is placed at the principal focus of the mirror. The reflected rays form a parallel beam of light and travel a long distance.
Car headlights, head lamps, or hand torch light (or flash light) use the same principle.

(iv) **Astronomical telescopes**
One of the important uses of concave mirrors is in the construction of large astronomical telescopes used to examine heavenly bodies like the stars. A big concave mirror of diameter of about 5m or more collects light rays from a star and forms the image at its principal focus. Distant stars which cannot be seen with unaided eye become clearly visible through the telescope.

(v) **Parabolic dish collectors**

Parabolic dish collectors called solar concentrators use large parabolic mirrors to concentrate the sun's rays on to a small area at their focus to produce very high temperatures.

Dentist's mirror.

(v) **Parabolic dish aerials**
In communication, parabolic dish aerial is used. By suitable arrangement radio waves are reflected as unidirectional parallel waves.

(vi) **Shaving mirror**
A concave mirror is used as a shaving or a make-up mirror. The mirror is placed at a distance less than its focal length, from the face. A virtual upright, magnified image of the face is seen in the mirror.

Attempt the revision exercise 1 on pages 21-24

Exercise

1. A concave mirror can be used as a shaving mirror because when an object is placed between the focus and the pole, the image formed is,
   A. magnified, virtual and erect
   B. magnified, real and inverted
   C. diminished, real and inverted
   D. diminished, virtual and erect

2. Which of the following information is true about the concave and convex mirrors?

	Concave mirror	**Convex mirror**
A	Converges light	Diverges light
B	Diverges light	Converges light
C	Refracts light	Reflects light
D	Has a wide field of view	Has a narrow field of view

3. The focal length of a concave mirror is the
   A. distance between the pole of the mirror and the focal point
   B. distance between the center of curvature and the mirror
   C. distance between the object and the image
   D. diameter of the mirror

4. (a) With the aid of the diagram explain why a parabolic mirror is most suitable for use in car head lights.
   (b) List three uses of a concave mirror.

5. (a) Draw a ray diagram to show the formation of an image of an object O placed in front of a convex mirror shown in the figure below. F is the principal focus of the mirror.
   (b) A convex mirror whose radius of curvature is 30 cm forms an image of a real object which has been 20 cm from the mirror.
   Calculate:
   (i) The position of the image
   (ii) The magnification produced.
   (c) Give reasons for use of convex mirrors in vehicles.