convex (diverging) mirror is negative (-ve).

## 30.6 Applications of Curved Mirrors

1. **Convex mirrors:** These have been the most useful of all the curved mirrors available in many ways, e.g.

(a) **Car driving mirrors:** These are used as car driving mirrors because they form upright images and also give wider field of view.

(b) **Super market security mirrors:** These enable the security men in the supermarket to monitor movement of people in the supermarket, because they give wide field of view of every thing and place in the supermarket.

2. **Concave mirrors:** Concave mirrors are used as:

(i) Shaving mirror

(ii) Dentist mirror

## 30.7 Parabolic Mirrors

Parabolic mirrors reflect rays parallel in all parts of their surface when a small lamp is on their focus, so that the beam deflected can go a long distance with its strength.

Parabolic mirrors are used in most case as:

(i) Search light (ii) Head lamp because they produce parallel beams of light to the same focus.

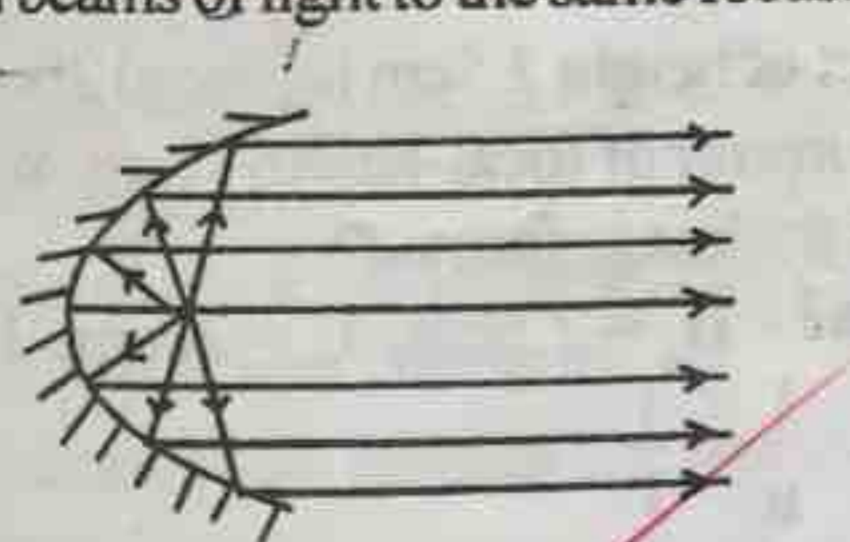

**Fig. 30.11 Parabolic mirrors**

## 30.8 Linear Magnification

Linear magnification is defined as the ratio of the image height to the object height or the ratio of the image distance to the object distance.

It has no unit. It can be mathematically expressed as:

$$M = \frac{\text{height of image}}{\text{height of object}} = \frac{\text{distance of image}}{\text{distance of object}}$$

$$M = \frac{H_1}{H_o} = \frac{V}{U}$$

Magnification can be found by drawing to scale

## 30.9 Mirror Formulae

When object at a distance U from a curved mirror, either concave or convex, of focal length $F_1$, radius of curvature r, and an image at a distance V are formed from the mirror, the general formula for mirror is represented by,

$$\frac{1}{V} + \frac{1}{U} = \frac{1}{F} \quad \text{....................(1)}$$

Where V = image distance

U = object distance

F = focal length, $F = \frac{r}{2}$ $\therefore$ $r = 2f$

$$\frac{1}{V} + \frac{1}{U} = \frac{2}{r} \quad \text{...............(2)}$$

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

multiplying throughout by V

$$\frac{1}{V}\cdot V + \frac{1}{u}\cdot V = \frac{1}{f}\cdot V$$

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

$$1 + m = \frac{V}{F}$$

$$m = \frac{V}{F} - 1 \quad \text{.................(3)}$$

$F = {}^{r}/2$

$$m = \frac{V}{{}^{r}/_{2}} - 1 = \frac{2V}{r} - 1 \quad \text{................. (4)}$$

### *Worked example 30.1*

A real image twice the size of an object is formed by a concave mirror. When the mirror and the object were shifted, the image formed becomes 4 times the size of the object. Find the focal length of the mirror if the image were to be shifted by 24cm.

***Solution***

$$2 = \frac{V}{f} - 1 \text{ .......... (i)}$$

$$4 = \frac{V+24}{f} - 1 \text{ .......... (ii)}$$

From (i) $F = \frac{V}{3}$

similarly, from (ii) $F = \frac{V+24}{5}$

equating equations (i) and (ii)

$$\frac{V+24}{5} = \frac{V}{3}$$

$$5V = 3V + 72$$

$$2V = 72$$

$$V = \frac{72}{2} = 36\text{cm}$$

$$F = \frac{V}{3} = \frac{36}{3} = 12\text{cm}$$

OR

$$F = \frac{V + 24}{5}$$

$$= \frac{36+25}{5}$$

$$= \frac{60}{5} = 12\text{cm}$$

***Worked example 30.2***

A concave mirror of radius of curvature 30cm produced an inverted image 4 times the size of an object placed perpendicular to the axis. Determine the position of the object and the image.

***Solution***

$r = 30\text{cm},\ U = x,\ V = 4x$

$$F = \frac{r}{2} = \frac{30}{2} = 15\text{cm}$$

$$m = \frac{V}{F} - 1$$

$$4 = \frac{4x}{15} - 1$$

$$4 + 1 = \frac{4x}{15}$$

$$5 = \frac{4x}{15}$$

$$V = 4x = 5 \times 15 = 75\text{cm}$$

$$x = \frac{75}{4}$$

$$= 18\tfrac{3}{4}\text{cm}$$

***Worked example 30.3***

An object, 40cm long is placed in front of a concave mirror of focal length, 15cm so that it is perpendicular to and has one end resting on the axis mirror. Calculate the linear position of the image and its linear magnification.

***Solution:***

$F = 15\text{cm}$

$U = 40\text{cm}$

using $\frac{1}{V} + \frac{1}{u} = \frac{1}{f}$

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

$$\frac{1}{V} = \frac{1}{15} - \frac{1}{40} = \frac{40 - 15}{600} = \frac{25}{600}$$

$$\therefore V = \frac{600}{25} = 24\text{cm}$$

$$m = \frac{V}{u} = \frac{24}{40}$$

$$m = \tfrac{3}{5} = 0.6$$

***Worked example 30.4***

An object of height 2.5cm is placed 20cm from a concave mirror of focal-length 10cm. What is the height of the image formed?

***Solution:*** $H_o = 2.5\text{cm},\ U = 20\text{cm},\ F = 10\text{cm}$

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

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

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

$$v = 20\text{cm}$$

$$m = \frac{V}{U} = \frac{H_1}{H_o} \Rightarrow \frac{20}{20} = \frac{H_1}{2.5}$$

$$\therefore H_1 = 2.5\text{cm}$$

*Worked example 30.5*

A convex mirror of focal-length 15cm produces an image on its axis 5cm away from the mirror. Find the position of the object.

*Solution:* F = - 15cm, V = - 5cm, U = ?

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

$$\therefore \frac{1}{u} - \frac{1}{5} = -\frac{1}{15}$$

$$\frac{1}{u} = \frac{1}{5} - \frac{1}{15} = \frac{2}{15}$$

$$u = 7.5cm$$

**Revision exercise**

1. Name two types of mirrors and differentiate between them.
2. Explain the following terms: (i) Pole (ii) Focal length (iii) Radius of curvature (iv) Centre of curvature (v) Principal aims.
3. Draw a ray diagram not necessarily up to scale to show how an image is formed on a concave mirror.
4. Draw a ray diagram showing how a convex mirror and parabolic mirror form their images.
5. Name five uses of plane mirrors and the uses of concave and convex mirrors respectively.
6. Draw a ray diagram to show the image formed in a concave mirror when the position of the object is:
(i) far beyond the center of curvature
(ii) at the curvature
(iii) between the curvature and the focus
(iv) on the focus
(v) between the focus point and the pole
(vi) just beyond the curvature.
The diagram must include the characteristics of the images formed.
7. Give the distinction between plane, concave and convex mirrors. Also give three differences between real and virtual images and how they are formed.
8. Draw a ray diagram to show how (i) convex mirror (ii) parabolic mirror form their images.
9(a) Describe an experiment to show how the focal length of a concave mirror can be formed with graph inclusive (b) If the radius of curvature of a mirror is 15m and the distance of the object from the mirror is 10m, find the distance of the image from the mirror and the magnification of the object in metre(M).
10. Explain with the aid of diagrams, how a concave mirror could be used to (i) ignite a piece of carbon paper (ii) produce an exact copy of a picture on a screen. [SSCE, June 1992.]
11. With the aid of a ray diagram, show how a virtual image of an object is formed by a (i) concave mirror (ii) converging lens.
12. Define the following as they apply to a convex mirror: (i) Principal focus (ii) pole (iii) radius of curvature (b) State one advantage and one disadvantage of using a convex mirror as a driving mirror.
(c) Draw a clearly labelled diagram to illustrate how two converging lenses may be arranged to form a compound microscope.
(d) An object, 2.5mm long is viewed through a converging lens of focal length, 10.0cm, held close to the eye. A magnified image of the object is formed, 30cm from the lens. Calculate the (i). distance of the object from the lens (ii) size of the image (iii) power of the lens. [WASSCE, June 2002]
13. A concave mirror of radius of curvature, 20cm has a pin placed at 15cm from its pole. What will be the magnification of the image formed? [SSCE, Nov. 1990]
14. An object is placed in front of a concave mirror whose radius of curvature is 12cm. If the height of the real image formed is three-times that of the object, calculate the distance of the object from the mirror [SSCE, Nov. 1998]
15. The image of an object is located 6cm behind a convex mirror. If its magnification is 0.6, calculate the focal length of the mirror. [WASSCE, June 1998]
16. An object, 15cm is placed in front of a concave mirror of focal length 20cm. Calculate the position of the image from the mirror. [NECO, 2001]

# 31. REFRACTION ON PLANE SURFACES

## 31.1 Refraction

Refraction is defined as the property of a change in the direction of light, when it passes from one medium to another. In the process of refraction, the direction to which the ray of light follows changes as well as the velocity, but the frequency remains the same along the line of propagation. The wavelength of the transmission also changes.

## 31.2 Laws of Refraction

Two laws are associated with refraction.
The first law of refraction states that, the incident ray, normal at the point of incidence, and the refracted ray all lie in the same plane.

The second law states that, the ratio of sine of the angle of incidence to the sine of the angle of refraction is constant for all rays passing from one medium to another.

The two laws of refraction were postulated by a physicist called Snell. Snell's first law of refraction is given as, $\frac{\text{Sin}\, \iota}{\text{Sin}\, r} = \text{a constant} = N$

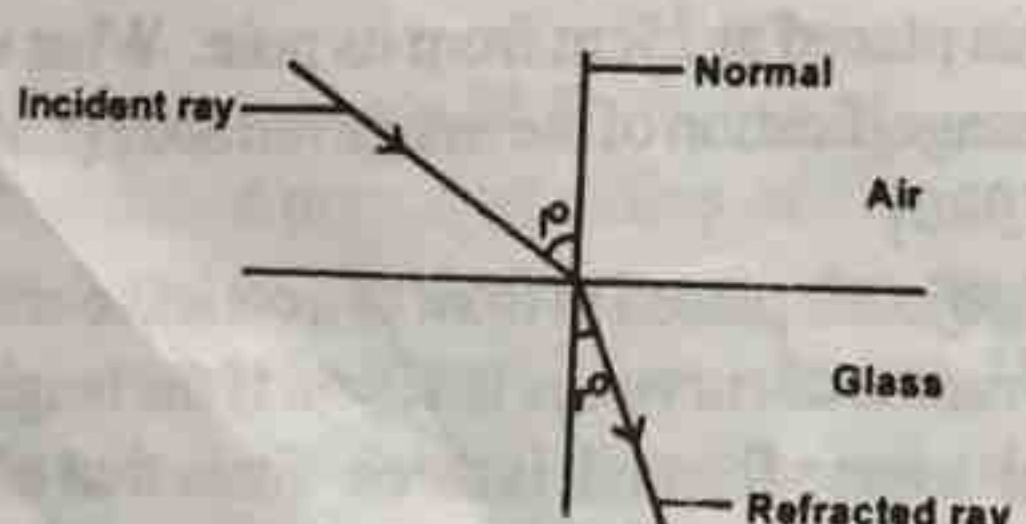


Fig. 31.1 Laws of refraction

## 31.3 Terms Associated with Refraction

**(i) The incident ray:** This is the direction of rays of the light from the source to the first medium.
**(ii) The refracted ray:** This is the direction to which the light travels from the point of incidence to the second medium which is always denser than the first medium.
**(iii) The angle of incidence:** This is the angle at which the incident ray mixes with the normal in the first medium.
**(iv) The angle of refraction:** This is the angle at which the refracted ray mixes with the normal in the second medium.

## 31.4 Experimental Proof of Refraction (Snell's Law)

**Aim:** To determine the constant
**Apparatus:** Pins, glass block, cardboard, table and a protractor.

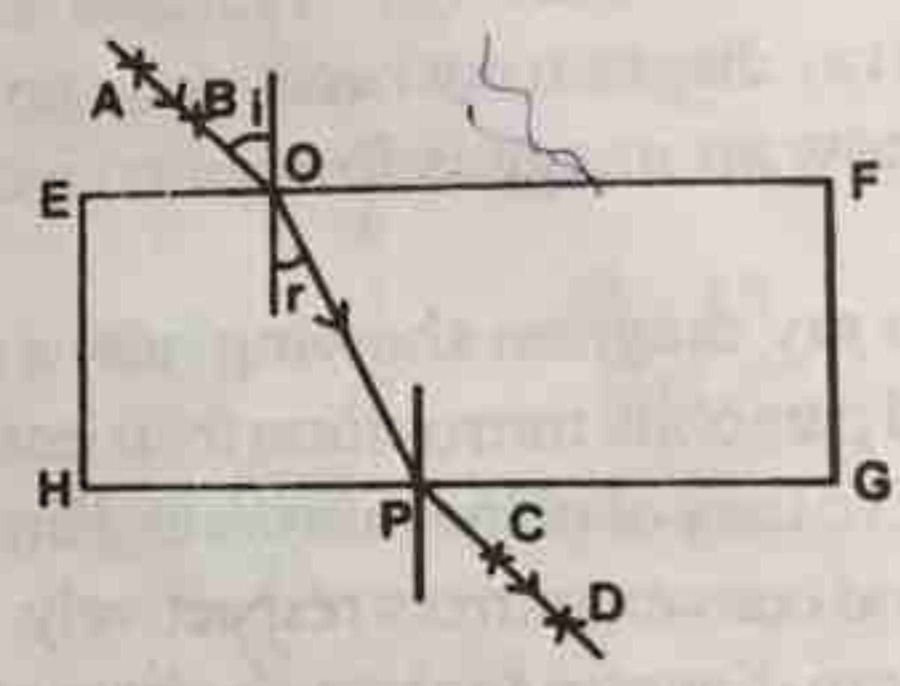


Fig. 31.2 Experiment to show Snell's law

**Method:** Two or more pins are fixed on a cardboard placed on a table in front of a glass block. Those pins are made to stand erect and on the same line. Search pins behind the prism are used to locate the incident pins. The moment those pins are located, the search pins are placed on the point of refraction behind the prism. The angle at which the incident pins meet with the normal is calculated using a protractor. The angle of refraction is also calculated.

According to the definition, the constant is determined by $\frac{\sin i}{\sin r} = n$
The medium through which the experiment is carried out is considered and the medium is air to glass. This is put at the base of the constant.

$\frac{\sin i}{\sin r} = {}_a\mu_g$ (i.e, air medium to glass medium)

**Conclusion:** Sin $i$ to sin $r$ is a constant for a particular medium. Different experiments were carried out with different incident angles, resulting in different angles of refractions.

Plotting the graph of sin $i$ to sin r, a straight line graph is obtained. The gradient is equal to refractive index μ.

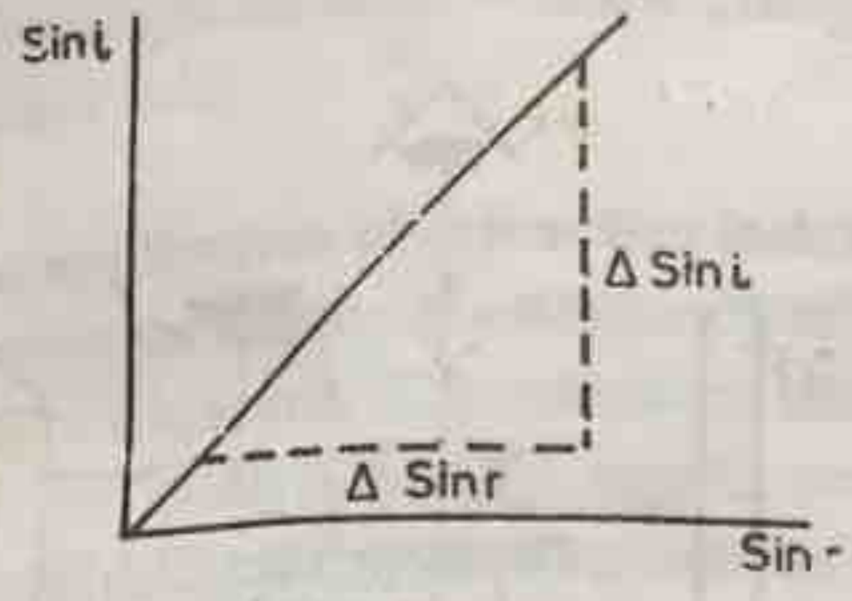


**Fig. 31.3 Graph of Snell's law**

## 31.5 Refractive Index from a Denser Medium to a Less Dense Medium

If refraction occurs from a dense medium to a less dense medium, e.g. glass to air, the refractive index μ is equal to

$$\mu \equiv {}_g\mu_a = \frac{1}{{}_a\mu_g}$$

If it is from water to air,

$$\mu \equiv {}_w\mu_a = \frac{1}{a\mu w}$$

A ray of light could be produced from a denser medium to a less dense medium or from a less dense medium to a denser medium. The refractive index from glass to water is given below

$${}_g\mu_w = \frac{1}{w\mu g}$$

## 31.6 Refractive Index [μ]

Refractive index is a constant used to express the nature of medium through which light ray is propagated. The refractive index determines the extent of permeability at which ray travels through a medium. The ratio of sin $i$ to sin r which is equal to a constant is known as the *refractive index μ*. This can also be defined as the nature of the material which a medium is made of. Sometimes it is defined in relation to the extent at which a medium allows light ray to pass through it.

Refractive index can be determined mathematically by bringing into consideration the various factors that change, i.e, wavelength μ, velocity V, and the direction during the process of refraction.

Mathematically, refractive index is denoted by μ and is given as:

$$\mu = \frac{\sin i}{\sin r} \text{ ----------(1)}$$

$$\mu = \frac{VA}{VB} = \frac{\lambda A}{\lambda B} = \frac{\text{velocity of A}}{\text{velocity of B}} = \frac{\text{wavelength A}}{\text{wavelength B}}$$

$$\mu = \frac{\text{Real depth}}{\text{Apparent depth}} \text{ ............ (3)}$$

***Worked example 31.1***

A ray of light is incidented in water at an angle of 20°, from water to glass plane surface. Calculate the angle of refraction in the glass ${}_a\mu_g = 1.5$ ${}_a\mu_w = 1.33 = 4/3$.

**Solution**

$${}_g\mu_w = \frac{a\mu w}{g\mu a}$$

$$g\mu a = \frac{1}{a\mu g} = \frac{1}{1.5} = \frac{2}{3}$$

$${}_g\mu_w = \frac{4/3}{2/3} = \frac{8}{9} = 0.8889$$

$$w\mu g = \frac{\sin i}{\sin r} = \frac{\sin 20^\circ}{\sin r}$$

$$0.8889 = \frac{\sin 20}{\sin r}$$

$$0.8889 \times \sin r = \sin 20$$

$$\sin r = \frac{\sin 20}{0.8889} = \frac{0.3420}{0.8889}$$

$$r = \sin^{-1}(0.3847)$$

$$r = 22.62$$

$$r \simeq 23^\circ$$