5 LIGHT

What we have already learnt

- A ray of light is a straight line which represents the path of travelling light. A collection of light rays is called a beam of light.
- A ray of light that falls on a surface is called incident ray.
- The light that is sent back by the reflecting surface is called reflection.
- The ray that is sent back by the reflecting surface is called the reflected ray.
- The angle between the normal and the incident ray is called the angle of incidence.
- The angle between the normal and the reflected ray is called the angle of reflection.
- Refraction is the deviation in the path of a ray of light occurring at the dividing plane between two media when it travels obliquely from one medium to another of different optical density.
- Laws of reflection at a plane mirror.
- The phenomena of dispersion and scattering of light.
- Lenses and the phenomena related to them.

Though light appears to be a very simple and commonplace phenomenon, it is a form of energy having a lot of peculiarities. You have learnt the different phenomena of reflection, refraction, dispersion and scattering and the interesting experiences they create. You know about the reflection of light on plane mirror and its refraction through transparent media. These phenomena can happen also on spherical surfaces. This chapter helps you to learn the fundamental laws about the formation of images of objects under such circumstances.

5.01 Spherical mirrors

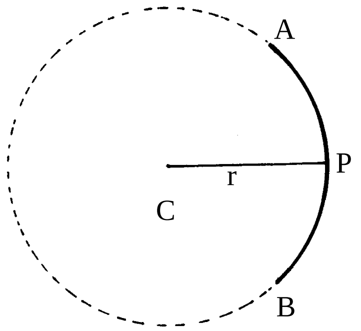

figure 5.1
Spherical surface

As shown in the figure, if the part AB is detached from a hollow sphere with centre C and radius **r** and polished or silver coated in such a way as to reflect the light falling on any side of it, it becomes a spherical mirror.

If the innerside of AB is polished to reflect light it becomes a concave mirror and if the outerside of AB is polished to reflect light, it becomes a convex mirror.

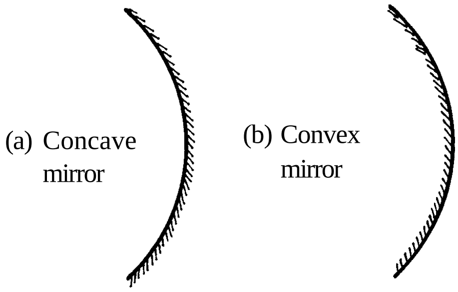

figure 5.2

Have you noticed the mirrors used in motor vehicles by drivers to see the vehicles coming from behind? Can you say what kind of mirrors they are?

Convex, concave and plane mirrors are available in your laboratories. Observe them and note down their peculiarities.

- Common mirror is plane.
- The plane mirror forms an image of the same size as the object.
- The surfaces of convex or concave mirrors are spherical.
-

5.02 Some technical terms relating to spherical mirrors

- **Centre of curvature**
  Centre of curvature is the centre of the sphere of which the spherical mirror is a part. (It is indicated as C in fig 5.3)
- **Pole**
  Pole is the geometric centre of the reflecting surface (It is indicated as P in figure 5.3)
- **Radius of curvature**
  Radius of curvature is the radius of the

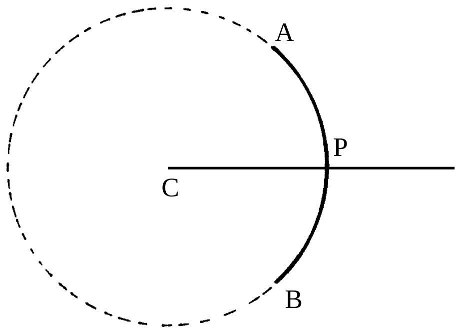

figure 5.3
Centre of curvature (C) and pole (P) of a spherrical mirror

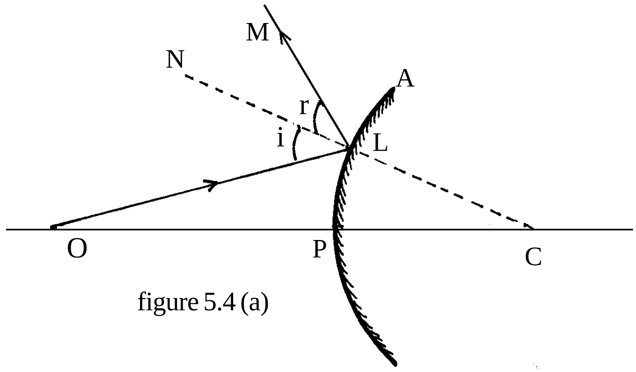

figure 5.4 (a)

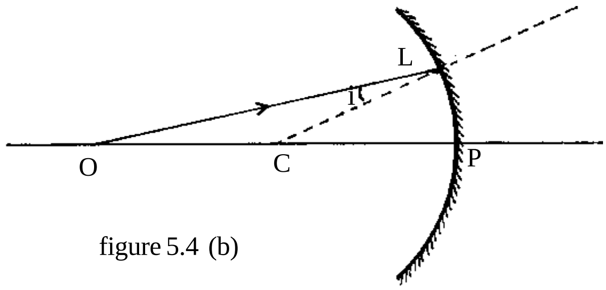

figure 5.4 (b)

Incident rays and angles of incidence in concave and convex mirror.

sphere of which the spherical mirror is a part (It is the length PC in the figure5.3).

- **Principal axis**

  Principal axis is the straight line passing through the centre of curvature and the pole. (It is a line passing through P and C as shown in figure5.3).

- **Aperture**

  Aperture is the diameter of the reflecting surface. When the diameter increases aperture also increases.

5.03 Reflection due to a spherical mirror

The laws of reflection of a plane mirror are applicable to a spherical mirror also. Recall the laws of reflection at the plane mirror and note them down in your science diary.

In the figure 5.4(a) it is shown that a ray of light OL starting from the point O on the principal axis and incident on the mirror is reflected in the direction LM.

You have already learnt that a line drawn from the centre of a circle to its circumference is perpendicular to the surface.

If so,

- How can you find out the normal to the mirror at the point of incidence L?
- Which is the angle of incidence?
- Which is the angle of reflection?
- What is the relationship between angle of incidence and angle of reflection?

Draw the reflecting ray and complete the fig 5.4(b) in the same manner.

5.04 Principal focus and focal length

Using a plane mirror, sunlight is made to fall on the concave mirror of small aperture fixed to a stand. Place a screen in front of the concave mirror without obstructing the incident rays. Adjust the screen in such a way that the light rays converge to a single point. This point is the focus of the concave mirror.

The figure 5.5 shows that the light rays parallel to the principal axis are incident on a concave mirror and get reflected. Complete the figure 5.5 by drawing a few rays incident on the mirror parallel to and below the principal axis, showing their path after reflection.

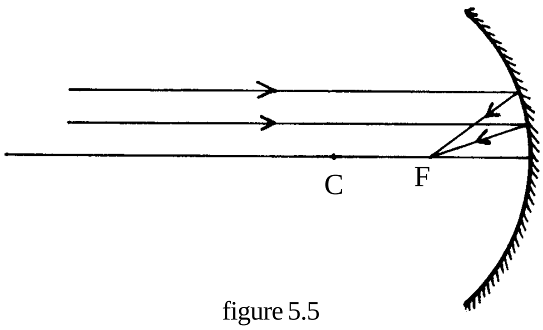

figure 5.5

Principal focus in the concave mirror

After reflection these rays can be really converged to a single point. Therefore, is not this focus real?

Repeat the same experiment using a convex mirror. Then what happens? Can the light rays be converged to a single point?

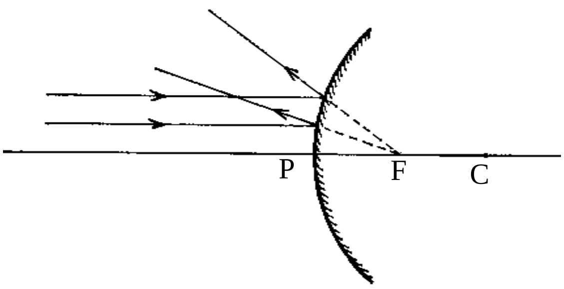

figure 5.6

Principal focus of a convex mirror

Draw the paths of a few more rays parallel to and below the principal axis and complete the figure 5.6.

Don't you see that the light rays falling parallel to the principal axis diverge from a point on the axis on the other side of the mirror after reflection.

This point is the principal focus of the convex mirror. Is the focus of a convex mirror real or virtual?

Note down in your science diary the difference between the principal focus of a concave mirror and that of a convex mirror.

The focal length is the distance between the principal focus and the pole of a spherical mirror.

5.05 Relation between radius of curvature and focal length

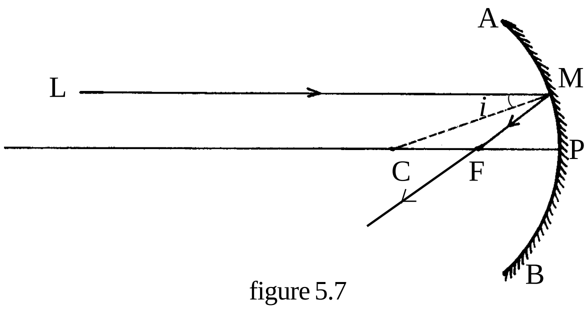

figure 5.7

The ray LM is incident parallel to the principal axis of the concave mirror

LM is a ray incident parallel to the principal axis of the concave mirror APB (figure 5.7). This ray after reflection passes through the point F on the principal axis. If C is the centre of curvature CM is normal to the mirror at M. Now, find out answers to the following questions based on the figure.

- What does the length PC indicate? What about PF?
- Which is the angle of incidence?
- Which is the angle of reflection?
- $\angle$ LMC=$\angle$FMC. What is the reason?
- $\angle$LMC = $\angle$MCF. What is the reason?

What is the relation between angles MCF and FMC?

Aren't the sides opposite to the equal angles in a triangle the same?

Therefore, in △CMF,

we get CF = FM

In a mirror of small aperture, the point of incidence M and the pole P are close to each other, aren't they?

Therefore PF = FM

Thus we can infer that

CF = MF or CF = PF

That is, F is the mid point of CP

If PC is radius of curvature (r) and PF the focal length (f) the relation between them is

PC = PF + FC = 2PF

That is **r** = 2**f**

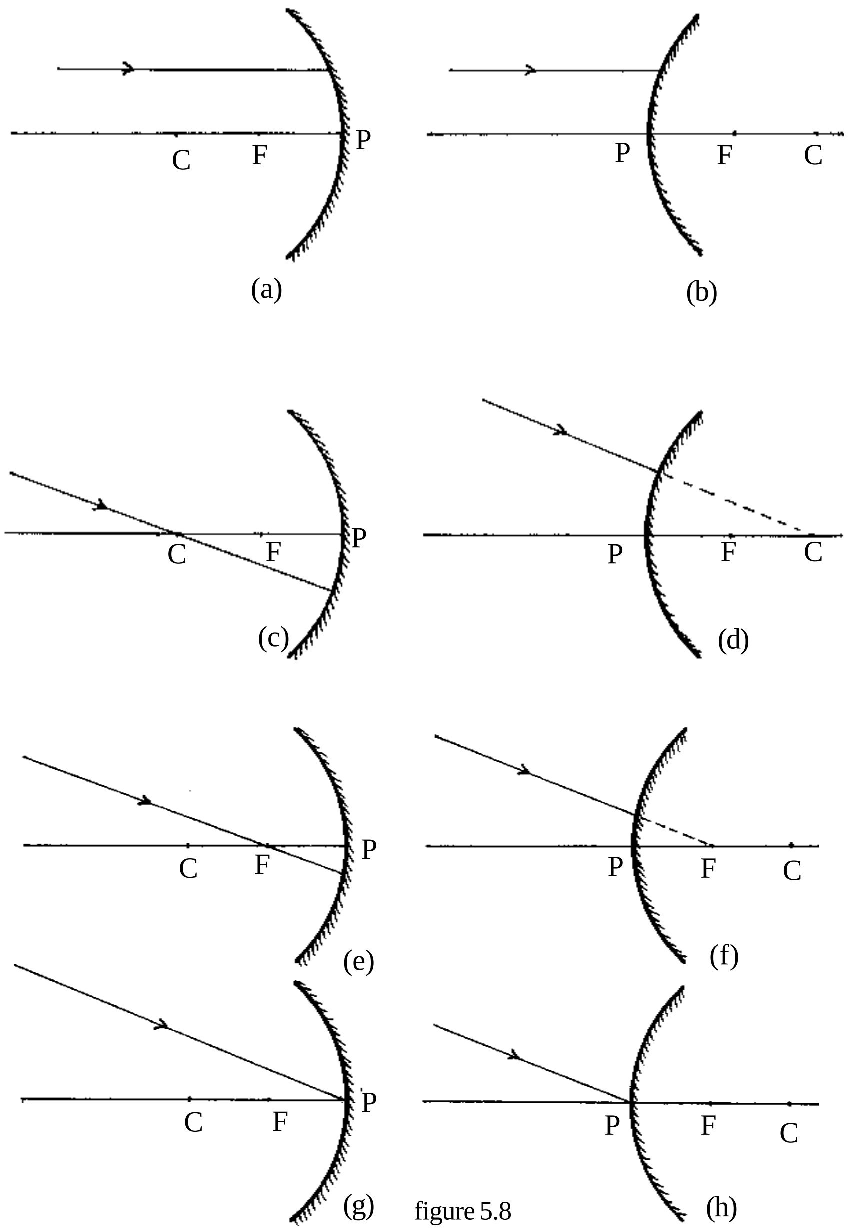

figure 5.8
Rays falling in different ways on spherical mirrors

Examine whether this equation is applicable to a convex mirror also and note it down in the science diary.

- What is the focal length of a concave mirror having radius of curvature 50cm?

5.06 Certain laws to determine the path of reflected rays

Figure 5.8 shows certain rays falling on a spherical mirror. Complete the figures by drawing the paths of the rays reflected based on the law of reflection. Fill in the table 5.1 indicating the details of the paths of reflected rays based on the completed figures.

Can you write down the laws to determine the paths of reflected rays making use of the table?

- The rays falling parallel to the principal axis of the concave mirror pass through the principal focus after reflection.
- Rays passing through the centre of curvature of a concave mirror retrace after reflection.
- Rays falling parallel to the principal axis of the convex mirror appear to diverge from the principal focus of the convex mirror.
-

5.07 Image formation by concave mirror

Let us examine the image formation of a linear object placed perpendicular to the principal axis of a concave mirror, on the basis of what we have learnt so far.

LM is an object placed perpendicular to the principal axis (figure 5.9) $L'M'$ is its image. The point at which any two rays starting from the point M and meeting after reflection is the image of M. Observe the figure and answer the questions given below.

The path of the incident ray	The path of the reflected ray
• The ray falling parallel to the principal axis on the concave mirror	• The ray passes through the principal focus.
• The ray falling on the concave mirror through the centre of curvature.	•
• The ray falling on the cocave mirror through the principal focus.	•
• The ray falling obliquely on the pole of the concave mirror.	•
• The ray travelling towards the principal focus and incident on the convex mirror.	•
• The ray passing parallel to the principal axis of the convex mirror.	•
• The ray proceeding towards the centre of curvarure and falling on the convex mirror.	•
• The ray falling on the pole of the convex mirror.	•

Table 5.1

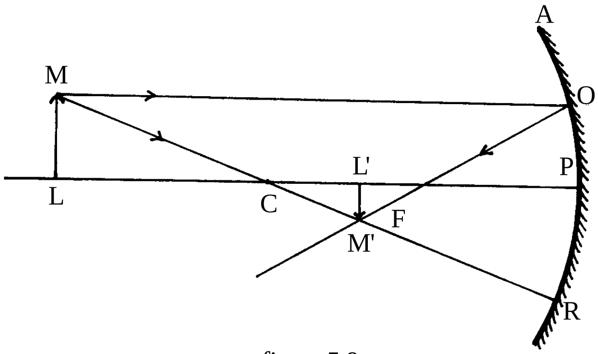

figure 5.9
Image formation using a concave mirror

- In the figure which are the light rays starting from M?
- What are the peculiarities of the path of the incident ray?
- Which are the path of these light rays after reflection and which is the point where they meet in the figure?

5.08 Image formation using a concave mirror

Focus the image of a distant object on a screen using a concave mirror fixed to a stand. Adjust the screen so as to make the image clear.

Now, the distance between the screen and the mirror is the focal length (**f**) of the mirror. Repeat the experiment and calculate the average of the distances.

Using the value of **f** obtained from the above experiment mark points F and C at distances **f** and 2**f** away from the first point

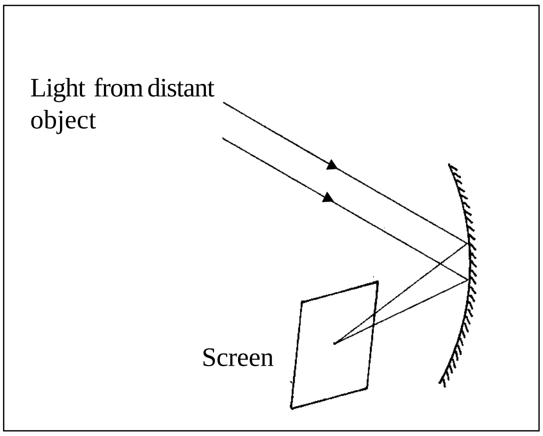

figure 5.10
Experiment to determine focal length

Position of the object	Position of the image	Size of the image in relation to the object	Nature of the image
At infinity			
Beyond the centre of curvature C			
At the centre of curvature C			
Between the centre of curvature and principal focus. (between C &F)			
At the principal focus F			
Between the pole and the principal focus (between P and F)			

Table 5.2

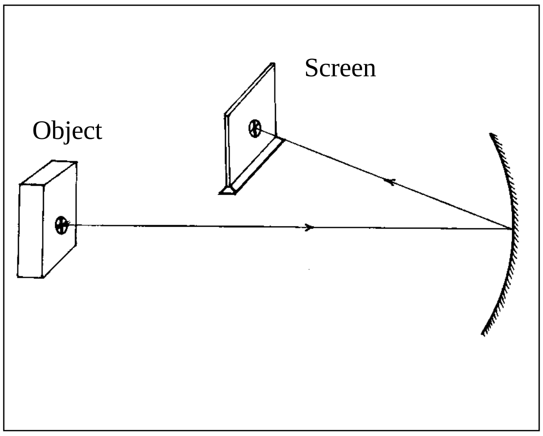

figure 5.11
Image formation according to the different positions of the object

marked on the line. Place the concave mirror at the first point facing the points F and C. Place a burning candle or a lamp box at the positions given in table 5.2. Adjust a screen so that a clear image of the object is obtained on it for each position of the object. Note down the results of your observations in table 5.2.

5.09 Image formed by a convex mirror

In the figure 5.12 an object placed before a convex mirror is marked as LM, pole as P and centre of curvature as C.

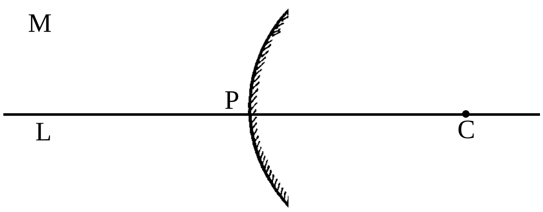

figure 5.12

Now mark the focus F on the basis of the information you have gained and find out the image drawing the rays. Make a list of the peculiarities of the image based on the figure.

- Image is always behind the mirror
- The image is virtual.
- It is erect and smaller than the object.
- Where ever be the object the image will always be between F and P.

5.10 The new Cartesian sign convention

We will have to measure different distances in relation to the reflection on the spherical mirror. The measured distances are indicated by a positive (+) sign or a negative (-) sign and this sign is dictated by the new Cartesian sign convention. Let us examine the peculiarities of this convention.

- Principal axis is conceived as X-axis and pole as origin.
- All distances are measured from the pole.
- The incident ray is conceived as passing from left to right.
- Distances measured in the same direction of the incident ray are taken as positive (+) and the distances measured in the opposite direction are taken as negative (-).

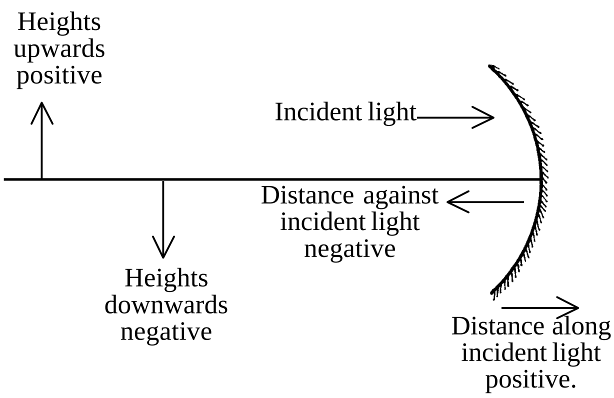

figure 5.13

In accordance with the above sign convention, find out the signs of the quantities mentioned below and note them down in your science diary.

- Focal length of a concave mirror

- Focal length of a convex mirror
- Radius of curvature of a concave mirror
- Radius of curvature of a convex mirror

5.11 Mirror formula

You have learnt that the position, size and property of the image of an object placed in different positions infront of the spherical mirror can be different. If the distance from the pole of the mirror to the object is **u**, the distance to the image is **v** and the focal length is **f** then, the relation among them is the mirror formula. Let us now see how this formula can be found out through an experiment.

Determine the focal length **f** of a concave mirror as in the experiment done based on figure 5.11

Measure the distance **u** placing the object a little further away from the pole beyond the focal length **f**. Adjust the position of the screen and find out the position of the clear image. This distance will be **v**. By gradually increasing the distance of the object from the pole, measure the distance to the image each time. Note down the values of **u** and **v** in table 5.3

Sl. No.	u	v			
1					
2					
3					
4					
5					
6					

Table 5.3

The values obtained in the last column will be more or less the same. Find out their average.

Determine $\frac{1}{f}$ from the previously obtained value of **f**. Compare the value of

with the average value of .

What are your conclusions?

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

or, f =

- When a bright object is placed 10 cm away from a concave mirror, its real image is formed at a distance 40cm from the mirror. What is the focal length of the mirror?

u = -10cm **v** = -40cm,

Then **f** = ?

$f = \frac{uv}{u+v} = \frac{(-10)\times(-40)}{(-10)+(-40)}$

$= \frac{400}{-50} = -8\text{cm}$

- An object placed 20cm away from a convex mirror is found to give a virtual image 10cm behind the mirror. Find out the focal length of the mirror.
- An object is placed at a distance 20cm from a concave mirror of focal length 15cm. Find howfar away is the image formed?

5.12 Magnification

You have seen that on a spherical mirror the size of the image and the distance to the image change according to the distance to the object. Magnification is that number which indicates howmany times the image is as large as the object. It is the ratio between the height of the image and the height of the object.

From figure 5.9,

magnification **m**

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

i.e., **m**

Besides, it can be proved that

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

This means that if **m** is negative (-) the image is inverted and real and if **m** is positive (+) the image is erect and virtual.

- An object placed at a distance of 15cm from a concave mirror produces an image at a distance 45cm from the mirror. Find out the magnification.
- An object 2.5mm in height placed at a distance 5cm from a mirror produces a real image of 1cm in height. Find the position and magnification of the image.

Can telescopes be made with mirrors?

Concave mirrors are used not only to form smaller images but also for making telescopes to observe distant astronomical objects. The light rays coming from the planet are focussed by using a concave mirror, or they are reflected towards the sides using a plane mirror and are focussed. In either case the final image is viewed with the help of an eye-piece.

In 1668, it was Sir Issac Newton who made the first reflecting telescope of diameter 2.94m. But in modern telescopes parabolical mirrors are used. Such a telescope installed at Mount Palomour in America has a diameter of 5.99m. This can receive light of intensity 3 lakh times more than the naked human eye can receive. With this type of telescope we can see the light of a candle at a distance of nearly 2400km. Efforts are now on to assemble a telescope of 10m diameter.

In 1990, Hubble Space Telescope with diameter 2.4m was installed in space 500km above NASA. Using this telescope, objects which are only 1/30 times as intense as that observed by a terrestrial telescope, can be viewed. This is because there is no atmospheric obstruction.

5.13 Refraction

You have already learnt what refraction is and how it happens in glass slabs, prisms and lenses. Now let us examine the laws relating to refraction.

Laws of refraction - Snell's law

Place a glass slab on a piece of paper and mark its four sides with a pencil. Draw a perpendicular at any point on the side AB as shown in the figure. Draw a line making an angle of 30° with the perpendicular. This is the angle of incidence. Through this line let a beam of light from a ray box fall on the glass

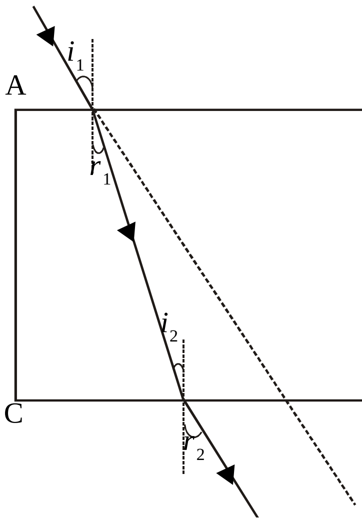

figure 5.14

slab. Draw the path of the beam of light coming out. After removing the glass slab draw the path of the beam of light through the glass slab and also the normal to the point on which light ray falls on the side CD. Measure the angle of refraction . Repeat the experiment taking angles of incidence of 35°, 40°, 45° etc and fill the table 5.4.

Calculate sin **i** and sin **r** and complete the last column of table 5.4 (use Clark's table).

Now you know on which plane the incident ray, the refracted ray and the normal at the point of incidence are . These are all on the same plane, namely, the plane of the paper.

Besides, you might have seen from this experiment that $\frac{\sin \mathbf{i}}{\sin \mathbf{r}}$ is a constant. From these conclusions laws of refraction can be formulated.

- The incident ray, refracted ray and the normal to the point of incidence lie in the same plane.
- When light rays travel from one medium to another $\frac{\sin \mathbf{i}}{\sin \mathbf{r}}$ is a constant as far as these two media are concerned. This is called Snell's law.

5.14 Refractive Index

AB is a plane that divides air and another medium. The incident ray PQ travels through air and falls at an angle **i**. QR is the refracted

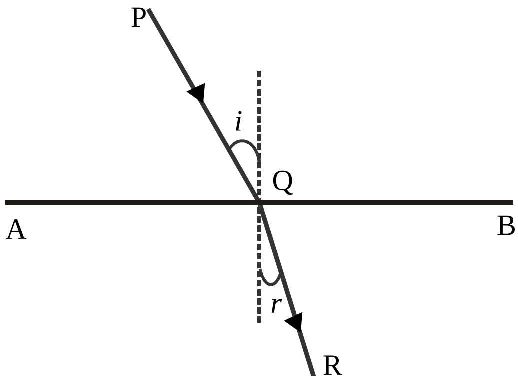

figure 5.15

number	angle of incidence (i)	angle of refraction r	sin i	sin r	sin i/sin r

Table 5.4

ray formed as a result of refraction taking place at the surface separating the two media. The angle of refraction is **r**.

According to snell's law $\frac{\sin \mathbf{i}}{\sin \mathbf{r}}$ is a constant. This is the refractive index of the medium and is indicated by the letter **n**.

That is , $\mathbf{n} = \frac{\sin \mathbf{i}}{\sin \mathbf{r}}$

- If the angle of incidence of a ray of light falling on the glass surface is 30° and the angle of refraction is 19°. what is the refractive index of glass?

angle of incidence $\mathbf{i} = 30°$
angle of refraction $\mathbf{r} = 19°$

refractive index $\mathbf{n} = \frac{\sin \mathbf{i}}{\sin \mathbf{r}} = \frac{\sin 30}{\sin 19} =$

$\frac{.5}{.3256} = 1.535$

Refractive index depends on the medium and the colour of light. Light travels through a medium at a constant velocity. The reason for refraction is the change in velocity that occurs when light enters from one medium to another. Based on the velocity of light in the medium, another equation for refractive index can also be stated.

The refractive index of the medium = **n** =

=

Taking refractive index of air as 1, the refractive index of other media are shown in the table

Sl. No.	Medium	Refractive index
1	water	1.33
2	petroleum	1.38
3	glass	1.5
4	diamond	2.4

Table 5.5

Velocity of light in vacuum and air are considered almost the same.

Lights of all colours are of equal velocity in vacuum. Can you say how much is it?

Summary

- **Concave mirror:** A curved surface whose inner side is capable of reflection.
- **Convex mirror:** A curved surface whose outer side is capable of reflection.
- The radius of curvature of a spherical mirror is twice of its focal length.
- **Mirror equation** : $\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$
- **Magnification:** The ratio of the size of the image to the size of the object.
- **The new cartesian sign convention:** The rule that determines the signs that are to be applied to the distance measured from the the pole of a spherical mirror.
- **Snell's law** : $\frac{\sin \mathbf{i}}{\sin \mathbf{r}} = \mathbf{n}$, is a constant. This is the refractive index of the medium.

More activities for you

1 What are the types of mirrors used in motor vehicles to view rear sights? Explain the reasons. What are the advantages of this?

2 Observe your face on the front side and backside of a steel spoon. Do you feel any difference between the two images? What can be the reason?

3 An object placed 24cm away from a spherical mirror is found to give a real image 12cm from the mirror. What is the focal length of the mirror?

4 An object is placed 4cm away from a concave mirror of focal length 12cm. Find the position and nature of the image.

5 An object 4cm in height is placed 24cm away from a concave mirror. The focal length of the concave mirror is 8cm. Draw a diagram on a graph paper and measure the position and height of the image. Find out the magnification also.

6 Make a table of the situations in which concave and convex mirrors are used.

r r r r r r r