CONTENTS

1. Light-Reflection and Refraction

Build A Strong Foundation

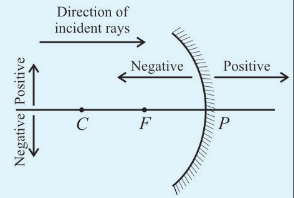
CONCEPT MAP

Light It is a form of energy that produces the sensation of vision in eyes.

Reflection Turning back of light in the same medium.

Laws
- Angle of incidence (i) = angle of reflection (r)
- Incident ray, the normal, reflected ray all lie in the same plane.

Sign Convention



Mirror Types & Formula

Concave Mirror Spherical glass polished on the outside. It is also known as converging mirror.
- Images produced are always real, inverted, can be enlarged based on the position except when object is placed between pole and focus.

Convex Mirror Spherical glass polished inside. It is also known as diverging mirror.
- It forms virtual, upright and small images.

Plane Mirror Is a looking glass, highly polished on one surface.

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

Refraction Bending of light ray while passing from one medium to other medium.

Laws
- $\frac{\sin i}{\sin r}$ = constant. Also called Snell's law
- Incident ray, normal and refracted ray all lie in the same plane.

Refractive Index Ratio of speed of light in air/vacuum (c) to that in a medium(v).
$n = c/v$

Refraction through a Glass Slab
Lateral displacement
$x = \frac{t \sin (i-r)}{\cos r}$ $\therefore x \propto t$

Power of a lens $P = \frac{1}{f\,(in\ metre)}$

Lens Piece of transparent material with two refracting surfaces, at least one is curved and refractive index should be different as that of the surrounding.

Concave Lens Central portion of lens is thinner than marginal. It is also known as diverging lens.
- It forms virtual, upright and small images.

Convex Lens Central portion of lens is thicker than marginal. It is also known as converging lens.
- Images produced are always real, inverted, can be enlarged based on the position except when object is placed between pole and focus.

Lens Formula $\frac{1}{f}=\frac{1}{v}-\frac{1}{u}$

Magnification $m=\frac{I}{O}=\frac{v}{u}=\frac{h_I}{h_o}$

★ **Lens maker formula** $\frac{1}{f}=(\mu-1)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)$

★ **Total Internal Reflection** Angle of refraction $\angle r \geq 90°$ in rarer medium correspond to angle of incidence $\angle i$ in denser medium
$\mu_{denser} = \frac{1}{(C)\ critical\ angle}$

★ **Refraction at spherical surfaces** $\frac{\mu_2}{v}-\frac{\mu_1}{u}=\frac{\mu_2-\mu_1}{R}$

★ **Combination of Lenses**
Case 1: When two thin lenses are in contact
$$\frac{1}{f}=\frac{1}{f_1}+\frac{1}{f_2}$$
Case 2: When two thin lenses are separated by a certain distance $\frac{1}{f}=\frac{1}{f_1}+\frac{1}{f_2}-\frac{d}{f_1 f_2}$

★*Belongs to connecting topic.*

WHAT IS LIGHT ?

Light is a form of energy that produces the sensation of vision on our eyes.

It is an electromagnetic radiation, such as that emitted by the Sun, which acts like a wave in a frequency range that the human eye can perceive. At the same time, light also acts like a stream of particles, which are called photons (hence the expression "beam of light"). Electrons can be shot out of atoms and molecules can be split simply by the impact of a photon striking them. A film in a camera is exposed in this way; the light splits the silver bromide into silver and bromine. The silver darkens the film and a negative is created. Light is a combination of electric and magnetic oscillations in mutually perpendicular directions as shown in Fig.1.1. But the light wave itself propagates in a direction perpendicular to both the oscillations.

The branch of physics which deals with nature, source, properties and the effects of light is callcd **optics.**

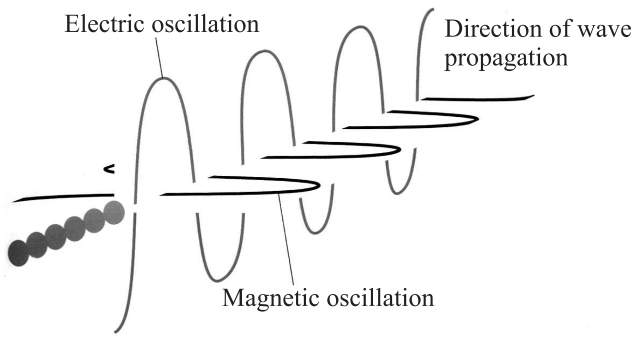


Fig. 1.1 Electric and magnetic oscillations are mutually perpendicular. The light wave propagates in a direction perpendicular to both.

CHARACTERISTICS OF LIGHT

- Light travels along a straight line in a medium or vacuum. The path of light changes only when the medium changes. This is also called the **rectilinear propagation of light.** The casting of shadows and eclipses are due to the rectilinear propagation of light.
- Light travels with a speed nearly equal to 3×10^8 m/s. i.e. the speed of light in vacuum. According to current theories, no material particle can travel at a speed greater than the speed of light.
- The speed of light waves depends on the medium through which they pass.
- Light shows different behaviour such as reflection, refraction, interference, diffraction, polarisation etc. some of which we will deal with subsequently in this book and some in higher classes.

RAY AND BEAM OF LIGHT

Let us consider a source of light(s). Also consider the light which passes from the point A to the point B in a medium.

Actually, the light passes through all the points of the straight line AB. Such a straight line path AB is called a **ray of light**, generally represented by a directed arrow (→).

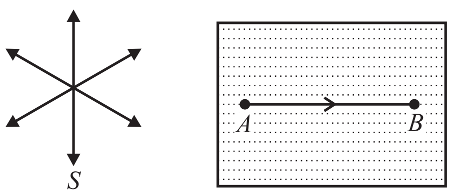


Fig. 1.2 AB is a ray of light in a medium

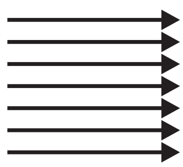


Fig. 1.3 A parallel beam of light.

A small bundle of these rays is called a **pencil of rays** and large bundles of these rays is called a **beam of light**.

A bundle of rays in which rays are parallel to one another is called parallel beam of light.

REFLECTION OF LIGHT

Most of the things we see around us do not emit their own light. They are visible because they reemit light reaching their surface from a primary source, such as the sun or a lamp, or from a secondary source, such as the illuminated sky. When light falls on the surface of a material, it is usually either reemitted without change in frequency or is absorbed into the material and turned into heat. Usually, both of these processes occur in varying degrees. When the reemitted light is returned into the medium from which it came, it is *reflected*, and the process is referred to as **reflection**. i.e. *the turning back of light in the same medium is called reflection of light.*

When this page is illuminated by sunlight or lamplight, electrons in the atoms of the paper vibrate more energetically in response to the oscillating electric fields of the illuminating light. The energized electrons reemit the light by which we see the page. When the page is illuminated by white light, it appears white, which reveals the fact that the electrons reemit all the visible frequencies. Very little absorption occurs. The ink on the page is a different story. Except for a bit of reflection, the ink absorbs all the visible frequencies and therefore appears black.

Time to Check Your Knowledge

☛ **A person in a dark room looking through a window can clearly see a person outside in the daylight, whereas the person outside cannot see the person inside. Explain.**

SOLUTION

When a person inside a darkroom is looking through a window to another person outside in broad daylight, then enough reflected rays come inside to the eye of the observer from the person outside. So he can be seen clearly. But if the person in daylight, looks through the same window to the person inside the dark room, there is hardly any reflected rays coming from the body of the person inside the dark room to the eyes of the observer outside. So the outside observer can't see the person inside the room.

LAWS OF REFLECTION

Anyone who has played pool or billiards knows that, when a ball bounces from a surface, the angle of incidence is equal to the angle of rebound. The same is true of light. This is the **law of reflection**, and it holds for all angles.

The law of reflection is illustrated with arrows representing light rays in Fig. 1.4 Instead of measuring the angles of incident and reflected rays from the reflecting surface, it is customary to measure them from a line perpendicular to the plane of the reflecting surface. This imaginary line is called the **normal**. The incident ray, the normal, and the reflected ray all lie in the same plane.

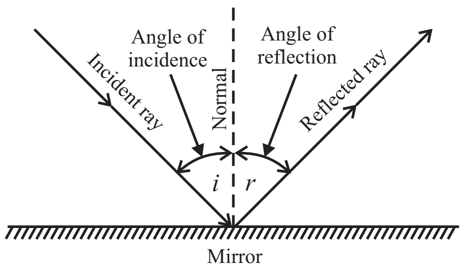


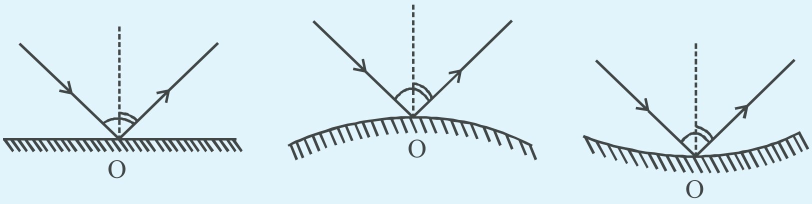
Fig.1.4 The incident ray, the reflected ray, and the normal all lie in the same plane; $\angle i = \angle r$

So, we can summarise the laws of reflection as below :

1. *The angle of incidence (i) is always equal to the angle of reflection (r), i.e.,* $\angle i = \angle r$
2. *The incident ray, the normal, and the reflected ray all lie in the same plane.*

Learn More

1. Laws of reflection are applicable for plane surfaces as well as curved surfaces.



(a) Plane surface (b) (c) Curved surfaces

Fig.1.5

2. After reflection, velocity, wavelength and frequency of light remains same but intensity decreases.
3. Most people are surprised by the fact that light can be reflected back from a less dense medium. For instance, if you are diving and you look up at the surface of the water, you will see a reflection of yourself.

Time to Check Your Knowledge

☛ **Each of these diagrams numbered 1, 2 and 3 is supposed to show two different rays being reflected from the same point on the same mirror. Which are correct, and which are incorrect ?**

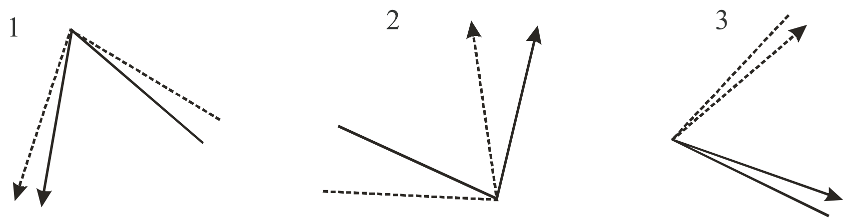


Fig. 1.6

SOLUTION

Only 1 is correct. Draw the normal that bisects the solid ray, it also bisects the dashed ray.

REGULAR AND DIFFUSE REFLECTION

When light is incident on a smooth surface it is reflected in the first medium in one direction. The reflected rays will also be parallel. This reflection on a smooth surface is called **regular reflection.** When light is incident on a rough surface, it is reflected in many directions. This is called **diffuse reflection.**

(a) Regular reflection

(b) diffuse reflection although reflection of each single ray obeys the law of reflection, the many different surface angles that light rays encounter in striking a rough surface produce reflection in many direction.

Fig. 1.7

If the surface is so smooth that the distances between successive elevations on the surface are less than about one-eighth the wavelength of the light, there is very little diffuse reflection, and the surface is said to be *polished*. A surface therefore may be polished for radiation of long wavelengths but rough for light of short wavelengths. The wire-mesh "dish" shown in fig. 1.8 is very rough for light waves of short wavelength. But, for long-wavelength radio waves, it is "polished" and is an excellent reflector. Light reflecting from this page is diffuse. The page may be smooth to a radio wave, but, to a light wave, it is rough. Smoothness is relative to the wavelength of the illuminating waves. Rays of light striking this page encounter millions of tiny flat surfaces facing in all directions. The incident light, therefore, is reflected in all directions.

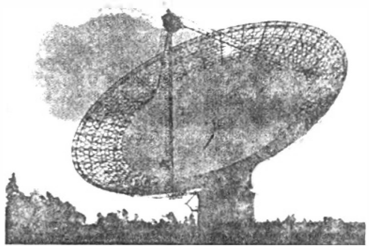


Fig. 1.8 The open-mesh parabolic dish is a diffuse reflector for short-wavelength light but a polished reflector for long-wavelength radio waves.

This is a desirable circumstance. It enables us to see objects from any direction or position. You can see the road ahead of your car at night, for instance because of diffuse reflection by the rough road surface. When the road is wet, it is smoother with less diffuse reflection, and therefore more difficult to see. Most of our environment is seen by diffuse reflection.

Time to Check Your Knowledge

☛ **An observer on the west-facing beach of a large lake is watching the beginning of a sunset. The water is very smooth except for some areas with small ripples. The observer notices that some areas of the water appear blue and some appear pink. Why does the water appear to be different colors in different areas?**

SOLUTION

The different colors arise from specular and diffuse reflection. The smooth areas of the water specularly reflect the light from the west, which is the pink light from the sunset. The areas with small ripples reflect the light diffusely. Thus, light from all parts of the sky is reflected into the observers' eyes. Because most of the sky is still blue at the beginning of the sunset, these areas appear to be blue.

ILLUSTRATION : 1.1

Two mirrors make an angle of 120º with each other as in Fig. 1.9, A ray is incident on mirror M_1 at an angle of 65º to the normal. Find the direction of the ray after it is reflected from mirror M_2.

SOLUTION :

From the law of reflection, we know that the first reflected ray also makes an angle of 65º with the normal. Thus, this ray makes an angle of 90º – 65º, or 25º, with the horizontal. We build the geometric model triangle shown in Figure 1.9 from the triangle made by the first reflected ray and the two mirrors. The first reflected ray makes an angle of 35º with M_2 (because the sum of the interior angles of any triangle is 180º). This means that this ray makes an angle of 55º with the normal to M_2. Hence, from the law of reflection, the second reflected ray makes an angle of 55º with the normal to M_2.

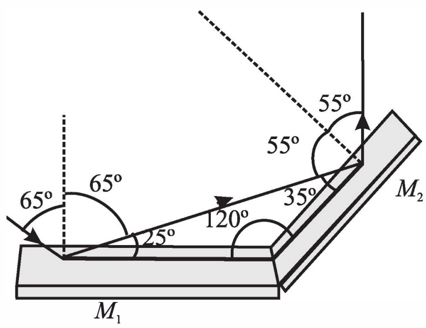


Fig. 1.9 Mirrors M_1 and M_2 make an angle of 120° with each other.

CONNECTING TOPIC

Reversibility of Light Rays

The fact that specular reflection displays equal angles of incidence and reflection means that there is a symmetry: if the ray had come in from the right instead of the left in the figure above, the angles would have looked exactly the same. This is not just a pointless detail about specular reflection.

It's a manifestation of a very deep and important fact about nature, which is that the laws of physics do not distinguish between past and future. Cannonballs and planets have trajectories that are equally natural in reverse, and so do light rays. This type of symmetry is called time-reversal symmetry. Typically, time-reversal symmetry is a characteristic of any process that does not involve heat. For instance, the planets do not experience any friction as they travel through empty space, so there is no frictional heating.

We should thus expect the time-reversed versions of their orbits to obey the laws of physics, which they do. In contrast, a book sliding across a table does generate heat from friction as it slows down, and it is therefore not surprising that this type of motion does not appear to obey time-reversal symmetry. A book lying still on a flat table is never observed to spontaneously start sliding, sucking up heat energy and transforming it into kinetic energy.

Similarly, the only situation we've observed so far where light does not obey time-reversal symmetry is absorption, which involves heat. Your skin absorbs visible light from the sun and heats up, but we never observe people's skin to glow, converting heat energy into visible light. People's skin does glow in infrared light, but that doesn't mean the situation is symmetric. Even if you absorb infrared, you don't emit visible light, because your skin isn't hot enough to glow in the visible spectrum.

REFLECTION AT A PLANE MIRROR

Plane mirror is a looking glass which is highly polished on one surface and silvered on the other surface. The images formed by mirrors are the most common examples of images formed by reflection.

Characteristics of Image Formed by Plane Mirror

- A plane mirror forms virtual and erect image of the object.
- Distance of object from mirror = Distance of image from mirror.
- The image is laterally inverted (better word perversion). i.e., the left of the object becomes the right of the image and vice versa.
- The line joining the object point with its image is normal to the reflecting surface.
- The size of the image is the same as that of the object.

Keep in Memory

(i) For a real object the image is virtual and for a virtual object the image is real.

(ii) When the object moves with speed u towards (or away) from the plane mirror then image also moves (or away) with speed u but relative speed of image w.r.t. object is $2u$.

(iii) If keeping the incident ray fixed, the mirror is rotated by an angle θ, about an axis in the plane of mirror, the reflected ray is rotated through an angle 2θ.

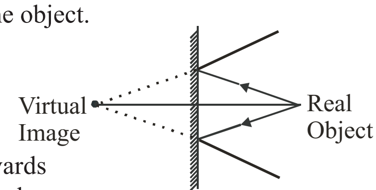


Fig. 1.10 (a)

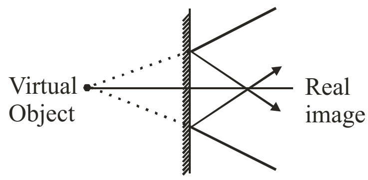


Fig. 1.10 (b)

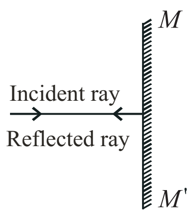


Fig. 1.11 (a)

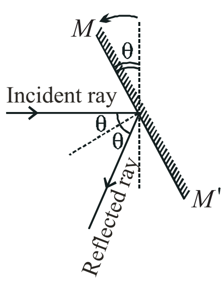
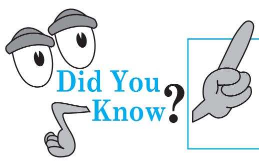


Fig. 1.11 (b)



A thick plane mirror forms a number of images due to multiple reflection of light. Out of these images, second image is the brightest and intensity of other images goes on decreasing.

Learn More

1. If two plane mirrors are kept inclined to each other at angle with their reflecting surfaces facing each other, multiple reflection takes place and more than one images are formed. Number of images (n) for $\theta \le 180°$ are given by :

   (i) If $n = \dfrac{360°}{\theta}$ is a fraction, then number of images formed will be equal to integral part.

   (ii) If $n = \dfrac{360°}{\theta}$ is an even integer, then number of images is $(n - 1)$.

   (iii) If $n = \dfrac{360°}{\theta}$ is odd integer, then number of images is $(n - 1)$, when the object lies on plane which bisects the angle between the mirrors.

   And number of images is n if it does not lie on the plane which bisects the angle between the mirrors.

   (a) If an object is placed between two parallel mirrors ($\theta = 0°$), the number of images formed will be $(360/0) = \infty$ but of decreasing intensity in accordance with $I \propto (1/r^2)$.

   (b) The number of images formed by two mutually perpendicular mirrors ($\theta = 90°$) will be 3. All these three images will lie on a circle with centre at C – the point of interesection of mirrors M_1 and M_2 and whose radius is equal to the distance between C and object O.

   (c) Two mirrors inclined to each other at different angles may provide same number of images, e.g., for any value of θ between 90° and 120° the number of maximum images formed (n) is 3. This in turn implies that if θ is given, n is unique but if n is given, θ is not unique.

   (d) The number of images seen may be different from the number of images formed and depends on the position of observer relative to object and mirrors – e.g., if $\theta = 120°$ maximum number of images formed will be 3 (object not on bisector) but no. of images seen can only be 1, 2 or 3 depending on the position of observer.

2. If an object moves towards (or away from) a plane mirror at speed v, the image will also approach (or recede) at same speed v, i.e., the speed of image relative to object will be $v - (-v) = 2v$. Similarly if the mirror is moved towards (or away) from the object with a speed v the image will move towards (or away) from the object with a speed $2v$.

3. To locate the image of an object from an inclined mirror, see the perpendicular distance of the object from the mirror.

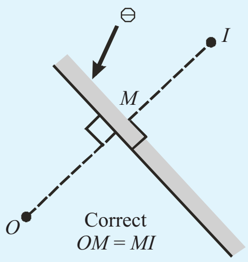


Fig 1.12 (a)

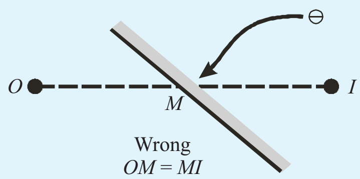


Fig 1.12 (b)

4. If angle between two mirrors is θ after consecutive reflection total deviation $\delta = \delta_1 + \delta_2 = 2\pi - 2\theta$

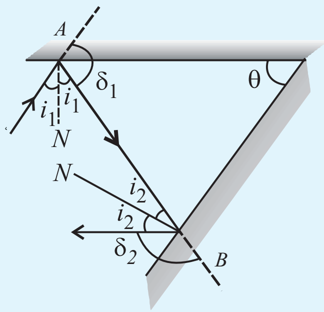


Fig. 1.13

Time to Check Your Knowledge

☛ **We see the bird and its reflection. Why do we not see the bird's feet in the reflection?**

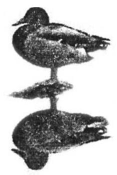


Fig. 1.14

SOLUTION

The bird's feet are on the reflecting surface so the image of feet is formed at the same place where actually the feet are. So the image of the feet cannot be distinguished from the actual feet. This is so because the distance of the object from the reflecting surface is equal to that of the image from same surface.

ILLUSTRATION : 1.2

Find the minimum height of a plane mirror where one can see his full image.

SOLUTION :

Let HL be the height of the person and E, the position of his eyes. Now applying laws of reflection,

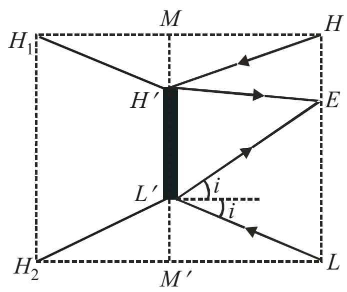


Fig. 1.15

we have, $M'L' = \frac{1}{2}EL$ and $MH' = \frac{1}{2}HE$

Now, $H'L' = MM' - MH' - L'M'$

$= HL - \frac{1}{2}EL - \frac{1}{2}HE = HL - \frac{1}{2}HL = \frac{1}{2}HL$

So the required height of the mirror be half of the height of the person.

ILLUSTRATION : 1.3

Two plane mirrors are inclined at an angle θ. A ray of light is incident on one mirror at an angle of incidence *i*. The ray is reflected from this mirror, falls on the second mirror from where it is reflected parallel to the first mirror. What is the value of *i*, the angle of incidence in term of θ ?

SOLUTION :

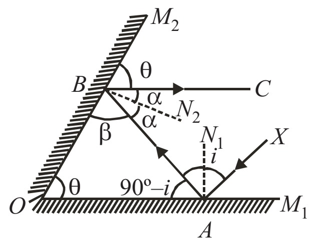


Fig. 1.16

The situation is illustrated in fig. 1.16. XA is the incident ray. BC is the final reflected ray. It is given that BC is parallel to mirror M_1. Look at the assignment of the angles carefully. Now N_2 is normal to mirror M_2.

Therefore $\beta = \theta$

Then from $\Delta\, OAB$, $\theta + \beta + 90^\circ - i = 180^\circ$

or $\theta + \theta + 90^\circ - i = 180^\circ$ or $i = 2\theta - 90^\circ$

Thus if the angle of incidence is $i = 2\theta - 90^\circ$, then the final reflected ray will be parallel to the first mirror.

ILLUSTRATION : 1.4

Find the *x* and *y* co-ordinates, of the image of a point *A* (2, 0). *MN* is a plane mirror.

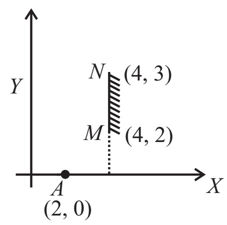


Fig. 1.17

SOLUTION :

Image of A will be at $A'(6, 0)$. Perpendicular distance of image from plane mirror = perpendicular distance of object from plane mirror.

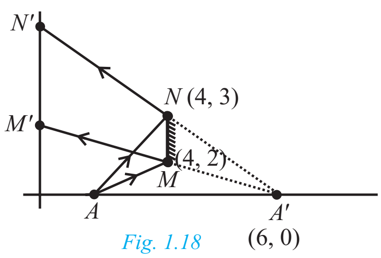


Fig. 1.18

SPHERICAL MIRRORS

A highly polished curved surface whose reflecting surface is a cut part of a hollow sphere of a glass or any polished metal is called spherical mirror. Spherical mirrors are of two types:

Concave Mirrors

Imagine a **sphere** of **hollow** glass. If we cut out a spherical cap and polished it with silver on the outside, we have a **concave mirror** if we look at it from the hollow side. These mirrors, which are referred to as **convergent** mirrors, concentrate the light rays, causing them to arrive onto a point known as the **focal point**. Concave mirrors form **real images** that can be **projected** onto a screen if the object is farther away than the focal point. If we place the object closer than the focal point, the image is formed upright and large but virtual (i.e., it cannot be projected).

Convex Mirrors

If we polished the **inner surface** of a concave mirror with silver and look at it toward the **outward bulge**, we have a **convex** mirror. Mirrors of this type are also called **divergent** mirrors because the light beams that reach their surface and are **parallel** to their main axis are diverted in such a way that they **separate**, but their **extensions** come back together again in a point known as the **focal point**. The images produced by a convex mirror are always **virtual, upright**, and **small**.

Let's Do Activity

Take a large shining spoon. Try to view your face in its curved surface

- *Do you get the image ? Is it smaller or larger?*
- *Move the spoon slowly away from your face. Observe the image. How does it change?*
- *Reverse the spoon and repeat the Activity. How does the image look like now?*
- *Compare the characteristics of the image on the two surfaces.*

TERMS RELATED TO SPHERICAL MIRROR

Centre of curvature (C) **:** It is the centre of sphere of which the mirror is a part.
Radius of curvature (R) **:** It is the radius of the sphere of which the mirror is a part.
Pole (P) **:** It is the geometrical centre of the spherical reflecting surface.
Principal axis : It is the straight line joining the centre of curvature to the pole.
Focus (F) **:** When a narrow beam of rays of light, parallel to the principal axis and close to it (know as paraxial rays), is incident on the surface of a mirror, the reflected beam is found to converge (concave mirror) or appear to diverge (convex mirror) from a point on principal axis. This point is called focus.
Focal length (f) **:** It is the distance between the pole and the principal focus. For spherical mirrors, $f = R/2$.

RULES FOR RAY DIAGRAMS

(i) A ray, parallel to the principal axis will after reflection, pass through the focus. Fig. 1.19 (*a*), and (*b*)

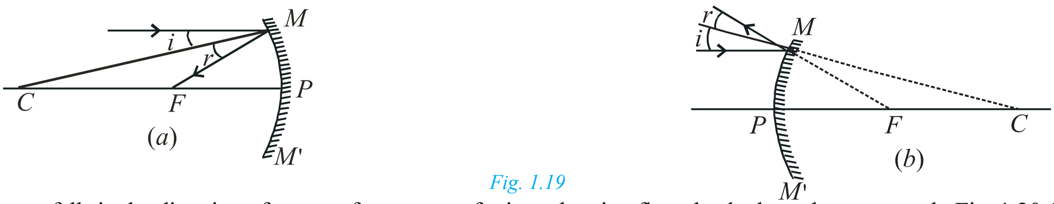


Fig. 1.19

(ii) When a ray falls in the direction of centre of curvature of mirror then it reflects back along the same path. Fig. 1.20 (*a*) and (*b*)

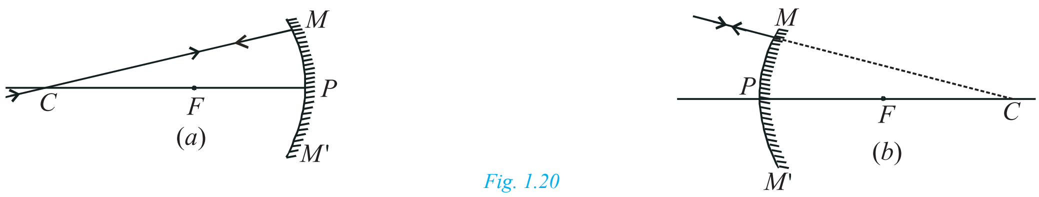


Fig. 1.20

(iii) A ray, passing through the focus is reflected parallel to the principal axis. Fig. 1.21 (*a*), and (*b*)

Fig. 1.21

REFLECTION THROUGH CONCAVE MIRROR

$F \rightarrow$ Principal focus $\qquad$ $P \rightarrow$ Pole of mirror

$C \rightarrow$ Centre of curvature $\qquad$ PC = Radius of curvature

PF = Focal length

When a narrow beam of light travelling parallel to the principal axis is incident on the reflecting surface of the concave mirror, the beam after reflection converge at a point on the principal axis.

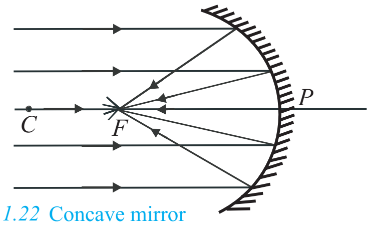
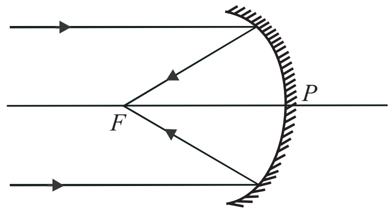
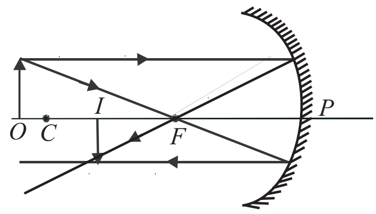
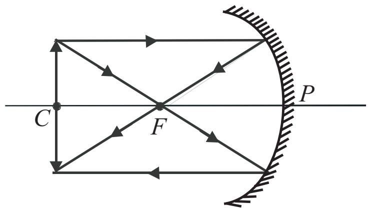
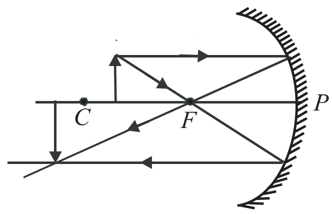
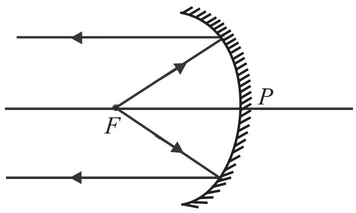
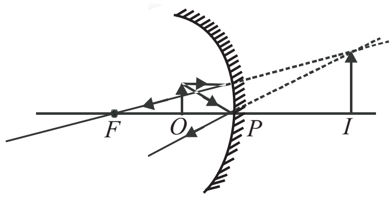


Fig. 1.22 Concave mirror

IMAGE FORMED BY THE CONCAVE MIRROR

Position of object	Position of image	Nature	Ray diagram
At infinity	At the focus	Real, inverted & diminished	
Between infinity & centre of curvature	Between focus & centre of curvature	Real, inverted & small in size	
At centre of curvature	At centre of curvature	Real, inverted and of same size	
Between focus & centre of curvature	Beyond centre of curvature	Real, inverted and enlarged	
At focus	At infinity	Real, inverted and very large	
Between Focus & Pole	Behind the mirror	Erect, virtual & enlarged	

Uses of Concave Mirror

Makeup and shaving mirrors are concave mirrors. When you place your face between the mirror and its focal point, you see an enlarged virtual image of yourself. Concave mirrors are also used in a new method for displaying the speed of a car, as a dentist mirror, in floodlight etc.

Let's Do Activity

Cautions:

Before doing this activity "Do not look at the Sun directly or even into a mirror reflecting sunlight. It may damage your eyes."

- *Hold a concave mirror in your hand and direct its reflecting surface towards the Sun.*
- *Direct the light reflected by the mirror on to a sheet of paper held close to the mirror.*
- *Move the sheet of paper back and forth gradually unitl you find on the paper sheet a bright, sharp spot of light.*
- *Hold the mirror and the paper in the same position for a few minutes. What do you observe? Why?*

REFLECTION THROUGH CONVEX MIRROR

When a narrow beam of light travelling parallel to the principal axis is incident on the reflecting surface of the mirror, the beam after reflection appear to diverge from a point on the principal axis.
When a ray incident on convex mirror in the direction of centre of curvature after reflection comes back along the same path.
When a ray incident on convex mirror parallel to the principal axis, after reflection, appears to come from the focus.

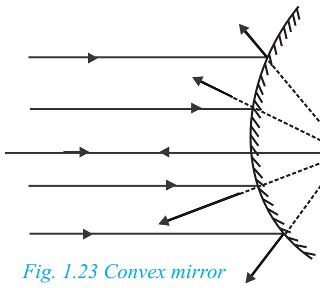


Fig. 1.23 Convex mirror

IMAGE FORMED BY CONVEX MIRROR

A convex mirror forms only virtual images for all positions of the real object. The image is always virtual, erect, smaller than the object and is located between the pole and the focus. The image becomes smaller and moves closer to the focus as the object is moved away from the mirror.

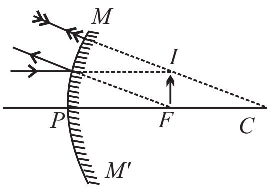


Fig. 1.24 (a)

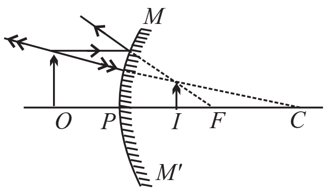


Fig. 1.24 (b)

The virtual image is diminished in size and upright, relative to the object. A convex mirror form a virtual image of the object, no matter where in front of the mirror the object is placed.

Uses of Convex Mirror

Convex mirrors, give a wider field of view than do other types of mirrors. Therefore, they are often used for security purposes, as in figure 1.25.
A mirror with a wide field of view is also needed to give a driver a good rear view. Thus, the outside mirror on the passenger side is often a convex mirror. Printed on such a mirror is usually the warning “vehicles in mirror are closer than they appear.”

Fig. 1.25 : Security mirror

Fig. 1.26 : Rear view mirror

The reason for the warning is that the virtual image in figure is reduced in size and therefore looks smaller, just as a distant object would appear in a plane mirror. An unwary driver, thinking that the side-view mirror is a plane mirror, might incorrectly deduce from the small size of the image that the car behind is far enough away to ignore.

Convex mirror also used in street lighting.

Did You Know?

Virtual image cannot be obtained on a screen. In case of mirror virtual image is formed behind the mirror and in case of lens, virtual image is formed on the same side as the object.

COMPARING THE FIELD OF VIEW OF A PLANE MIRROR AND A CONVEX MIRROR

For a fair comparison to be made the two mirrors must be the same size and the eye must be placed at the same distance from each of them. The maximum angle of view is obtained when the angle of reflection at the mirror is a maximum, i.e., when the normal to the mirror are drawn at the extreme edges of the mirror.

The normals to the convex mirror are lines which are continuations of the radii at the edges of the mirror. Once the angles of reflection have been drawn, equal angles must be drawn on the other side of the normals to give the position of the incident rays. The angle of incidence for the convex mirror is much greater than the angle of incidence for the plane mirror, hence the convex mirror has a greater field of view than that of plane mirror.

SIGN CONVENTION

(1) All distances are measured from the pole.

(2) The distance measured along the direction of propagation of light are taken as positive and the direction opposite to the propagation of light is taken as negative.

(3) The distances (heights) measured above the principal axis i.e. along positive Y axis, are taken as positive while distances below the principal axis i.e. along negative Y axis are taken as negative.

In this convention, the focal length (f) and radius of curvature (R) are negative for a concave mirror and positive for a convex mirror.

The sign convention can be summarized in the following figure.

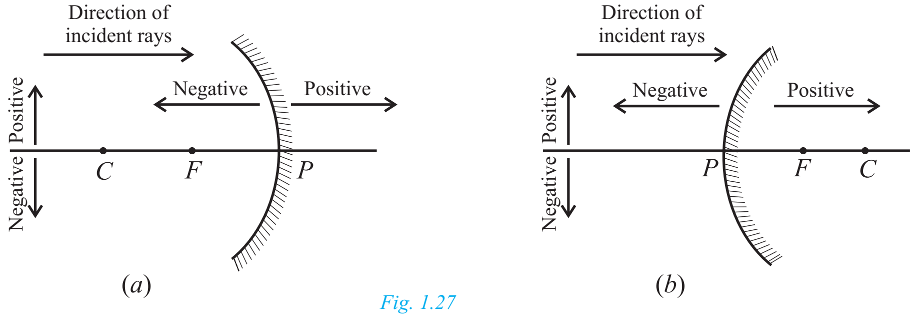


Fig. 1.27

Note : Many students get confused in applying sign convention and a small error in sign of one variable will throw all your calculation. Please study 3 points carefully (put known quantities with proper sign, unknown quantity will come automatically with proper sign).

In following situations, the sign convention has been applied.

1. Consider the mirror shown in Fig. 1.28 (*a*). Here, the object is on the left and image is also on the left. The mirror is a concave mirror. The incident ray is directed from left to right and so the positive X-axis is also from left to right.

Here, object distance $u = -PO$, image distance $v = -PI$ radius of curvature $R = -PC$, focal length f = negative.

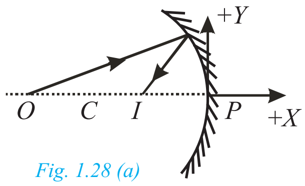


Fig. 1.28 (a)

2. Consider the mirror shown in Fig. 1.28 (*b*). Here, the object is on the left and image is on the right and the mirror is concave. The incident ray is once again from left to right and so the positive X-axis.

Here, object distance $u = -PO$, image distance $v = +PI$, radius of curvature $R = -PC$, focal length f = negative.

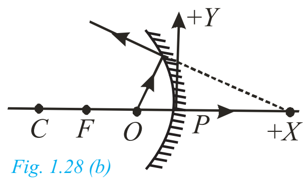


Fig. 1.28 (b)

3. Consider the mirror shown in Fig. 1.27 (c). Here, the object is virtual and on the left, image is also on the right and the mirror is a convex. The incident ray is from the right and the positive X-axis is from right to left.

Here, object distance $u = +PO$, image distance $v = -PI$, radius of curvature $R = +PC$, focal length f = positive.

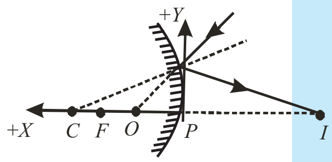


Fig. 1.28 (c)

RELATION BETWEEN FOCAL LENGTH (f) AND RADIUS OF CURVATURE (R) FOR SPHERICAL MIRRORS

The focal length (f) of a mirror is half of the radius of curvature (R), that is, $f = \dfrac{R}{2}$

Proof : In fig. 1.29, incident ray OX is parallel to the principal axis. After reflection, it actually passes through focus F in case of concave mirror and appears to come from focus F in case of a convex mirror. CXN is normal to mirror at X.

For concave mirror (Fig.1.29 (a) (because $\angle i = \angle r$)

$\angle OXC = \angle FXC = \theta$

But $\angle OXC = \angle XCF$ (alternate angles)

For convex mirror (Fig. 1.29 (b)

$\angle OXN = \angle YXN = \theta$

But $\angle OXN = \angle XCF$ (corresponding angles) and $\angle YXN = \angle FXC$ (vertically opposite)

Hence (in both cases), $\angle FXC = \angle XCF$ there fore, in ΔFCX, $FC = FX$

For mirror of small aperture, X will be near P, then $FX = FP$

Hence, $FC = PF$ and $2PF = PF + PF = PF + FC = PC$ i.e. $2f = R$ or $f = R/2$ (Proved).

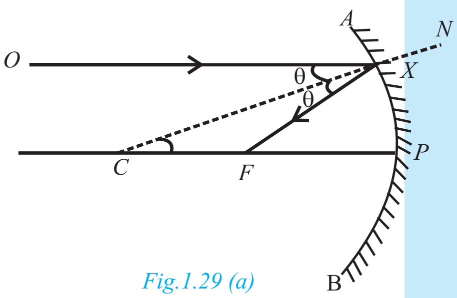


Fig.1.29 (a)

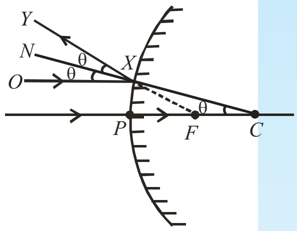


Fig. 1.29 (b)

Time to Check Your Knowledge

☛ **Her eye at point P looks into the mirror. Which of the numbered cards can she see reflected in the mirror?**

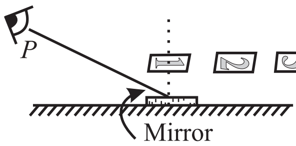


Fig. 1.30

SOLUTION

Card number 2, she can see through the mirror. According to law of reflection, angle of incidence is equal to angle of reflection. Light ray coming from card number 2 makes the same angle with the normal at the point of incidence as the light ray going to eye makes with the normal.

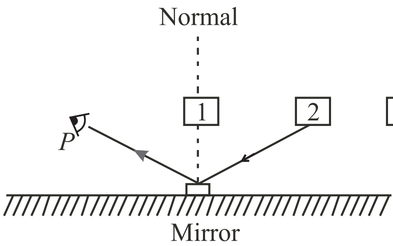


Fig. 1.31

MIRROR FORMULA

A relationship among the object distance (u), the image distance (v) and the focal length (f) of a mirror is called the mirror formula.

The formula is given by $\frac{1}{f}=\frac{1}{u}+\frac{1}{v}$

Proof: Take an object AB beyond C of a concave mirror MM'. A ray AD parallel to principal axis passes through focus after reflection. Another ray AE which is passing through C comes back along the same path after reflection. These two reflected rays intersect at A'. From A' draw perpendicular $A'B'$ on the principal axis. So $A'B'$ is real and inverted image which is formed between C and F which is smaller than the object in size.

Draw DG perpendicular to the principal axis. So, applying sign convention, we get $PB = -u$; $PB' = -v$; $PF = -f$; $PC = -2f$

In ΔABC and $\Delta A'B'C$, $\angle ABC = \angle A'B'C = 90°$

$\angle ACB = \angle A'CB'$ (Vertically opposite angles)

$\therefore \Delta ABC \sim \Delta A'B'C$ (AA similarity)

$\frac{AB}{A'B'}=\frac{BC}{B'C}$ (Corresponding sides of similar triangles are in proportion)....(1)

In ΔDGF and $\Delta A'B'F$, $\angle DGF = \angle A'B'F = 90°$

$\angle DFG = \angle A'FB'$ (Vertically opposite angles)

$\Delta DGF \sim \Delta A'B'F$ (AA similarity)

$\frac{DG}{A'B'}=\frac{GF}{B'F}$ (Corresponding sides of similar triangles are in proportion)

But $AB = DG$ (the perpendicular distance between two parallel lines are equal)

$\therefore \frac{AB}{A'B'}=\frac{GF}{B'F}$ ...(2)

From eq. (1) and (2), we get, $\frac{BC}{B'C}=\frac{GF}{B'F}$ ...(3)

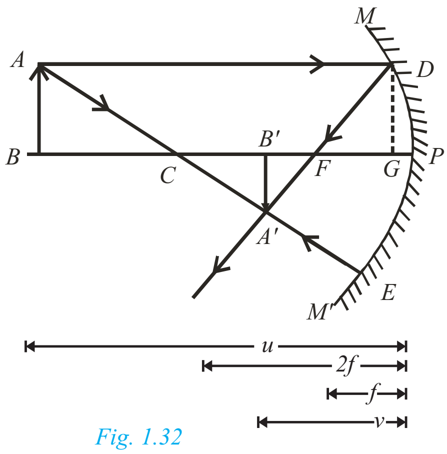


Fig. 1.32

Let us assume that mirror is very small,

$\therefore$ G and P are very close to each other so that $GF = PF$.

From (3), $\frac{BC}{B'C}=\frac{PF}{B'F} \Rightarrow \frac{PB-PC}{PC-PB'}=\frac{PF}{PB'-PF} \Rightarrow \frac{-u-(-2f)}{-2f-(-v)}=\frac{-f}{-v-(-f)}$

$\Rightarrow \frac{-u+2f}{-2f+v}=\frac{-f}{-v+f} \Rightarrow (-v+f)(-u+2f) = -f(-2f+v)$

$\Rightarrow vu - 2fv - fu + 2f^2 = 2f^2 - fv \Rightarrow uv = -fv + 2fv + fu$

$\therefore uv = vf + uf$

Dividing both sides by uvf,

$\frac{uv}{uvf}=\frac{vf}{uvf}+\frac{uf}{uvf} \Rightarrow \frac{1}{f}=\frac{1}{u}+\frac{1}{v}$

ILLUSTRATION : 1.5

The radius of curvature of a spherical mirror is 20 cm. What is its focal length ?

SOLUTION :

As we know, focal length (f) of a mirror is half of the radius of curvature (R).

$\therefore f=\frac{R}{2}=\frac{20}{2}=10\,\text{cm.}$

ILLUSTRATION : 1.6

An object is placed at a distance of 10 cm from a convex mirror of focal length 15 cm. Find the position and nature of the image.

SOLUTION :

Given : $u = -10$ cm, $f = +15$ cm, $v = ?$

Using the mirror formula $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$, we have

$$\frac{1}{v} = \frac{1}{f} - \frac{1}{u} = \frac{1}{15} - \frac{1}{(-10)} \quad \text{or} \quad \frac{1}{v} = \frac{1}{15} + \frac{1}{10} = \frac{2+3}{30} = \frac{5}{30} \quad \text{or} \quad v = \frac{30}{5} = 6 \text{ cm.}$$

Hence, the image is formed at a distance of 6 cm behind the mirror. The image is virtual and erect.

ILLUSTRATION : 1.7

We wish to obtain an erect image of an object, using a concave mirror of focal length 15 cm. What should be the range of distance of the object from the mirror ? What is the nature of the image? Is the image larger or smaller than the object? Draw a ray diagram to show the image formation in this case.

SOLUTION :

Here, focal length, $f = -15$ cm.

For getting an erect image using a concave mirror the object should be placed at a distance less than the focal length (i.e.) 15 cm from pole. Image will be virtual, enlarged and erect.

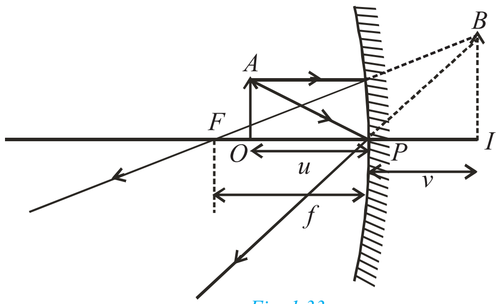


Fig. 1.33

MAGNIFICATION

If the mirror is plane, the size of the image is always equal to the size of the object i.e., **magnification is unity**. But the case is different for a curved mirror. The size of the image is different from the size of the object in such a 'mirror'. Image may be greater or smaller in size than the object depending upon the nature of the mirror or the location of the object.

Let I and O be the size of the image and the object respectively. The ratio $\frac{I}{O}$ is called **magnification**, and it is denoted by m.

Magnification, $m = \frac{I}{O}$

This is also called **linear magnification.**

Superficial magnification: It is the ratio of area of image to the area of object. Superficial magnification $= \frac{\text{area of image}}{\text{area of object}} = \frac{(I_{area})^2}{(O_{area})^2}$

Other formulae of magnification

$$\text{Magnification, } m = -\frac{v}{u} = -\left(\frac{v-f}{f}\right) = \frac{f-v}{f} = -\left(\frac{f}{u-f}\right) = \frac{f}{f-u}$$

NEWTON'S FORMULA

This formula provides a relationship among the focal length (f), the distance of the object from focus (x) and the distance of the image from focus (y).

This can be expressed as $xy = f^2$

Note that here the object distance and the image distance are measured from the focus of the mirror not from the pole.

CASE STUDY-1 : Nature, Position, Relative size and Magnification of the Image Formed by the Spherical Mirror.

The size of image formed by a spherical mirror depends on the position of the object from the mirror, the size of the object and magnification of the mirror. The image formed by a spherical mirror can be bigger than the object, equal to the object, smaller than the object, errect or inverted.

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

i.e., $m = \dfrac{\text{height of image}}{\text{height of object}} = \dfrac{h_2}{h_1}$

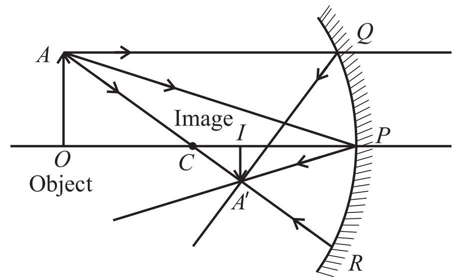


Fig. 1.34

From triangles APO and A'PI

$\dfrac{AO}{A'I} = \dfrac{PO}{PI} = \dfrac{-v}{u} \Rightarrow m = \dfrac{\text{height of image}}{\text{height of object}} = \dfrac{-v}{u}$ where v = image distance, u = object distance

Generally, in our ray diagram, the object is placed above the principle axis, so the height (h_1) of the object will be positive.

CASE - I: If the magnification has positive sign i.e., m > 0 then the image is virtual and errect.

i.e., for virtual image h_2 is positive and object h_1 is positive so magnification $m = \dfrac{h_2}{h_1} = +ve > 0$

CASE - II: If the magnification has a minus sign i.e., m < 0 then the image is real and inverted.

For real image, h_2 is negative and h_1 is positive, so the magnification $m = \dfrac{h_2}{h_1} = -ve < 0$

CASE - III: If the magnification m has a value greater than 1 i.e., m > 1, then the image is bigger than the object. It means magnified and enlarged image is formed.

CASE - IV: If the magnification m is exactly 1 i.e, m = 1 then the image is of the same size as the object size.

$m = \dfrac{h_2}{h_1} = 1 \Rightarrow h_2 = h_1$

CASE - V: If the magnification m is less than 1 i.e., if $0 < m < 1$, then the image formed will be smaller than the object. i.e., diminished image will form.

CASE-VI: Magnification produced by a concave mirror can be either positive or negative because concave mirror can produce virtual as well as real image. For concave mirror. m > 1 or m < 1 or m = 1

CASE-VII: Magnification produced by a convex mirror is always positive as the convex mirror forms only virtual image.

Also as the convex mirror forms images which are always smaller than the object, so magnification m produced by the convex mirror is always less than 1.

Think Out of the Box

Q 1. What is the nature of the image formed by a concave mirror if the magnification produced by the mirror is +3?

Q 2. The magnification produced by a plane mirror is +1. What does it mean?

Q 3. How could you distinguish convex mirror with concave mirror in terms of nature, magnification and size of the image formed.

Q 4. Find the size, nature and magnification of the image formed when an object of size 1 cm is placed at a distance 15 cm from a concave mirror of focal length 10 cm.

[**Hint :** use, $\dfrac{1}{v} + \dfrac{1}{u} = \dfrac{1}{f}$ and $m = \dfrac{-v}{u} = \dfrac{h_2}{h_1}$ **Ans.** Size of image is 2 cm long, image is real and inverted, magnification $m = -2$]

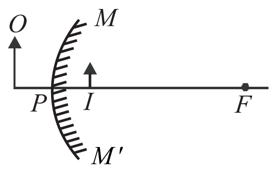
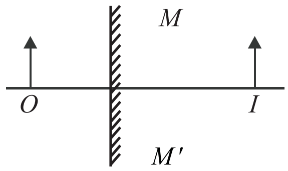
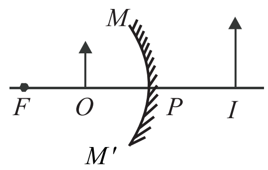
Q 5. An object 2 cm high is placed at a distance 16 cm from a concave mirror which produces a real image 3 cm high. Find the position, magnification and nature of the image formed.

[**Hint :** $m = \dfrac{h_2}{h_1} = \dfrac{-v}{u}$ **Ans.** The position of the image is 24 cm in front and left side of the mirror. Magnification $m = -1.5$ Image is real and inverted.]

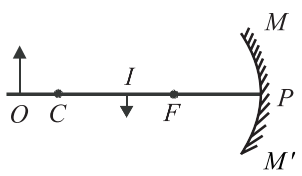
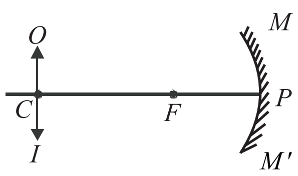
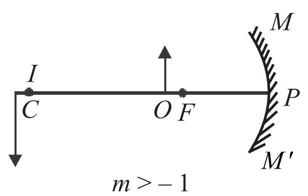
IDENTIFICATION OF MIRROR BY THE SIZE AND NATURE OF THE IMAGE

(i) If object and image are of same nature (i.e. both on the same side of the mirror) then they will be inverted.

(ii) If the object and image are on the opposite sides of the mirror then image is erect relative to object.
For real extended object if the image formed by a single mirror is erect it is always virtual (i.e. m is $+ve$) and in this situation if the size of image is

Smaller than object, the mirror is convex	Equal to object, the mirror is plane	Larger than object, the mirror is concave
 $m < +1$ *Fig. 1.35*	 $m = +1$ *Fig. 1.36*	 $m > +1$ *Fig. 1.37*

So, by observing the size of erect image in a mirror we can decide the nature of the mirror i.e. whether it is convex, concave or plane. For real extended object if the image formed by a single mirror is inverted it is always real (i.e., m is $-ve$) and the mirror is concave. In this situation if the size of image is

Smaller than object, object is between the ∞ and C and image is between F and C	Equal to object, object is at C and image is at C	Larger than object, object is between C and F and image is between C & ∞
 $m < -1$ *Fig. 1.38*	 $m = -1$ *Fig. 1.39*	 $m > -1$ *Fig. 1.40*

Learn More

Every part of a mirror forms complete image, if a part of mirror (say half) is obstructed (say covered with black paper) full image will be formed but intensity will be reduced.

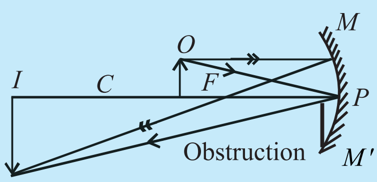


Fig. 1.41

ILLUSTRATION : 1.8

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

SOLUTION :

Here, size of object, $h = 3$ cm
$u = -10$ cm (sign convention)
$f = -20$ cm (sign convention)

Using $\frac{1}{u}+\frac{1}{v}=\frac{1}{f}$, we have $-\frac{1}{10}+\frac{1}{v}=-\frac{1}{20}$ or $\frac{1}{v}=-\frac{1}{20}+\frac{1}{10}=\frac{1}{20}$ $\quad \therefore v = 20$ cm

Thus, image is formed at a distance of 20 cm from the concave mirror. Since v is positive, so image is formed behind the concave mirror. It means the image is virtual (nature).

Using, $m=\frac{h'}{h}=-\frac{v}{u'}$ we get $\frac{h'}{h}=\frac{-20\text{cm}}{-10\text{cm}}=2$

or $h' = 2 \times h = 2 \times 3$ cm = 6 cm

Thus, size of the image is 6 cm.

ILLUSTRATION : 1.9

An object, 4.0 cm in size, is placed at 25.0 cm in front of a concave mirror of focal length 15.0 cm. At what distance from the mirror should a screen be placed in order to obtain a sharp image? Find the nature and the size of the image.

SOLUTION :

Object-size, $h = +4.0$ cm; Object-distance, $u = -25.0$ cm; Focal length, $f = -15.0$ cm;

Image-distance, v = ? Image-size, h' = ?

From $\frac{1}{v}+\frac{1}{u}=\frac{1}{f}$ or $\frac{1}{v}=\frac{1}{f}-\frac{1}{u}=\frac{1}{-15.0}-\frac{1}{-25.0}=-\frac{1}{15.0}+\frac{1}{25.0}$

or $\frac{1}{v}=\frac{-5.0+3.0}{75.0}=\frac{-2.0}{75.0}$ or $v = -37.5$ cm.

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

Also, magnification, $m=\frac{h'}{h}=-\frac{v}{u}$ or $h'=-\frac{vh}{u}=\frac{(-37.5\text{cm})(+4.0\text{cm})}{(-25.0\text{cm})}$

Height of the image, $h' = -6.0$ cm.

The image is inverted and enlarged.

ILLUSTRATION : 1.10

A convex mirror used for rear-view on an automobile has a radius of curvature of 3.00 m. If a bus is located at 5.00 m from this mirror, find the position, nature and size of the image.

SOLUTION :

Radius of curvature, $R = +3.00\ m$; Object-distance, $u = -5.00\ m$; Image-distance, v = ? Height of the image, h'= ?

Focal length, $f = R/2 = +\frac{3.00\text{ m}}{2} = +1.50$ m

Since $\frac{1}{v}+\frac{1}{u}=\frac{1}{f}$ or $\frac{1}{v}=\frac{1}{f}-\frac{1}{u}=+\frac{1}{1.50}-\frac{1}{(-5.00)}=\frac{1}{1.50}+\frac{1}{5.00}=\frac{5.00+1.50}{7.50} \Rightarrow v=\frac{+7.50}{6.50}=+1.15\text{m}$

The image is 1.15m at the back of the mirror.

Magnification, $m=\frac{h'}{h}=-\frac{v}{u}=-\frac{1.15\text{m}}{-5.00\text{m}}=+0.23$

The image is virtual, erect and smaller in size by a factor of 0.23.

ILLUSTRATION : 1.11

An object is placed at a distance of 8 cm from a concave mirror of focal length 10 cm. Find the position and nature of the image formed. Also draw the ray diagram.

SOLUTION :

Here, (using sign convention)

Focal length, $f = -10$ cm

Object distance, $u = -8$ cm

Image distance, v = ?

From mirror formula, $\frac{1}{u}+\frac{1}{v}=\frac{1}{f}$

Putting values, we get

$\frac{1}{v}=\frac{1}{-10}-\frac{1}{-8}=\frac{-4+5}{40}=\frac{1}{40}$

$\therefore v = +40$ cm

The image is formed at a distance of 40 cm behind the mirror.

It is virtual, erect and enlarged.

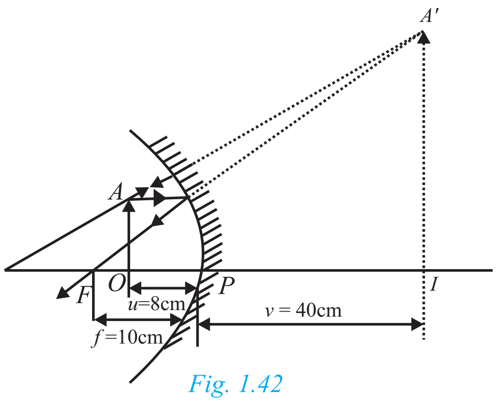


Fig. 1.42

The ray diagram is shown.

Incident rays taken are one parallel to principal axis and the other appearing to come from side of centre. Reflected ray appear to come from A', forming virtual image of A, IA' is erect, virtual of real obejct OA.

ILLUSTRATION : 1.12

An object 4.0 cm in size is placed at a distance of 25.0 cm in front of a convex mirror of radius of curvature 40 cm. Find (i) the position, (ii) the size and (iii) nature of the image.

SOLUTION :

Here, $h = +\,4.0$ cm

$u = -\,25.0$ cm (sign conventions)

$R = +\,40$ cm

$\therefore\ f = \frac{R}{2} = \frac{40}{2} = 20.0$ cm

(i) Determination of the position of the image.

Using, $\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$ we get $\frac{1}{v} = \frac{1}{f} - \frac{1}{u} = \frac{1}{20} - \frac{1}{(-25)} = \frac{1}{20} + \frac{1}{25} = \frac{9}{100}$

or $v = \frac{100}{9} 11.11$ cm

Thus, the image is at 11.11 cm behind the convex mirror.

(ii) Determination of the size of the image

Using, $m = \frac{h'}{h} = -\frac{v}{u}$ or $h' = -\frac{v}{u}h$ or, $h' = -\frac{(100/9)(4)}{-25} = \frac{16}{9} = 1.78$ cm

Thus, size of image = 1.78 cm.

(iii) Nature of the image : Since h' is positive, so the image is erect.

ILLUSTRATION : 1.13

A concave mirror of focal length *f* produces a real image n times the size of the object. What is the distance of the object from the mirror?

SOLUTION :

Here, magnification, $m = -\,n$; $m = \frac{f}{f-u}$

$-\,n = \frac{-f}{-(f-u)} \Rightarrow nf - nu = -f$

$-\,nu = -f - nf \Rightarrow u = \frac{(n+1)}{n} f$

ILLUSTRATION : 1.14

The focal length of a concave mirror is 30 cm. Find the position of the object in front of the mirror, so that the image is three times the size of the object.

SOLUTION :

Here image can be real or virtual. If the image is real

$f = -30$ cm, $u = ?$, $m = -\,3$

$m = \frac{f}{f-u} \Rightarrow -3 = \frac{-30}{-30-u} \Rightarrow u = -\,40$ cm.

If the image is virtual $m = \frac{f}{f-u} \Rightarrow 3 = \frac{-30}{-30-u} \Rightarrow u = -\,20$ cm.

REFRACTION OF LIGHT

The bending of the light ray from its path in passing from one medium to the other medium is called refraction of light.
If the refracted ray bends towards the normal relative to the incident ray (passing obliquely), then the second medium is said to be denser than the first medium. But if the refracted ray bends away from the normal, then the second medium is said to be rarer than the first medium.

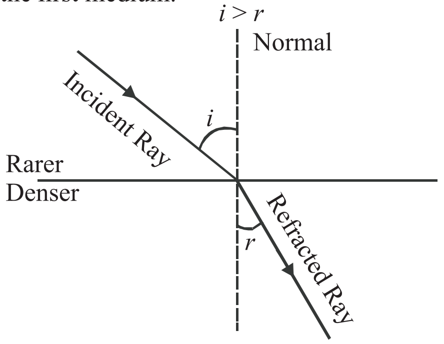


Fig. 1.43 (a)

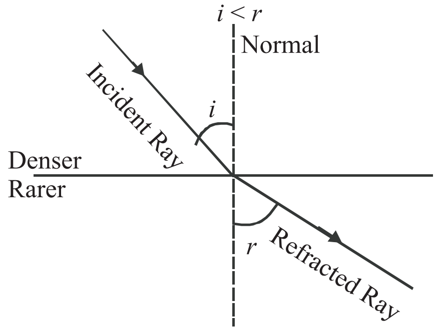


Fig. 1.43 (b)

If a ray of light passing normally i.e., at right angles from one medium to another optical medium then it does not bend or deviate from its path.

Cause of refraction of light: Refraction of light takes place due to change in the speed of light as it enters from one medium to another medium.

Refraction causes many illusions. One of them is the **apparent bending of a stick that is partially submerged in water**. The submerged part appears closer to the surface than it actually is. The same is true when you look at a fish in water. The fish appears nearer to the surface and closer than it really is (Fig. 1.44). If we look straight down into water, an object submerged 4 meters beneath the surface appears to be only 3 meters deep. Because of refraction, submerged objects appear to be magnified.

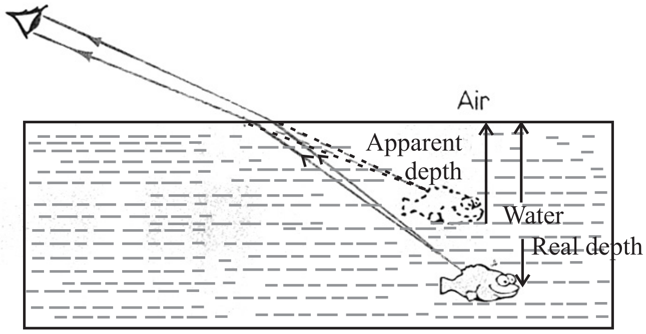


Fig.1.44 Because of refraction, a submerged object appears to be nearer to the surface than it actually is

Atmospheric Refraction

Refraction occurs in the earth's atmosphere. Whenever we watch a sunset, we see the sun for several minutes after it has sunk below the horizon (Fig. 1.45). The earth's atmosphere is thin at the top and dense at the bottom. Because light travels faster in thin air than in dense air, parts of the wavefronts of sunlight at high altitude travel faster than parts closer to the ground. Light rays bend. The density of the atmosphere changes gradually, so light rays bend gradually and follow a curved path. So we gain additional minutes of daylight each day. Furthermore, when the sun (or moon) is near the horizon, the rays from the lower edge are bent more than the rays from the upper edge. This shortens the vertical diameter, causing the sun to appear elliptical figure).

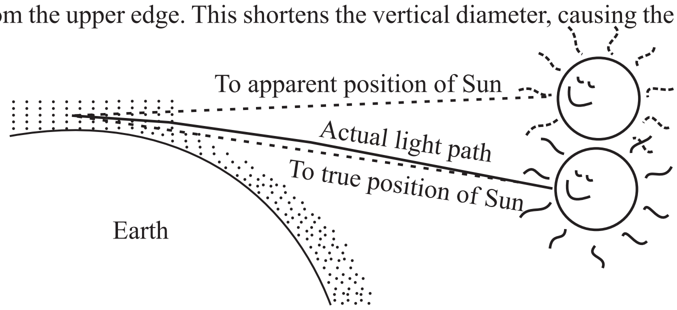


Fig. 1.45. Because of atmospheric refraction, when the sun is near the horizon it appears to be higher in the sky.

Time to Check Your Knowledge

☛ **If, while standing on the bank of a stream, you wished to spear a fish swimming in the water out in front of you, would you aim above, below, or directly at the observed fish to make a direct hit? If you decided instead to zap the fish with a laser, would you aim above, below, or directly at the observed fish? Defend your answer.**

SOLUTION

When you try to hit the fish with a spear, you need to aim below as the fish is actually at a lower depth than that observed by you from outside the water due to refraction of light.
When you aim with a laser light then you should aim above as the path of laser will change as it enters in water. Since it is going from rarer to denser medium, it bends towards the normal and deviates from the original path.

Laws of Refraction

There is two laws of refraction

1. The incident ray, the refracted ray, and the normal to the refracting surface at the point of incidence are in the same plane.
2. The ratio of *sine* of angle of incidence to the *sine* of angle of refraction is constant for a pair of media i.e. $\frac{\sin i}{\sin r}$ = constant $({}_1\mu_2)$

   Where ${}_1\mu_2$ is the refractive index of medium 2 w.r.t. medium 1. This law is also known as **snell's law.**

Application of Snell's Law

When light passes from rarer to denser medium it bends toward the normal fig 1.46 (a).
Using Snell's law

$\mu_1 \sin\theta_1 = \mu_2 \sin\theta_2 \Rightarrow \frac{\sin\theta_1}{\sin\theta_2} = \frac{\mu_2}{\mu_1}$

Thus, if $\mu_2 > \mu_1$ then $\theta_2 < \theta_1$

When light passes from denser to rarer medium it bends away from the normal fig 1.46(b).

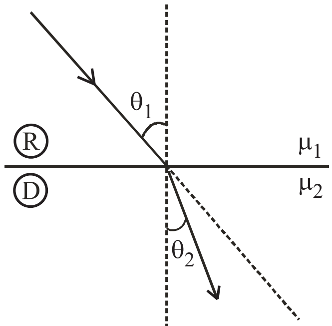


Fig. 1.46 (a) Ray bending towards normal.

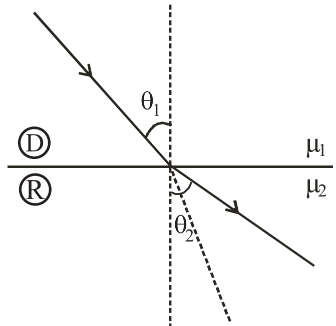


Fig. 1.46 (b) Ray bending away from normal.

From Snell's law, $\frac{\sin\theta_1}{\sin\theta_2} = \frac{\mu_2}{\mu_1}$

When light propagates through a series of layers of different medium, then according to Snell's law

$\mu_1 \sin\phi_1 = \mu_2 \sin\phi_2 = \mu_3 \sin\phi_3 = \text{.........} = \text{constant}$

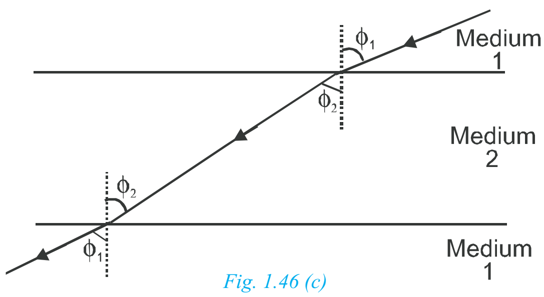


Fig. 1.46 (c)

Did You Know?

If ${}_1\mu_2$, ${}_2\mu_3$ and ${}_3\mu_1$ be refractive index of medium 2 w.r.t. medium 1, refractive index of medium 3 w.r.t medium 2 and refractive index of medium 1 w.r.t. medium 3 respectively then ${}_1\mu_2 \times {}_2\mu_3 \times {}_3\mu_1 = 1$.

REFRACTIVE INDEX

Light travels through a vacuum at a speed c = 3.00 × 10^8 m/s. It can also travel through many materials, such as air, water and glass. Atoms in the material absorb, re-emit and scatter the light, however. Therefore, light travels through the material at a speed that is less than c, the actual speed depending on the nature of the material.
To describe the extent to which the speed of light in a material medium differs from that in a vacuum, we use a parameter called the index of refraction (or refractive index).

Absolute Refractive Index

It is defined as *the ratio of speed of light in free space c to that in a given medium v.*

i.e. μ or $n = \dfrac{c}{v}$ ... (1)

Also, μ or $n = \dfrac{\sin i}{\sin r}$ (incident ray in vacuum or air)

It is a scalar and has no units and dimensions.
As in vacuum or free space, speed of light of all wavelengths is maximum and equal to c, so, for all wavelengths the refractive index of free space is minimum and is $\mu = \dfrac{c}{v} = \dfrac{c}{c} = 1$

For a given light, denser is the medium, lesser will be the speed of light and so greater will be the refractive index, e.g. as $v_{glass} < v_{water}$, $\mu_G > \mu_w$

i.e. for a given light refractive index depends on nature of medium [i.e., $\mu \propto (1/v)$

For a given medium (other than free-space), the speed of light of different wavelengths is different,i.e., $v \propto \lambda$ and $\mu = (c/v)$, $\mu \propto \dfrac{1}{\lambda}$ i.e. greater the wavelength of light lesser will be the refractive index e.g. $\lambda_R > \lambda_B$, so in water or glass $\mu_R > \mu_B$, i.e., for a given medium (other than free space) refractive index depends on wavelength of light.
As for light in free space $c = f\,\lambda_0$ vand in a medium $v = f\,\lambda$,

$$\mu = \frac{c}{v} = \frac{\lambda_0}{\lambda} \quad \text{... (2)}$$

i.e., for a given light and medium refractive index is equal to the ratio of wavelength of light in free space to that in the medium.
Refractive index decreases with the increase in temperature.

Relative Refractive Index

When light passes from one medium to the other, the refractive index of medium 2 relative to 1 is written as ${}_1\mu_2$ and is defined as ${}_1\mu_2 = \dfrac{\mu_2}{\mu_1} = \dfrac{(c/v_2)}{(c/v_1)} = \dfrac{v_1}{v_2}$ ... (3)

While using the concept of relative μ, it must be kept in mind that :

$${}_2\mu_1 = \frac{\mu_1}{\mu_2} = \frac{v_2}{v_1} \text{ So that, } ({}_1\mu_2)({}_2\mu_1) = \frac{v_1}{v_2} \times \frac{v_2}{v_1} = 1 \text{ i.e., } {}_1\mu_2 = \frac{1}{{}_2\mu_1} \quad \text{.... (4)}$$

Usually 'μ' is used for relative refractive index and it implies the refractive index of denser medium relative to rarer one,

i.e., $\mu = \dfrac{\mu_D}{\mu_R} = \dfrac{v_R}{v_D} > 1$

In lens theory μ is used for the refractive index of material of lens relative to the medium,

i.e., $\mu = \dfrac{(\mu)_{\text{Lens}}}{(\mu)_{\text{Medium}}}$ and can be greater than, less than or equal to unity.

Time to Check Your Knowledge

- **If you place a glass test tube in water, you will be able to see the tube. If you place it in clear soyabean oil, you may not be able to see it. What does this tell you about the speed of light in the oil and in the glass?**

SOLUTION

If a glass test tube is placed in water and it can be seen, this indicates the speed of light in glass and water is different. So refraction takes place.

When the same glass tube is placed in soyabean oil, it cannot be seen that means the speed of light is same in both oil and glass. So no refraction takes place between the two media.

Learn More

Conditions of no refraction : If light is incident normally on a boundary i.e., $\angle i = 0°$

Then from Snell's law

$$\mu_1 \sin 0 = \mu_2 \sin r \Rightarrow \sin r = 0 \text{ i.e. } \angle r = 0$$

i.e., light passes undeviated from the boundary. (so boundary will be invisible)

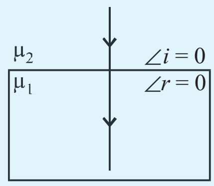


Fig. 1.47 (a)

If the refractive indices of two media are equal i.e., if,

$$\mu_1 = \mu_2 = \mu$$

Then from Snell's law $\mu_1 \sin i = \mu_2 \sin r \Rightarrow \angle i = \angle r$

i.e., ray passes undeviated from the boundary with $\angle i = \angle r \neq 0$ and boundary will not be visible.

This is also why a transparent solid is invisible in a liquid if $\mu_s = \mu_L$

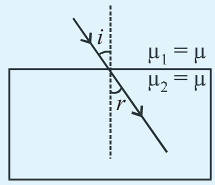


Fig. 1.47 (b)

REFRACTION THROUGH A RECTANGULAR GLASS SLAB

Let us consider a glass slab of thickness t and refractive index μ on which a ray AB is incident at B. BC and CD are the refracted ray and emergent ray respectively. x is the displacement in the emergent ray due to refraction.

From ΔBCE,

$$\sin(i-r) = \frac{CE}{BC}$$

or $$\sin(i-r) = \frac{x}{BC} \quad \text{..... (1)}$$

Also, from ΔBFC,

$$\cos r = \frac{BF}{BC} = \frac{t}{BC} \quad \text{..... (2)}$$

Equating BC from (1) and (2), we get

$$\frac{x}{\sin(i-r)} = \frac{t}{\cos r} \Rightarrow x = \frac{t\sin(i-r)}{\cos r}$$

$$\Rightarrow x = t \sec r . \sin(i-r)$$

where x is called the lateral displacement

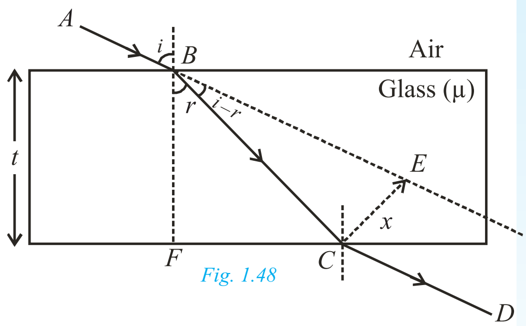


Fig. 1.48

Lateral displacement depends on the following factors.

(i) Refractive index of the medium (μ) $x \propto \mu$

(ii) Thickness of the medium (t) $x \propto t$

(iii) Angle of incidence (i) $x \propto i$

(iv) Wavelength of light (λ) $x \propto \frac{1}{\lambda}$

Did You Know?

Refrangibility is the ability of light to get refracted when passing from one medium to another and it depends on the refractive index of the medium for a given wavelength of light.

ILLUSTRATION : 1.15

Light waves of 5895 Å wavelength travels from vacuum to a medium of refractive index of 1.5. Find the velocity of light and wavelength in medium.

SOLUTION :

If velocity of light in vacuum is c then velocity of light in medium is $v = \frac{c}{n} = \frac{3\times10^8}{1.5} = 2 \times 10^8$ m/sec

Wavelength of light in medium $\lambda_m = \frac{\lambda}{n} = \frac{5895}{1.5} = 3930$ Å.

ILLUSTRATION : 1.16

The refractive index of water is 4/3 and of glass is 3/2. Calculate the refractive index of glass with respect to water.

SOLUTION :

Let the 3 media be 1, 2 and 3, 1 for air, 2 for water, 3 for glass in that order.

Given : $_1\mu_2 = \frac{4}{3}$, $_2\mu_3 = ?$, $_3\mu_1 = \frac{1}{3/2}$, [$\because$ $_1\mu_3 = \frac{3}{2}$ and $\therefore$ $_3\mu_1$ is the reciprocal of $_1\mu_3$]

Now using the formula, $_1\mu_2 \cdot {}_2\mu_3 \cdot {}_3\mu_1 = 1$ and substituting values, we have

$$\frac{4}{3} \cdot {}_2\mu_3 \cdot \frac{2}{3} = 1 \Rightarrow {}_2\mu_3 = \frac{1\times3\times3}{4\times2} = \frac{9}{8}$$

$\therefore$ The refractive index of glass with respect to water is 9/8

ILLUSTRATION : 1.17

The refractive index of a material is 1.33. If velocity of light in vacuum is 3×10^8 ms^{-1}, find the velocity of light in the material.

SOLUTION :

Refractivge index, $\mu = \frac{\text{Velocity of light in vacuum}}{\text{Velocity of light in material}}$

$$\therefore \quad 1.33 = \frac{3\times10^8 \text{ ms}^{-1}}{\text{Velocity of light in material}}$$

$$\therefore \quad \text{Velocity of light in material} = \frac{3\times10^8}{1.33} = 2.25\times10^8 \text{ ms}^{-1}$$

LLUSTRATION : 1.18

The angle of incidence in air for a ray of light is 40°. If ray travels through water of refractive index 4/3, find angle of refraction.

SOLUTION :

According to snell's law, ${}^a\mu_w = \frac{\sin i}{\sin r}$

$$\therefore \quad \sin r = \frac{\sin i}{{}^a\mu_w} = \frac{\sin 40}{4/3} = \frac{3\times0.6427}{4} = 0.4820$$

$r = \sin^{-1}(0.4820) = 28.82°$ (approx.)

ILLUSTRATION : 1.19

Light reflected from a fish strikes the surface of the water at an angle of 38° to the normal. What is the angle of refraction of the light into the air ?

SOLUTION :

Snell's law gives, $n_w \sin\theta_1 = n_a \sin\theta_2 \Rightarrow \sin\theta_2 = (1.33)\sin 38°$
Therefore, the angle of refraction of the light into air $\theta_2 = 55°$

ILLUSTRATION : 1.20

Light strikes an interface between two materials of refractive indices n_1 and n_2, at an angle θ_1 to the normal to the surface. Show that a ray of light is bent towards the normal if $n_1 < n_2$ and that a ray is bent away from the normal if $n_1 > n_2$.

SOLUTION :

Snell's law gives for any light ray $\sin\theta_2 = \dfrac{n_1}{n_2}\sin\theta_1$

If $n_1 < n_2$ then $\sin\theta_2 < \sin\theta_1$ and $\theta_2 < \theta_1$. This means that the ray is bent toward the normal.

If $n_1 > n_2$ then $\sin\theta_2 > \sin\theta_1$ and $\theta_2 > \theta_1$. This means that the ray is bent away from the normal.

ILLUSTRATION : 1.21

One light wave is incident upon a plate of refractive index μ. Find the incident angle *i*, for which refractive and reflective waves are mutually perpendicular.

SOLUTION :

According to snell's laws, $\dfrac{\sin i}{\sin r} = \mu$

Angle between refractive and reflective waves = $180^\circ - (i + r) = 90^\circ$ $i + r = 90^\circ \Rightarrow r = 90^\circ - i$

$$\mu = \frac{\sin i}{\sin(90^\circ - i)} = \frac{\sin i}{\cos i} = \tan i \quad \Rightarrow \quad i = \tan^{-1}(\mu)$$

ILLUSTRATION : 1.22

Figure 1.49, shows the path of ray of light passing through a glass slab. By geometrical construction calculate the refractive index of glass applying Snell's law.

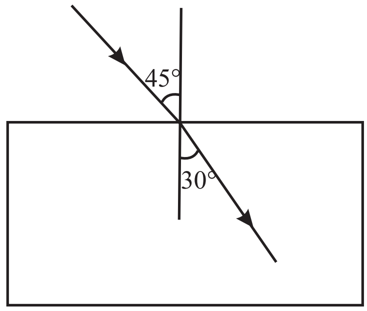


Fig. 1.49

SOLUTION :

AO is the incident ray on the surface of glass and *OB* is the refracted ray through the glass. With *O* as centre draw a circle of some suitable radius cutting the incident ray at *A* and the refracted ray at *B*. Draw perpen
diculars *AC* and *BD* to the normal *COD*.

Refractive index $\mu = \dfrac{\sin i}{\sin r} = \dfrac{AC}{BD} = \dfrac{1.2\text{ cm}}{0.8\text{ cm}} = 1.5$

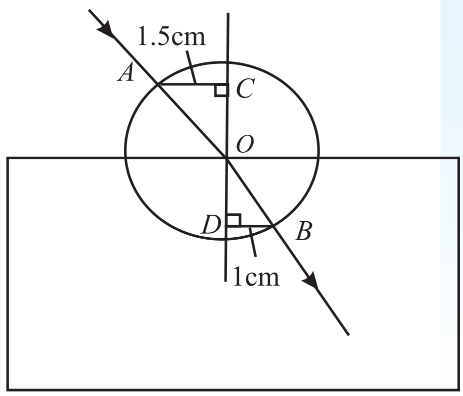


Fig. 1.50

CASE STUDY-2 : Where will the Object Shift During Change of Medium

If object and observer are situated in different medium (having different refractive index) then due to refraction object appears to be displaced from its real position.

CASE - I : Object in optically denser medium and observer in optically rarer medium

Here object O is in optically denser medium (say rectangular glass slab or water). A ray of light which travels along OA (Fig. 1.51) on striking the interface of two mediums at 90° will pass undeviated, while the another ray OB gets refracted at the interface as shown in figure. Image will form at the point I which is intersection point of OE and the produced (backward) line BC. Image will appear at point I.

Here AO = actual depth of object

AI = apparent depth

Now, according to Snell's law,

$$\Rightarrow \quad {}_{denser}\mu_{rarer} = \frac{\sin i}{\sin r} = \frac{AB/OB}{AB/IB} = \frac{IB}{OB}$$

For very small value of i, point B will close to point A.

So, $\quad OB \approx AO$ and $IB \approx AI$

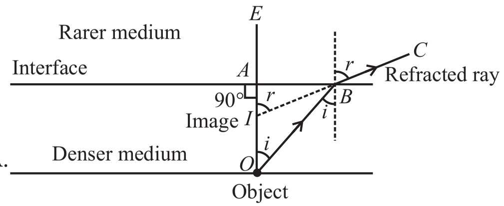


Fig. 1.51

$$\text{Now, } {}_{denser}\mu_{rarer} = \frac{AI}{AO} = \frac{\text{apparent depth}}{\text{real depth}} \Rightarrow {}_{rarer}\mu_{denser} = \mu(\text{say}) = \frac{\text{real depth}}{\text{apparent depth}}$$

So the shift in position of object

$$\Delta s = \text{Real depth} - \text{apparent depth} = AO - \frac{AO}{\mu} = AO\left(1 - \frac{}{}\right)$$

Let $\quad AO = t =$ (thickness of the glass slab) then $\Delta t = t\left(1 - \frac{1}{\mu}\right)$

CASE - II : When object in rarer medium (air) and observer in denser medium (water).

Here i and r are the angle of incidence and angle of refraction.

Also object is in rarer medium and ray comes from rarer medium and entres to the denser medium when the observer is observing the object.

Now applying Snell's law,

$${}_{rarer}\mu_{denser} = \frac{\sin i}{\sin r}$$

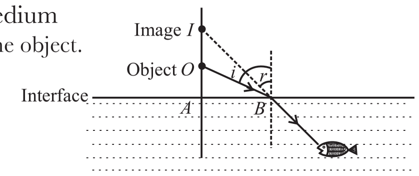


Fig. 1.52

For very small angles

$$\frac{\sin i}{\sin r} \approx \frac{\tan i}{\tan r} = \frac{AB/AO}{AB/AI} = \frac{AI}{AO} \Rightarrow {}_{rarer}\mu_{denser} = \frac{AI}{AO} = \frac{\text{apparent depth}}{\text{real depth}}$$

CASE - III : When extended object is situated perpendicular to the refracting surface.

Here an object of height x is in denser medium (say water) and observer is in rarer medium (say air) as shown in figure.

Let height of image = x'

$${}_{a}\mu_{\omega} = \frac{x}{x'} \Rightarrow x' = \frac{x}{{}_{a}\mu_{\omega}} \qquad \text{....... (i)}$$

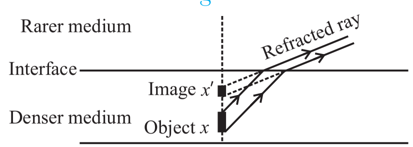


Fig. 1.53

CASE - IV : When extended objected is situated parallel to the refracting surface.

Here an object of height x is in denser medium (say water) and observer is in rarer medium (say air) as shown in figure.

Let height of image = x'

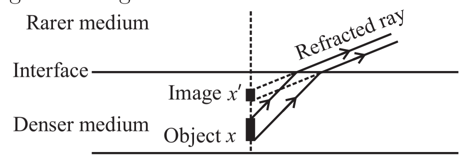


Fig. 1.54

$${}_{a}\mu_{\omega} = \frac{x}{x'} \Rightarrow x' = \frac{x}{{}_{a}\mu_{\omega}} \qquad \text{....... (i)}$$

CASE - V : Shift produced by a glass slab.

Here an object O placed at a distance AO from the left face of the glass slab of thickness t and refractive index μ. Due to refraction by the first face the image formed at I'. Now this image I' will acts as an object formed at I after refraction by the right face of the glass slab.

Now for the left face of the slab using Snell's law

(AI') = μ(AO)

Now for right face :

$$\mu(BI) = BI' = BA + AI' = BA + \mu AO \Rightarrow BI = \frac{BA + \mu AO}{\mu}$$

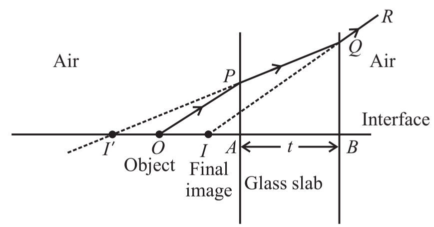


Fig. 1.55

$$\text{Now, } AI = BI - BA = \frac{BA + \mu AO}{\mu} = \frac{BA + \mu(AO - BA)}{\mu}$$

$$\text{So, shift} = OI = AO - AI = \frac{\mu AO - BA - \mu BO + \mu BA}{\mu}$$

$$= BA - \frac{BA}{\mu} = BA\left(1 - \frac{1}{\mu}\right) = t\left(1 - \frac{1}{\mu}\right)$$

Think Out of the Box

Q. 1 Why a swimming pool appears less deep than it really is?

Q. 2 When a thick glass slab is placed over some printed matter, letters appears raised when viewed from the top. Why ?

Q. 3 Why an object placed under water appears to be raised?

Q. 4 A small air bubble is inside a glass cube of side 12 cm. When looking the top face, the bubble appears at a distance of 3 cm and when seen from the opposite face, it appears at a distance of 5 cm. Find refractive index of the glass.

Hint : $\left[\mu = \dfrac{\text{real depth}}{\text{apparent depth}}\right]$ **Ans.** $\mu = 1.5$

Q. 5 When a glass slab is placed on a dot on a paper, it appears displaced by 4 cm, viewed normally. What is the thickness of slab if the refractive index of glass slab is 1.5.

Ans. Displacement $= t\left(1-\dfrac{1}{\mu}\right)$ so $4 = t\left(1-\dfrac{1}{\mu}\right) \Rightarrow t = \dfrac{\mu\times 4}{\mu-1} = \dfrac{1.5\times 4}{1.5-1} = 12$ cm

CONNECTING TOPIC

CONNECTING TOPIC

Total Internal Reflection

When a light ray, travelling from a denser medium to a rarer medium is incident at the interface at an angle of incidence greater than critical angle (C) i.e., the angle of incidence in a denser medium for which the angle of refraction in rarer medium becomes 90º, then light rays reflected back into the denser medium. This phenomenon is called total internal reflection (TIR). Sparkling of diamond, optical fibres etc. are the applications of total internal reflection.

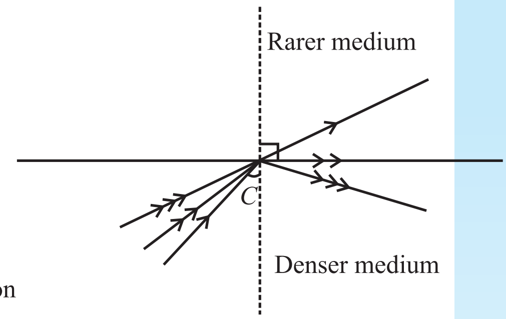


Fig. 1.56

Critical Angle

The angle of incidence in a denser medium for which the angle of refraction in rarer medium becomes 90º is called critical angle.

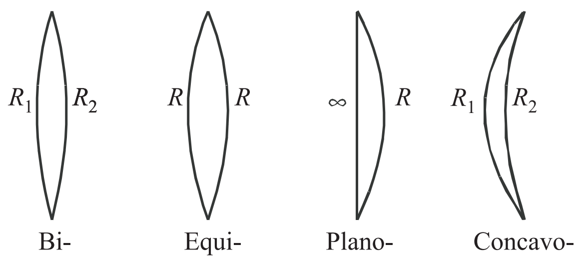
Refractive index of denser medium $\mu = \dfrac{1}{\sin C}$

LENS

A lens is a piece of transparent material with two refracting surfaces such that at least one is curved and refractive index of used material is different from that of the surroundings.

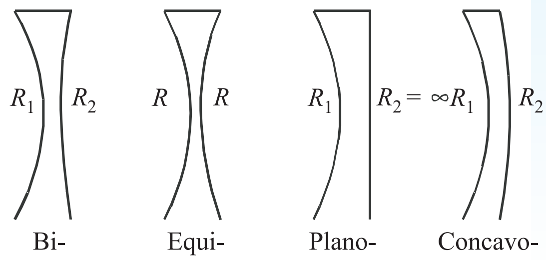
Convex lens: A thin spherical lens with refractive index greater than that of surrounding behaves as a convergent or convex lens i.e. converges parallel rays. Its central (i.e. paraxial) portion is thicker than marginal one.

Convex lens: If the central portion of a lens (with $\mu_L > \mu_M$) is thinner than marginal, it diverges parallel rays and behaves as a divergent or a concave lens.



Convex lens
If $\mu_L > \mu_M$ Converging lens
If $\mu_L > \mu_M$ Diverging lens

Fig. 1.57 (a)



Concave lens
If $\mu_L > \mu_M$ Diverging lens
If $\mu_L < \mu_M$ Converging lens

Fig. 1.57 (b)

TERMS RELATED TO THIN SPHERICAL LENS

Optical centre (O) - It is a point for a given lens through which any ray passes undeviated.
Principal axis (C_1C_2) - It is a line passing through optical centre and perpendicular to the lens. The centre of curvature of curved surface always lie on the principal axis (as in a sphere is always perpendicular to surface)

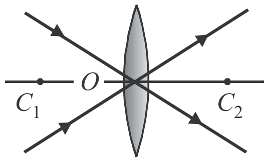


Fig. 1.58 (a)

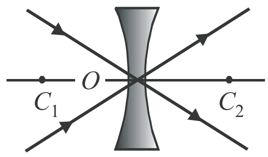


Fig. 1.58 (b)

Principal focus - A lens has two surfaces and hence two focal points first focal point is an object point on the principal axis for which image is at infinity while second focal point is an image point on the principal axis for which object is at infinity.

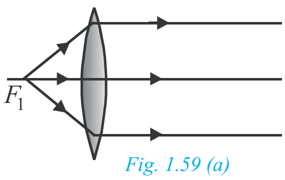


Fig. 1.59 (a)

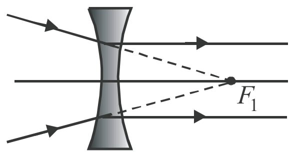


Fig. 1.59 (b)

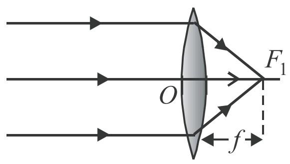


Fig. 1.59 (c)

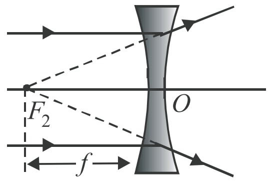


Fig. 1.59 (d)

Focal length (f) - It is defined as the distance between optical centre of a lens and the point where the parallel beam of light converges or appear to converge i.e., focus.
Aperture - In reference to lens, aperture means to effective diameter of its light transmitting area so that brightness i.e. intensity of image formed by a lens which depends on the light passing through the lens will depend on the square of aperture.
i.e. $I \propto (\text{aperture})^2$

SIGN - CONVENTION

1. Whenever and where possible, rays of light are taken to travel from left to right.
2. Transverse distances are measured from optical centre and distances measured upward and perpendicular to principal axis are taken to be positive while distances measured dwonward and perpendicular to principal axis are taken as negative.
3. Longitudinal distances are measured from optical centre and are taken to be positive if in the direction of light propagation and negative if opposite to it e.g., according to our convention the sign of R_1, R_2 and f are given.

$R_1(= OC_1)$ = Positive
$R_2(= OC_2)$ = Negative
$f(= OF)$ = Positive

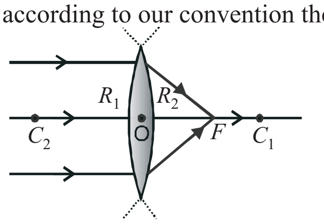


Fig. 1.60 (a)

$R_1(= OC_1)$ = Negative
$R_2(= OC_2)$ = Positive
$f(= OF)$ = Negative

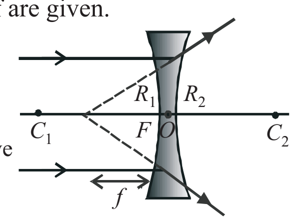


Fig. 1.60 (b)

While using the sign convention it must be kept in mind that
(i) to calculate an unknown quantity the known quantities are substituted with sign in a given formula.
(ii) in the result, sign must be interpreted as there are number of sign conventions and same sign has different meaning in different conventions.

RULES FOR IMAGE FORMATION

In order to locate the image formed by a lens graphically following rules are adopted.
1. A ray passing through optical centre proceeds undeviated through the lens (by definition of optical centre).
2. A ray passing through first focus or directed towards it, after refraction from the lens becomes parallel to the principal axis (by definition of F_1).

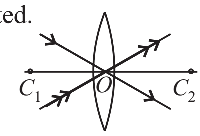


Fig. 1.61 (a)

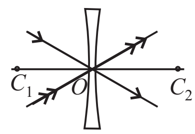
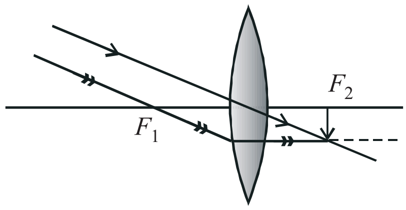
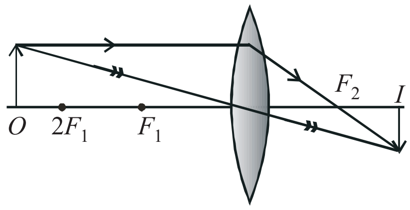
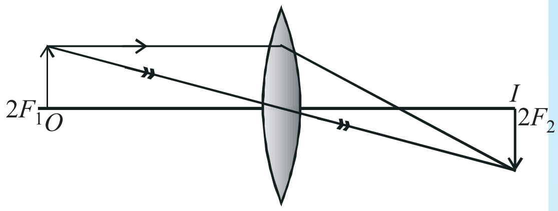
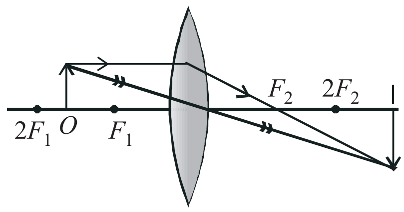
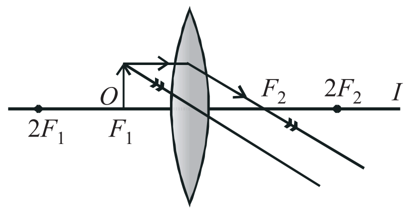
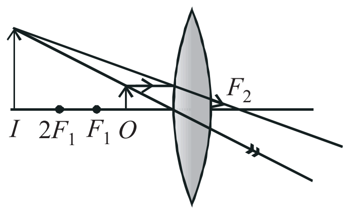


Fig. 1.61 (b)

3. A ray passing parallel to the principal axis after refraction through the lens passes or appear to pass through F_2 (by definition of F_2).
4. Only two rays from the same point of an object are needed for image formation and the point where the rays after refraction through the lens intersect or appear to intersect is the image of the object. If they actually intersect each other the image is *real* and if they appear to intersect the image is said to be *virtual*.

IMAGE FORMATION BY A LENS

(a) For Convergent or Convex Lens

Position of object	Details of image	Ray diagram
At infinity	Real, inverted, diminished ($m << -1$), at F	
Between infinity and $2F$	Real, inverted, diminished ($m < -1$), between F and $2F$	
At $2F$	Real, inverted, equal in size, ($m = -1$) at $2F$	
Between $2F$ and F	Real, inverted, enlarged ($m > -1$), between $2F$ and ∞	
At F	Real, inverted, enlarged ($m >> -1$), at infinity	
Between focus F and Pole P	Virtual, erect, enlarged ($m > +1$), on same side of object	

(b) For Divergent or Concave lens

1. If object is at infinity image will be formed at focus on the same side of the lens as the object, virtual, erect and point sized.
2. If object is in front of lens, anywhere between the optical centre and infinity image will be formed between focus and the optical centre, on the same side of the lens, highly diminished, virtual and erect.

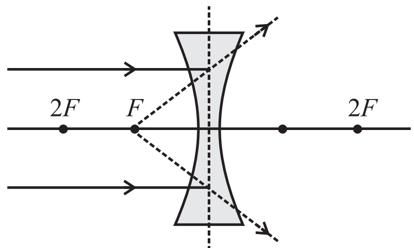


Fig. 1.62 (a)

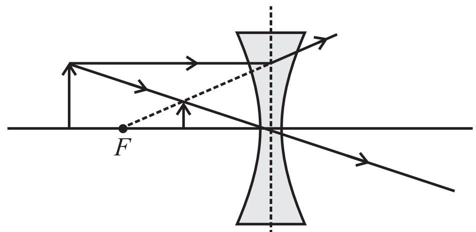


Fig. 1.62 (b)

Time to Check Your Knowledge

☛ **The diagram shows an object OA and its image IB formed by a lens. Complete the ray diagram and locate the focus of the lens by labelling as F. State whether the lens is convex or concave ?**

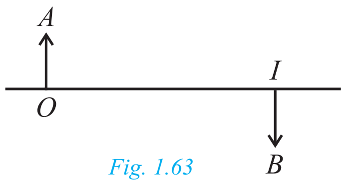


Fig. 1.63

SOLUTION

The completed ray diagram is given below.
Since the image is inverted and magnified, the lens is convex.

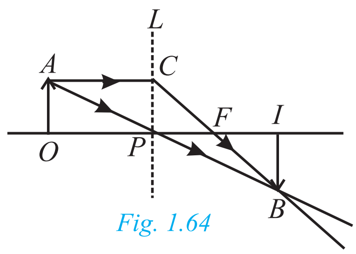


Fig. 1.64

LENS FORMULA

If an object is placed at a distance u from the optical centre 'O' of a lens and its images is formed at a distance v (from the optical centre) and focal length of this lens is f then $\frac{1}{v}-\frac{1}{u}=\frac{1}{f}$ this relationship is known as Lens formula

Proof : Consider an object AB placed beyond $2F$ infront of a convex lens. A real, inverted and smaller image is formed between F and $2F$ on the other side of the lens. Applying sign convention, we obtain.

(Object distance) $OB = -u$

(Image distance) $OB' = +v$

(Focal length) $OF = +f$

In $\Delta\, ABO$ and $\Delta\, A'B'O$,

$\angle 1 = \angle 2$ (Vertically opposite angles)

$\angle 3 = \angle 4$ (Each 90°)

$\therefore\ \angle BAO \sim \angle B'A'O$ (By AA similarity)

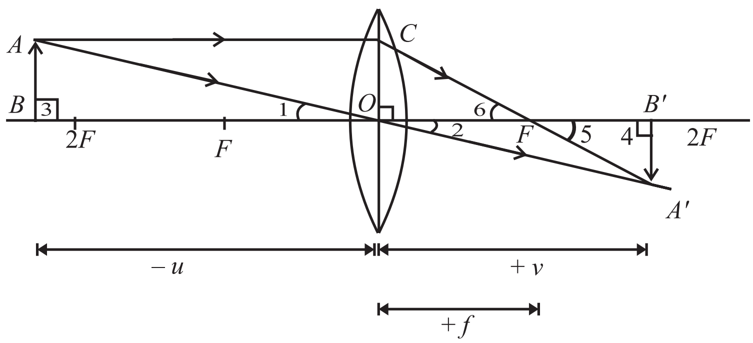


Fig. 1.65

Therefore, $\Delta\, ABO$ and $\Delta\, A'B'O$ are equiangular and hence they are similar.

$$\therefore\ \frac{A'B'}{AB}=\frac{OB'}{OB}=\frac{+v}{-u} \Rightarrow \frac{A'B'}{AB}=\frac{+v}{-u} \qquad ...(1)$$

Now $\Delta\, OCF$ and $\Delta\, A'B'F$ are also equiangular, hence similar.

In particular, $\dfrac{A'B'}{OC} = \dfrac{FB'}{OF}$ But $OC = AB$.

$\therefore \dfrac{A'B'}{AB} = \dfrac{FB'}{OF}$

Since all distances are measured from optical centre, therefore,

$$\frac{A'B'}{AB} = \frac{FB'}{OF} = \frac{OB'-OF}{OF} = \frac{+v-(+f)}{+f} = \frac{v-f}{f} \qquad ...(2)$$

Now comparing eq. (1) and (2), $\dfrac{+v}{-u} = \dfrac{v-f}{f} \Rightarrow fv = -uv + fu$

Dividing both sides by uvf, $\dfrac{1}{u} = -\dfrac{1}{f} + \dfrac{1}{v} \Rightarrow \dfrac{1}{f} = \dfrac{1}{v} - \dfrac{1}{u}$ **(Lens formula)**

Similarly, we can prove the lens formula for a concave lens.

MAGNIFICATION

If a thin object of linear size O situated vertically on the axis of a lens at a distance u from the optical centre and its image of size I is formed at a distance v (from the optical centre) then magnification (transverse) is defined as

Magnification, $m = \dfrac{I}{O} = \dfrac{v}{u}$

Magnification m can be negative or positive.

Negative magnification implies that image is inverted with respect to object while positive magnification means that image is erect with respect to object.

Other formulae of magnification $m = \dfrac{f}{f+u}$, $m = \dfrac{f-v}{f}$

For real extended object, if the image formed by a single lens in inverted (i.e., m is negative) it is always real and the lens is convergent i.e., convex.

ILLUSTRATION : 1.23

Two converging lenses with focal lengths 15 cm and 25 cm are placed 18 cm apart. An object is located 8.0 cm to the left of the 15 cm focal length lens. Where is the final image formed ?

SOLUTION :

Find the image location for the first lens using the lens formula, $\dfrac{1}{v} - \dfrac{1}{u} = \dfrac{1}{f}$

$$\frac{1}{v_1} = \frac{1}{f_1} + \frac{1}{u_1} = \frac{1}{15} - \frac{1}{8.0} \qquad \text{which gives } v_1 = -17 \text{ cm}$$

This image forms the object of the second lens located 17 cm + 18 cm = 35 cm away. Then for the second lens

$$\frac{1}{v_2} = \frac{1}{f_2} + \frac{1}{u_2} = \frac{1}{25} - \frac{1}{35} \qquad \text{which gives } v_2 = 87.5 \text{ cm}$$

The final image lies 87.5 cm to the right of the second lens (25 cm) lens.

ILLUSTRATION : 1.24

An object is placed at a distance of 1.50 m from a screen and a convex lens placed in between produces an image magnified 4 times on the screen. What is the focal length and the position of the lens?

SOLUTION :

Here, magnification $m = \dfrac{I}{O} = -4$

Let lens is placed at a distance of x from the object. Then

$u = -x$, and $v = (1.5 - x)$

using $m = \dfrac{v}{u}$, we get $\quad -4 = \dfrac{1.5-x}{-x}$

or $\quad 4x = 1.5 - x \quad$ or $\quad 5x = 1.5$

Thus $\quad x = 0.3$ m

The lens is placed at a distance of 0.3 m from the object (or 1.20 m from the screen)

For focal length, we may use $m = \dfrac{f}{f+u}$

or $\quad -4 = \dfrac{f}{f+(-0.3)}$ or $-4f + 1.2 = f$ or $5f = 1.2$

Thus $\quad f = \dfrac{1.2}{5} = 0.24$

The focal length is 0.24 m (or 24 cm)

CONNECTING TOPIC

Refraction at Spherical Surfaces

Refraction formula

$$\frac{\mu_2}{v} - \frac{\mu_1}{u} = \frac{\mu_2 - \mu_1}{R}$$

Where μ_1 = refractive index of the medium from which light ray are coming = refractive index of the medium in which light rays are entering

u = distance of object; v = distance of image; R = radius of curvature of spherical surface

Lens Maker Formula

This formula gives a relation among the focal length (f), the refractive index of a lens with respect to the medium in which it is placed (${}_m\mu_l$) and its radii of curvatures (R_1 and R_2). This formula is expressed as

$$\frac{1}{f} = ({}_m\mu_\ell - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \quad \text{or} \quad \frac{1}{f} = \left(\frac{{}_a\mu_\ell}{{}_a\mu_m} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

where, ${}_a\mu_l$ = refractive index of lens with respect to air.

${}_a\mu_m$ = refractive index of medium with respect to air.

R_1 = radius of curvature of first surface of lens.

R_2 = radius of curvature of second surface of lens.

If lens is placed in air, then

${}_a\mu_m = 1$ and ${}_a\mu_l = \mu$ (say)

$$\therefore \frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

Combination of Lenses

Case I : When two thin lenses are in contact.

In case of two thin lenses in contact if the first lens of focal length f_1 forms the image I_1 (of an object) at a distance v_1 from it,

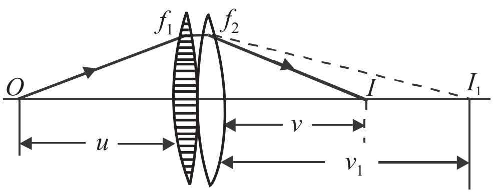


Fig.1.66

$$\frac{1}{v_1} - \frac{1}{u} = \frac{1}{f_1} \qquad \text{...(1)}$$

Now the image I_1 will act as object for second lens and if the second lens forms image I at a distance v from it,

$$\frac{1}{v} - \frac{1}{v_1} = \frac{1}{f_2} \qquad \text{...(2)}$$

Adding equations (1) & (2) $\dfrac{1}{v} - \dfrac{1}{u} = \dfrac{1}{f_1} + \dfrac{1}{f_2}$ or $\dfrac{1}{v} - \dfrac{1}{u} = \dfrac{1}{F}$ with $\dfrac{1}{F} = \dfrac{1}{f_1} + \dfrac{1}{f_2}$

i.e. the combination behaves as a single lens of equivalent focal length F given by

$$\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2} \quad \text{or} \quad P = P_1 + P_2$$

Case II : When two thin lenses are separated by a certain distance.

If the two thin lens are separated by a distance d apart, then F is given by

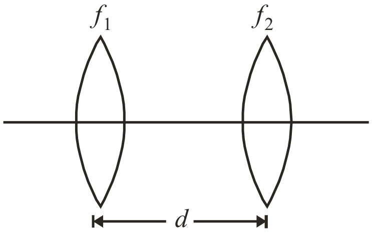


Fig. 1.67

$$\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2} - \frac{d}{f_1 f_2}$$

so, $\quad P = P_1 + P_2 - P_1 P_2 d.$

Note :

(1) If two thin lenses of equal focal length but of opposite nature (i.e. one convergent and other divergent) are put in contact, the resultant focal length of the combination will be

$\frac{1}{F}=\frac{1}{+f}+\frac{1}{-f}=0$ i.e, $F=\infty$ and $P=0$ i.e., the system will behave as a plane glass plate.

(2) If two thin lens of same nature are put in contact then as

$$\frac{1}{F}=\frac{1}{f_1}+\frac{1}{f_2}$$

$\frac{1}{F}>\frac{1}{f_1}$ and $\frac{1}{F}>\frac{1}{f_2}$ i.e. $F<f_1$ and $F<f_2$

i.e. the resultant focal length will be lesser than smallest individual.

(3) If two thin lenses of opposite nature with different focal lengths are put in contact the resultant focal length will be of same nature as that of the lens of shorter focal length but its magnitude will be more than that of shorter focal length.

If a lens of focal length f is divided into two equal parts as in figure (*a*)

each part has a focal length f′ then as $\frac{1}{f}=\frac{1}{f'}+\frac{1}{f'}$ $f'=2f$

i.e. each part have focal length $2f$ now if the se parts are put in contact as in (*b*) or (*c*), the resultant focal length of the combination will be $\frac{1}{F}=\frac{1}{2f}+\frac{1}{2f}$ i.e. $F=f\,(=\text{initial value})$

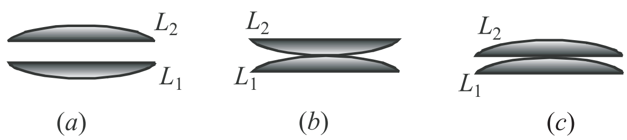


Fig. 1.68

Silvering of Lens

A lens has two surfaces. If one of the surfaces is silvered, the lens behaves as a mirror. The mechanism of the image formation can be understood in brief as given below.

Light from the object falls on the lens which produces a virtual image I_1. This image acts as object for the silvered surface (which acts as a mirror) and a second virtual image I_2 is formed. Finally, this image acts as object for the lens and final image I_3 is formed. Thus, refraction takes place two times at the lens and reflection takes place one time at the mirror.

Thus, on silvering the lens behaves as a mirror of focal length F given by

$$\frac{1}{F}=\frac{2}{F_\ell}+\frac{1}{F_m} \qquad \text{....... (1)}$$

where F_ℓ = focal length of lens from which refraction take place two times.
F_m = focal length of mirror from which reflection takes place one time.

Case I : When a double convex lens is silvered.

Clearly, $F_m=\frac{R}{2}$

Also, by lens maker formula,

$$\frac{1}{F_\ell}=(\mu-1)\left(\frac{1}{R}+\frac{1}{R}\right)=(\mu-1).\frac{2}{R} \qquad \therefore F_\ell=\frac{R}{2(\mu-1)}$$

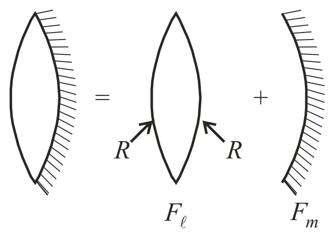


Fig. 1.69 (a)

Putting the values of F_m and F_l in (1), we get

$$\frac{1}{F}=\frac{2\times 2(\mu-1)}{R}+\frac{2}{R}=\frac{2(2\mu-1)}{R} \qquad \therefore F=\frac{R}{2(2\mu-1)}$$

Case II : When a plane convex lens is silvered.

(i) If curved surface is silvered

In this case,

$$F_m = \frac{R}{2} \quad \text{and} \quad F_\ell = \frac{R}{\mu - 1}$$

$$\therefore \quad F = \frac{R}{2\mu}$$

(ii) **If plane surface is silvered.**

In this case, $F_m = \infty$ ($\because R = \infty$)

and $F_\ell = \dfrac{R}{\mu - 1}$

$$\therefore \quad F = \frac{R}{2(\mu - 1)}$$

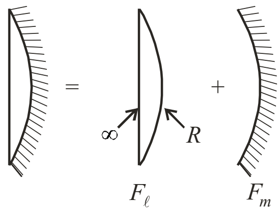


Fig. 1.68 (b)

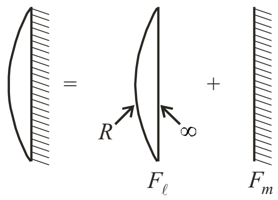


Fig. 1.69 (c)

ILLUSTRATION : 1.25

The radius of curvature of a thin plano-convex lens is 10 cm (of curved surface) and the refractive index is 1.5. If the plane surface is silvered, then it behaves like a concave mirror of focal length

(a) 10 cm (b) 15 cm (c) 20 cm (d) 5 cm

SOLUTION :

(a) The silvered plano convex lens behaves as a concave mirror; whose focal length is given by

$$\frac{1}{F} = \frac{2}{f_1} + \frac{1}{f_m}$$

If plane surface is silvered

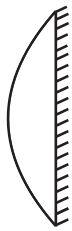


Fig. 1.70

$$f_m = \frac{R_2}{2} = \frac{\infty}{2} = \infty$$

$$\therefore \frac{1}{f_1} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) = (\mu - 1)\left(\frac{1}{R} - \frac{1}{\infty}\right) = \frac{\mu - 1}{R}$$

$$\therefore \frac{1}{F} = \frac{2(\mu - 1)}{R} + \frac{1}{\infty} = \frac{2(\mu - 1)}{R} \Rightarrow F = \frac{R}{2(\mu - 1)}$$

Here, $R = 10$ cm, $\mu = 1.5$

$$\therefore F = \frac{10}{2(1.5 - 1)} = 10 \text{ cm}$$

POWER OF A LENS

If focal length of a lens is measured in metre then its reciprocal gives the power (P) of the lens.

i.e., Power of a lens, $P = \dfrac{1}{f\,(\text{in m})}$

The **S.I. unit** of power is diopter (D).

Power of a combination of lenses: If a number of lenses are placed in close contact with each other, then the power of the combination of lenses is equal to the algebraic sum of the powers of individual lenses. i.e. $P = P_1 + P_2 + ...P_n$

ILLUSTRATION : 1.26

A doctor has prescribed a corrective lens of power +1.5 D. Find the focal length of the lens. Is the prescribed lens diverging or converging?

SOLUTION :

Given: $P = +1.5$ D

Focal length $f = \dfrac{100}{P}\text{ cm} = \dfrac{100}{1.5} = \dfrac{1000}{15} = +66.67 \text{ cm} = +0.67 \text{ m}$

As the focal length is + *ve*, hence it is a converging or convex lens.

ILLUSTRATION : 1.27

A convex lens of focal length 40 cm is in compact with a concave lens of focal length 25 cm. Find the power of the combination of lenses.

SOLUTION :

Focal length of combination, $\frac{1}{F}=\frac{1}{f_1}+\frac{1}{f_2}=\frac{1}{40}+\frac{1}{-25}$

(Since focal length is negative for concave lens)

$\Rightarrow \quad F=\frac{-200}{3}\text{cm}$

And, Power, $P=\frac{1}{f\,(\text{in metre})}=\frac{100}{F}=\frac{100}{\frac{-200}{3}}=-1.50$

ILLUSTRATION : 1.28

A convex lens of focal length 20 cm is placed in contact with concave lens of focal length 60 cm. Calculate : (a) power of each of the lens (b) power of combination (c) focal length of combination (d) nature of combination.

SOLUTION :

As we know, power of a lens $P=\frac{1}{f\,(\text{in metre})}$

(a) Power of convex lens $=\frac{100}{20}=+5\text{D}$, Power of concave lens $=\frac{100}{-60}=-1.67\text{ D}$

(b) Power of combination $P=P_1+P_2=(+5\text{D})+(-1.67\text{D})=+3.33\text{ D}$

(c) Focal length of combination

$f\,(\text{in cm})=\frac{100}{P}=\frac{100}{3.33}=+30.0\text{ cm}$

(d) As power of combination is positive, therefore, combination behaves like a convex lens.

ILLUSTRATION : 1.29

A convex lens of focal length 10.0 cm is placed in contact with a convex lens of 15.0 cm focal length. What is the focal length of the combination.

SOLUTION :

For combination of lenses

$$\frac{1}{f}=\frac{1}{f_1}+\frac{1}{f_2}=\frac{1}{10}+\frac{1}{15}=\frac{25}{150}=\frac{1}{6}$$

Therefore, $f=6$ cm

ILLUSTRATION : 1.30

Ten identical converging thin lenses, each of focal length 10 cm, are in contact. What is the power of the combined lens.

SOLUTION :

For thin lenses in contact

$$P=P_1+P_2+\ldots\ldots\ldots\ldots\ldots\ldots$$

$$=10\,P_1=\frac{10\times100}{10}=100\text{ D}$$

CONNECTING TOPIC

INTERFERENCE, DIFFRACTION AND POLARISATION OF LIGHT

Interference of Light

The colours in soap bubbles and oil slicks are due to this property of light. When two light waves of exactly same frequency travels in a medium, in the same direction simultaneously then due to their superposition, the intensity of light is maximum at some points while the intensity is minimum at some other points. This phenomenon is called interference of light. It is of two types :

(i) Constructive interference and

(ii) Destructive interference

When the waves meet a point with same phase, constructive interference is obtained at that point. Hence, at that point bright spot of light is seen.

But when the waves meet a point with opposite phase, destructive interference is obtained at that point. Hence, at that point dark spot of light is seen.

Diffraction of Light

The wavelength of light is of the order of angstroms. So, when light waves encounter obstacles of very small sizes, the light waves bend around the edges of the obstacle and travel. This is known as diffraction of light. It is due to the diffraction of light that a sharp shadow of an object cannot be obtained on any screen placed behind it. Due to diffraction, light bends and travels into the region of geometrical shadow of the object and thus complete darkness is not found in the shadow. The brightness of light gradually decreases towards complete darkness as we go gradually into the geometrical shadow of the object.

Polarisation of Light

An ordinary source of light such as bulb consists of a large number of waves emitted by atoms or molecules in all directions symmetrically. Such light is called unpolarized light (Fig. 1.71 (*a*))

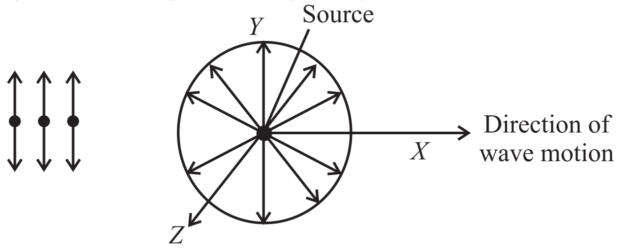


Fig.1.71 (a) Unpolarised light

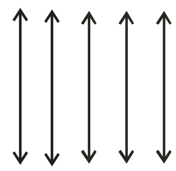


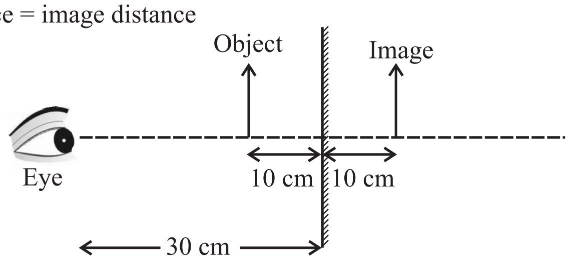
Fig.1.71 (b) Polarised light

If we confine the direction of wave vibration of electric vector in one direction (with the help of polaroids or Nicol prism) perpendicular to the direction of wave propagation, then such type of light is called plane polarised or linearly polarised. The phenomenon by which, we restrict the vibrations of wave in a particular direction (fig.1.71 (*b*) perpendicular to direction of wave propagation is called polarisation.

MISCELLANEOUS SOLVED EXAMPLES

1. **A small object is placed 10 cm in front of a plane mirror. If you stand behind the object 30 cm from the mirror and look at its image, find the distance focused for your eye.**

Sol. In plane mirror, object distance = image distance

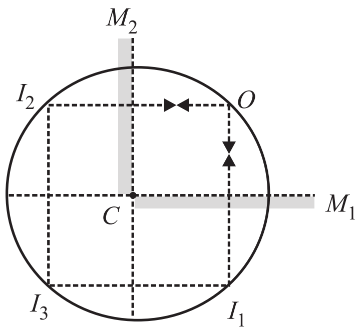


The distance focused for eye = distance of eye from mirror + image distance = 30 + 10 = 40 cm

2. **Find the number of images formed by two mutually perpendicular plane mirrors.**

Sol. Here, $n = \frac{360^o}{\theta} = \frac{360^o}{90} = 4$

$\therefore$ n is an even number



Thus, number of images formed = $n - 1 = 3$. All these three images lie on a circle with centre at C (The point of intersection of mirrors M_1 and M_2) and whose radius is equal to the distance between C and object 'O'.

3. **The focal length of a concave mirror is 30 cm. Find the position of the object in front of the mirror, so that the image is three times the size of the object.**

Sol. Here image can be real or virtual. If the image is real

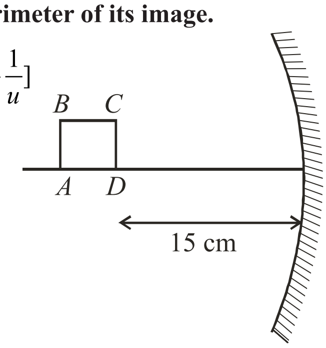
$f = -30$, $u = ?$, $m = -3$

Magnification $m = \frac{f}{f-u} \Rightarrow -3 = \frac{-30}{-30-u} \Rightarrow$ u = –40 cm.

If the image is virtual,

$m = \frac{f}{f-u} \Rightarrow 3 = \frac{-30}{-30-u} \Rightarrow$ u = –20 cm.

4. **A square *ABCD* of side 1mm is kept at distance 15 cm infront of the concave mirror as shown in the figure. The focal length of the mirror is 10 cm. Find the length of the perimeter of its image.**



Sol. Given: $u = -15$ cm, f = –10 cm $\quad \therefore \; v = -30$, [using $\frac{1}{v} = \frac{1}{f} - \frac{1}{u}$]

$m = -\frac{v}{u} = -2$

$\therefore \; A'B' = C'D' = 2 \times 1 = 2$ mm

Now $\frac{B'C'}{BC} = \frac{A'D'}{AD} = \frac{v^2}{u^2} = 4 \Rightarrow B'C' = A'D' = 4$ mm

$\therefore$ Length = 2 + 2 + 4 + 4 = 12 mm

5. An object of length 1 cm is placed at a distance of 15 cm from a concave mirror of focal length 10 cm. Find the nature and size of the image.

Sol. Given: $u = -15$ cm, $f = -10$ cm, $h_0 = 1$ cm

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

$\therefore \quad v = -30$ cm $\qquad m = \frac{I}{O} = -\frac{v}{u} = -\frac{(-30)}{(-15)} = -2$

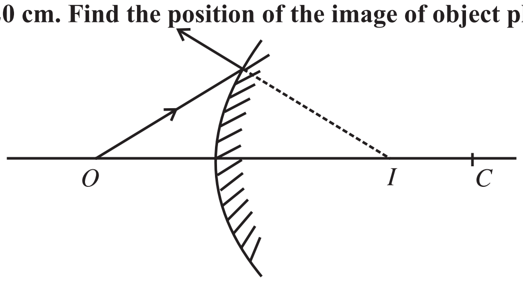
$I = -2 \times 1 = -2$ cm

Image is inverted and on the same side of object.

6. A convex mirror has its radius of curvature 20 cm. Find the position of the image of object placed at a distance of 12 cm from the mirror.

Sol. The situation is shown in figure.

Here $u = -12$ cm and $R = +20$ cm. We have



$$\frac{1}{u}+\frac{1}{v}=\frac{2}{R} \text{ or } \frac{1}{v}=\frac{2}{R}-\frac{1}{u}$$

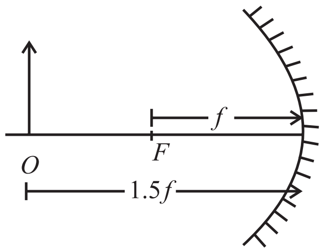
$$\Rightarrow \frac{1}{v}=\frac{2}{20}\text{ cm}-\frac{1}{-12}\text{ cm}=\frac{11}{60}\text{ cm}$$

$\therefore \quad v = \frac{60}{11}$ cm

7. An object of length 2.5 cm is placed at a distance of 1.5 *f* from a concave mirror where *f* is the magnitude of the focal length of the mirror. The length of the object is perpendicular to the principal axis. Find the length of the image. Is the image erect or inverted?

Sol. The given situation is shown in figure.

The focal length $f = -f$ and $u = -1.5f$, we have



$$\frac{1}{u}+\frac{1}{v}=\frac{1}{f} \qquad \text{or} \quad -\frac{1}{1.5f}+\frac{1}{v}=-\frac{1}{f}$$

$$\text{or} \quad \frac{1}{v}=\frac{1}{1.5f}-\frac{1}{f}=\frac{-1}{3f} \qquad \text{or} \quad v = -3f$$

Now $m = -\frac{v}{u} = \frac{-(-3f)}{-1.5f} = -2$ or $\frac{h_2}{h_1} = -2$

or $h_2 = -2h_1 = -5.0$ cm

The length of image is 5.0 cm. The minus sign shows that it is inverted.

8. The velocity of light in air is 3×10^8 ms^{-1}. If the refractive index of water is 4/3, find the velocity of light in water.

Sol. Given,

Velocity of light in air, c = 3×10^8 ms^{-1} ; Refractive index of water $\mu_w = \frac{4}{3}$

Refractive index of water, $\mu_w = \frac{c}{v_w}$

Where v_w is the velocity of light in water

$$\frac{4}{3}=\frac{3\times10^8}{v_w} \Rightarrow v_w = \frac{3\times3\times10^8}{4} = 2.25\times10^8 \text{ ms}^{-1}$$

Velocity of light in water is 2.25×10^8 ms^{-1}.

9. An object is situated at a distance of *f*/2 from a convex lens of focal length *f*. Find the distance of image.

Sol. For a spherical lens, $\frac{1}{v}-\frac{1}{u}=\frac{1}{f}$

For convex lens, $u = -f/2$ and f is + ve

$$\therefore \quad \frac{1}{v}=\frac{1}{f}+\frac{1}{u}=+\frac{1}{f}-\frac{2}{f}=-\frac{1}{f} \qquad \therefore v = -f$$

10. A convex lens throws on a screen 12 m from the lens a magnified image of the object. If the magnification is 15, find the focal length of the lens.

Sol. Magnification m = 15; Image distance = v

Magnification $= +\frac{v}{u}$ ..... (1)

From lens formula $\frac{1}{f} = \frac{1}{u} - \frac{1}{u}$; using Cartesian sign $\frac{1}{f} = \frac{1}{v} - \frac{1}{-u} \Rightarrow \frac{1}{f} = \frac{1}{v} + \frac{1}{u}$ $\therefore$ $\frac{1}{u} = \frac{1}{f} - \frac{1}{v}$

$$\Rightarrow \frac{1}{u} = \frac{v-f}{vf} \Rightarrow u = \frac{vf}{v-f} \quad m = \frac{v(v-f)}{vf}$$

Substituting value of v in eq. (1) $\quad m = \frac{v(v-f)}{vf} \qquad \therefore\ 15 = \frac{12-f}{f}$

$15f = 12 - f \Rightarrow 16f = 12 \Rightarrow f = \frac{12}{16} = 0.75\,\text{m}$

11. An object is placed at a distance of 50 cm from a concave lens of focal length 20 cm. Find the nature and position of the image.

Sol. Here, object distance, u = – 50 (object on the left of the lens)
Focal length, f = – 20 cm (focus on the left of the lens)
Image distance, v = ?

From lens formula, $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$

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

Putting values, we get $\frac{1}{v} = \frac{1}{-20} + \frac{1}{-50} = \frac{-5-2}{100} = \frac{-7}{100}$ or $v = -\frac{100}{7}$ cm = – 14.3 cm.

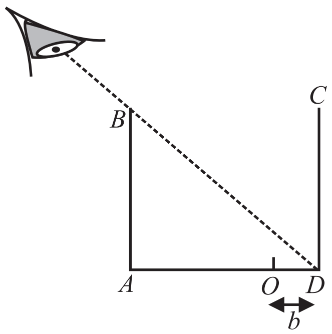
Image is formed at distance 14.3 cm on the left of the lens.

From relation, $m = \frac{h_2}{h_1} = \frac{v}{u}$ we have, $h_2 = h_1\frac{v}{u}$

Putting values, we get $h_2 = h_1 \times \frac{-100/7}{-50} = +\frac{2}{7}h_1$

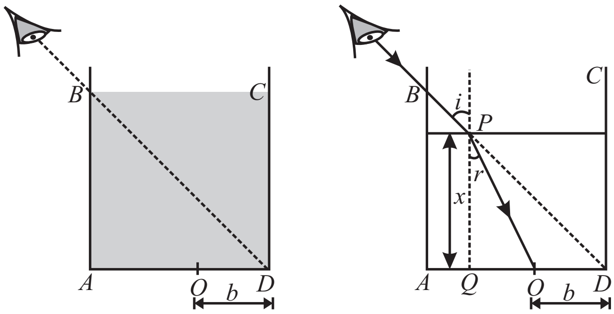
Since h_1 is positive (erect object), h_2 is also positive. The image is erect and virtual.

12. A cubical vessel with opaque walls, is so placed that the eye of an observer cannot see its bottom but can see the entire wall *CD*. A small object is placed at *O* at a distane b = 10 cm from corner *D*. What minimum depth of water $\left(\mu = \frac{4}{3}\right)$ should be poured into the vessel which will enable the observer to see the object?



Sol. Let minimum depth of water be x. Since the vessel is cubical ($AB = AD$), it is clear that angle $i = 45°$. From Snell's law, the angle of refraction is given by

$$\sin r = \frac{\sin i}{n} = \frac{\sin 45°}{4/3} = 0.5303 \qquad \therefore \; r = 32.03°$$



Since $\angle QPD = 45°$, $PQ = x = QD$

Hence, $QO = x - b$

Now, ΔPQO, $QO = x \tan r$

$$\Rightarrow \quad x - b = x \tan r \Rightarrow \; x = \frac{b}{1 - \tan r}$$

Substituting for b and r, we get

$x = 26.7$ cm

13. A convex lens forms a real and inverted image of a needle at a distance of 25 cm from the lens. If the image of the same size as that of the needle, then where should the needle be placed in front of the lens. Also calculate the power of the lens.

Sol. Step 1. We know, if the size of the real and inverted image is same as that of the object, then the object is at $2F$ and image is also formed at $2F$ on the other side of the convex lens.

$$m = \frac{I}{0} = \frac{-h}{h} = -1 \Rightarrow \frac{v}{u} = -1 \Rightarrow u = -v = -25 \text{ cm} \qquad (\because h_2 = h_1)$$

Using $-\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$, we get

$$\frac{1}{f} = \frac{1}{25} - \frac{1}{(-25)} = \frac{2}{25} \qquad \text{or } f = \frac{25}{2} = 12.5\text{cm}$$

In this case, $2f = 25$ cm or $f = 12.5$ cm

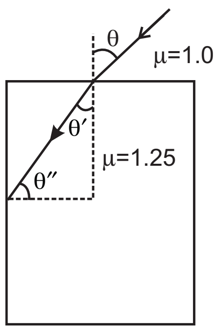
Thus, needle must be placed at a distance of 25 cm in front of the convex lens.

Step 2. Now, power of lens,

$$P = \frac{100}{f\,(\text{in cm})} = \frac{100}{12.5} = +8.0 \text{ D}$$

SOLVED EXAMPLES BASED ON CONNECTING TOPICS

14. Consider the situation shown in figure. Find maximum angle for which the light suffers total internal reflection at the vertical surface.



Sol. The critical angle for this case is $\theta'' = \sin^{-1}\frac{1}{1.25} = \sin^{-1}\frac{4}{5}$ so, $\sin\theta'' = \frac{4}{5}$

Since $\theta'' = \frac{\pi}{2} - \theta'$, we have $\sin\theta' = \cos\theta'' = \frac{3}{5}$

From Snell's law,

$$\frac{\sin\theta}{\sin\theta'} = 1.25 \text{ and } \sin\theta = 1.25 \times \sin\theta' = 1.25 \times \frac{3}{5} = \frac{3}{4} \text{ and } \theta = \sin^{-1}\frac{3}{4}$$

If θ" is greater than the critical angle, θ will be smaller than this value. Thus, the maximum value of θ' for which total internal reflection takes place at the vertical surface is $\sin^{-1}$ (3/4).

15. A converging lens has a focal length of 20 cm in air. It is made of a material of refractive index 1.6. If the lens is immersed in a liquid of refractive index 1.3. What will be the new focal length of the lens?

Sol. $\frac{1}{f_1} = (u_{\text{air}} - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \Rightarrow \frac{1}{f_1} = (1.6 - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$

$$\Rightarrow \frac{1}{f_1} = 0.6\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \quad \text{..... (i)}$$

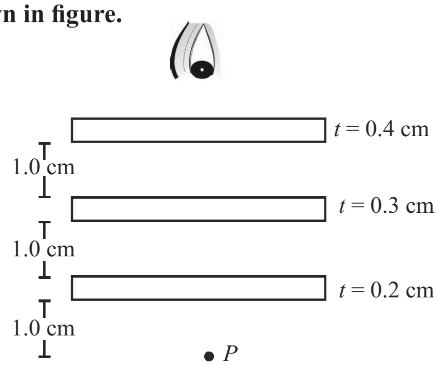
When lens is increased in liquid of refractive index 1.3

$$\frac{1}{f_2} = \left(\frac{1.6}{1.3} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \Rightarrow \frac{1}{f_2} = 0.2307\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \quad \text{..... (ii)}$$

Dividing (i) by (ii) we get

$$\frac{f_2}{20} = \frac{0.6}{0.2307} = 52 \text{ cm}$$

16. Locate the image of the point *P* as seen by the eye through the slabs of refrective index (*m* = 1.2, 1.3, 1.4 respectively starting from the bottom) as shown in figure.



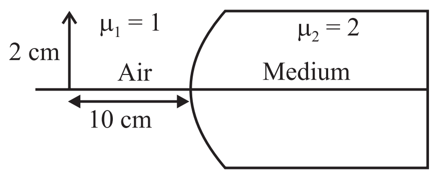
Sol. The net shift from one slab is $t\left(1 - \frac{1}{\mu}\right)$ where t is the thickness of slab, μ is the refractive index of slab.

Total shift $t_1 = \left(1 - \frac{1}{\mu_1}\right) + t_2\left(1 - \frac{1}{\mu_2}\right) + t_3\left(1 - \frac{1}{\mu_3}\right) = 0.2\left(1 - \frac{1}{1.2}\right) + 0.3\left(1 - \frac{1}{1.3}\right) + 0.4\left(1 - \frac{1}{1.4}\right)$

$$= 0.2\left(\frac{0.2}{1.2}\right) + \frac{0.3 \times 0.3}{1.3} + \frac{0.4 \times 0.4}{1.4}$$

$= 0.0333 + 0.0692 + 0.114 = 0.2$ cm above point P.

17. An extended object of size 2 cm is placed at a distance of 10 cm in air (μ_1=1) from pole, on the principal axis of a spherical curved surface. The medium on the other side of refracting surface has refractive index μ_2= 2. Find the position, nature and size of image formed after single refraction through the curved surface.



$R = 10$ cm

Sol. For refraction at spherical surface

$$\frac{\mu_2}{v} - \frac{\mu_1}{u} = \frac{\mu_2 - \mu_1}{R} \Rightarrow \frac{2}{v} - \frac{1}{-10} = \frac{2-1}{+20} \Rightarrow \frac{2}{v} + \frac{1}{10} = \frac{1}{20} \Rightarrow \frac{2}{v} = -\frac{1}{20}$$

$= v = -40$ cm (virtual)

Position : 40 cm from curved surface

Nature : virtual and erect

using magnification formula, in case when object is kept in one medium μ_1 and image is formed in another medium μ_2.

$$m = \frac{h_2}{h_1} = \left(\frac{\mu_1}{\mu_2}\right)\left(\frac{v}{\mu}\right) \Rightarrow \frac{h_2}{2} = \frac{1 \times (-40)}{2 \times (-10)} \Rightarrow h_2 = +4 \text{ cm (erect)}$$

Size of image : 4 cm

Exercise 1 Master Boards

Multiple Choice Questions (MCQs)

DIRECTIONS : *This section contains multiple choice questions. Each question has 4 choices (a), (b), (c) and (d) out of which ONLY ONE is correct.*

1. An object is at a distance of 0.5 m in front of a plane mirror. Distance between the object and image is

(a) 0.5 m (b) 1 m (c) 0.25 m (d) 1.5 m

2. Number of images formed when two plane mirrors are inclined at an angle 90° is

(a) 3 (b) 2 (c) 4 (d) 5

3. Which one of the following statements is not correct?

(a) A convex mirror is often used as driving rear-view mirror.
(b) A convex mirror is often used as a shaving mirror.
(c) A concave mirror is often used in a search light or a torch.
(d) A concave mirror is often used as the reflector behind lamp in a projector

4. The relation, $R = 2f$ holds true for :

(a) concave mirrors only
(b) convex mirrors only
(c) all spherical mirrors
(d) lens as well as for all spherical mirrors.

5. A magnification greater than unity indicates :

(a) real image
(b) size of the image is smaller than that of object
(c) size of the object is smaller than that of image
(d) size of object is equal to that of image

6. The image formed by a convex mirror

(a) is always real (b) is always virtual
(c) cannot say (d) None of these

7. In case of erect object having inverted image, linear magnification is :

(a) positive (b) negative
(c) zero (d) no definite sign.

8. If object lies symmetrically and number of images formed are 9, therefore two plane mirrors are kept at an angle of :

(a) 72° (b) 40° (c) 36° (d) 50°

9. Reciprocal of focal length of a lens gives the

(a) power (b) radius
(c) magnification (d) none of these

10. Magnification of a lens is given by

(a) $\dfrac{\text{image height}}{\text{object height}}$ (b) $\dfrac{2}{\text{Radius}}$

(c) $\dfrac{1}{\text{focal length}}$ (d) $\dfrac{\text{object distance}}{\text{image distance}}$

Assertion-Reason

DIRECTIONS: *Two statements are given- one labeled Assertion (A) and the other labelled Reason (R). Select the correct answer to these questions from the codes (a), (b), (c) and (d) as given below*

(a) If both **Assertion** and **Reason** are **correct** and Reason is the **correct explanation** of Assertion.
(b) If both **Assertion** and **Reason** are correct, but Reason is **not the correct explanation** of Assertion.
(c) If **Assertion** is **correct** but **Reason** is **incorrect**.
(d) If **Assertion** is **incorrect** but **Reason** is **correct**.

1. **Assertion :** The diameter of convex lens required to form full image of an object is half the height of the object.
Reason : The smaller diameter lens will give full image of lower intensity.

2. **Assertion :** The image of a point object situated at the centre of hemispherical lens is also at the centre.
Reason : For hemisphere Snell's law is not valid.

Fill in the Blanks

DIRECTIONS : *Complete the following statements with an appropriate word / term to be filled in the blank space(s).*

1. The power of a convex lens is .... and that of a concave lens is ....
2. Light seems to travel in ....
3. A light ray travelling obliquely from a denser medium to a rarer medium bends .... the normal. A light ray bends .... the normal when it travels obliquely from a rarer to a denser medium.
4. In case of a rectangular glass slab, the refraction takes place at both .... interface and .... interface. The emergent ray is .... to the direction of incident ray.
5. Power of a lens is the reciprocal of its ....
6. The SI unit of power of a lens is ....
7. The angle of incidence is .... to the angle of reflection.
8. The reflecting surface of a spherical mirror may be curved .... or ....
9. The inner surface of the spoon can be approximated to a .... mirror.
10. The centre of the reflecting surface of a spherical mirror is a point called the ....
11. The centre of curvature of a concave mirror lies in .... of it.
12. Line passing through the pole and the centre of curvature of a spherical mirror is called the ....

13. A ray parallel to the principal axis, after reflection, will pass through the ....
14. The dentists use .... mirrors to see large images of the teeth of patients.
15. A transparent material bound by two surfaces, of which one or both surfaces are spherical, forms a ....
16. The degree of .... of light rays achieved by a lens is expressed in terms of its power.
17. An object is placed in front of a spherical mirror. The image is found to be virtual for all positions of the object. The spherical mirror is ....
18. Two immiscible transparent liquids A and B have 1.2 and 1.5 as their refractive indices (with respect to air). The refractive index of B with respect to A is ....

True / False

DIRECTIONS : *Read the following statements and write your answer as true or false.*

1. The reflecting surfaces, of all types, obey the laws of reflection.
2. Light travels in vacuum with an enormous speed of 3×10^8 ms^{-1}.
3. The speed of light is different in different media.
4. The refractive index of a transparent medium is the ratio of the speed of light in vacuum to that in the medium.
5. The incident ray, the normal to the mirror at the point of incidence and the reflected ray, all lie in the same plane.
6. Image formed by a plane mirror is always virtual and erect.
7. The principal focus of a spherical mirror lies midway between the pole and centre of curvature.
8. Convex mirrors enable the driver to view much larger area than would be possible with a plane mirror.
9. A concave lens will always give a virtual, erect and diminished image.
10. A ray of light passing through the optical centre of a lens will emerge without any deviation.
11. The image in a plane mirror lies as far behind the mirror.
12. An object is placed in front of a mirror and an image of it is formed at the object itself. The mirror mentioned in question is a convex mirror.
13. A concave mirror can produce both real and virtual images.
14. Light travels faster in glass than in air.
15. Light has transverse wave nature.
16. The laws of reflection are valid for plane mirrors and not for spherical mirrors.
17. The mirror formula is valid only if the aperture of the mirror is small.
18. When a ray of light travels from air to water, its speeds up.
19. A lens that is thicker at the middle than at the edges is a diverging lens.

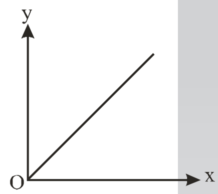
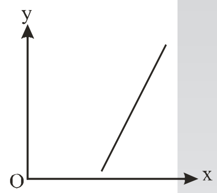
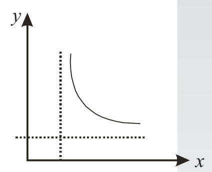
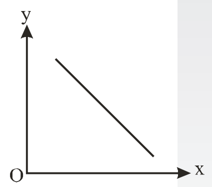
Match the Following

DIRECTIONS : *Each question contains statements given in two columns which have to be matched. Statements (A, B, C, D) in column I have to be matched with statements (p, q, r, s) in column II.*

1. Match the following :

Column I	Column II
(A) Power of convex mirror	(p) Positive power
(B) Power of concave mirror	(q) Negative power
(C) Power of plane mirror	(r) Zero power
(D) Power of convex lens	(s) Infinite power

2. The graphs given apply to convex lens of focal length f, producing a real image at a distance v from the optical centre when self luminous object is at distance u from the optical centre. The magnitude of magnification is m. Identify the following graphs with the first named quantity being plotted along y-axis.

Column I	Column II
(A) v against u	(p) 
(B) $\frac{1}{v}$ against $\frac{1}{u}$	(q) 
(C) m against v	(r) 
(D) $(m + 1)$ against $\frac{v}{f}$	(s) 

Passage Based Questions

DIRECTIONS : *Study the given passage and answer the following questions.*

Passage

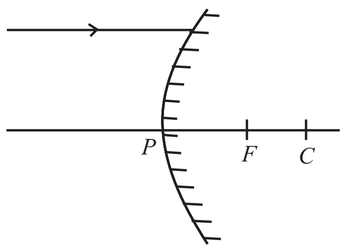
A 5.0 cm tall object is placed perpendicular to the principal axis of a convex lens of focal length 20 cm. The distance of the object from the lens is 30 cm.

1. What is the distance of image from the pole of lens?
(a) $v = 60$ cm (b) $v = -60$ cm
(c) $v = 30$ cm (d) $v = -30$ cm

2. What is the power of the used lens?
   (a) + 5 D (b) – 5 D
   (c) + 0.5 D (d) – 0.5 D

Very Short Answer Questions

1. What is the relation between focal length and radius of curvature?
2. What is reflection of light?
3. A man is moving towards a plane mirror at the speed of 8 cm/sec. What is the relative speed of man towards his image?
4. Magnification of a mirror is always less than 1, which mirror is this?
5. Refractive indices of benzene and kerosene oil are 1.5 and 1.4 respectively. Which is optically denser?
6. What do you understand by optically denser and optically rarer medium?
7. For the same angle of incidence; the angle of refraction in three different media *A*, *B* and *C* are 150°; 25° and 35° respectively. In which medium velocity of light will be minimum?
8. Which lens is known as converging and which is known as diverging lens?
9. For what position convex lens form real, inverted and diminished image?
10. What is the magnification of the images formed by plane mirror and why?
11. A ray of light is incident on a convex mirror as shown. Redraw the diagram and complete the path of this ray after reflection from the mirror. Mark angle of incidence and angle of reflection on it.



12. List two properties of the images formed by convex mirrors. Draw ray diagram in support of your answer.

Short Answer Questions

1. Prove that the refractive index of glass with respect to air is the reciprocal of the refractive index of air with respect to glass.
2. What is dispersion of light and what is its cause?
3. Find the focal length of a lens of power –2.0 D. What type of lens is this ?
4. Under what condition will a concave mirror produce an erect image? A virtual image ? An image smaller than the object? An image larger than the object?
5. A boy is standing in front of plane mirror finds his image at a distance of 20 m from himself. Find the distance between boy and mirror.
6. Refractive index of glass for light of yellow, green and red colours are μ_y, μ_g and μ_r respectively. Rearrange these symbols in the increasing order of values.
7. An object is placed at a distance of 12 cm in front of a concave mirror. It forms a real image four times larger than the object. Calculate the distance of the image from the mirror.
8. With respect to air, the refractive index of ice is 1.31 and that of rock salt is 1.54. Calculate the refractive index of rock salt with respect to ice.
9. A concave mirror and a convex lens are held separately in water. What changes, if any, do you expect in the focal length of either?
10. Briefly describe an activity to find approximate focal length of a convex lens.
11. If the image formed by mirror for all positions of the object placed in front of it is always virtual and diminished, state the type of the mirror. Draw a ray diagram in support of your answer. Where are such mirrors commonly used and why?
12. What is meant by power of a lens? What does its sign (+ ve or – ve) indicate? State its S.I. unit. How is this unit related to focal length of a lens?
13. An objects 4 cm in height, is placed at 15 cm in front of a concave mirror of focal length 10 cm. At what distance from the mirror should a screen be placed to obtain a sharp image of the object. Calculate the height of the image.
14. An object is placed at a distance of 30 cm in front of a convex mirror of focal length 15 cm. write four characteristics of the image formed by the mirror.
15. If the image formed by a spherical mirror for all positions of the object placed in front of it is always erect and diminished, what type of mirror is it? Draw a labelled ray diagram to support your answer.

Long Answer Questions

1. An object 5.0 cm in length is placed at a distance of 20 cm. in front of a convex mirror of radius of curvature 30 cm. Find the position of the image, its nature and size.
2. A truck uses a convex mirror as view finder whose radius of curvature is 2.0 m. A maruti car is coming behind the truck at a distance of 10 m. What will be the position of the image of the car and size of the image of the car when observed by the driver of the truck through the convex mirror ?
3. An object is placed 90 cm away from a concave mirror of focal length 30 cm. Find the position and the nature of the image formed.

4. What is the focal length of the combination of a convex lens of focal length 30 cm with a concave lens of focal length 20 cm? Is the system a converging or diverging lens? Ignore thickness of the lenses.
5. Two thin lenses of focal lengths + 10 cm and – 5cm are kept in contact. What is the focal length and power of the combination?
6. Use the mirror formula to show that for an object lying between the pole and focus of a concave mirror, the image formed is always virtual in nature.
7. Prove that the size of image formed by a plane mirror is equal to that of object.
8. (a) State the laws of refraction of light. Explain the term absolute refractive index of a medium and write an expression to relate it with the speed of light in vacuum.
   (b) The absolute refractive indices of two media '*A*' and '*B*' are 2.0 and 1.5 respectively. If the speed of light in medium '*B*' is 2×10^8 m/s, calculate the speed of light in:
   (i) vacuum, (ii) medium '*A*'
9. (i) Define optical centre of a spherical lens.
   (ii) A divergent lens has a focal length of 20 cm. At what distance should an object of height 4 cm from the optical centre of the lens be placed so that its image if formed 10 cm away from the lens. Find the size of the image also.
   (iii) Draw a ray diagram to show the formation of image in above situation.
10. (i) To construct a ray diagram we use two rays which are so chosen that it easy to know their directions after reflection from the mirror. List two such rays and state the path of these rays after reflection in case of concave mirrors. Use these two rays and draw ray diagram to locate the image of an object placed between pole and focus of a concave mirror.
    (ii) A concave mirror produces three times magnified image on a screen. If the objects is placed 20 cm in front of the mirror, how far is the screen from the object?
11. An object is placed at a distance of 60 cm from a concave lens of focal length 30 cm.
    (i) Use lens formula to find the distance of the image from the lens.
    (ii) List four characteristics of the image (nature, position, size, erect/inverted) formed by the lens in this case.
    (iii) Draw ray diagram to justify your answer of part (ii).
12. (a) A security mirror used in a big showroom has radius of curvature 5m. If a customer is standing at a distance of 20 m from the cash counter, find the position, nature and size of the image formed in the security mirror.
    (b) Neha visited a dentist in his clinic. She observed that the dentist was holding an instrument fitted with a mirror. State the nature of this mirror and reason for its use in the instrument used by dentist.
13. Rishi went to a palmist to show his palm.
    The palmist used a special lens for this purpose.
    (i) State the nature of the lens and reason for its use.
    (ii) Where should the palmist place/hold the lens so as to have a real and magnified images of an object?
    (iii) If the focal length of this lens is 10 cm and the lens is held at a distance of 5 cm from the palm, use lens formula to find the position and size of the image.

Reasoning Based Questions

1. When we sit in front of a plane mirror and write with our right hand, it appears in the mirror that we are writing with the left hand. Why?
2. Explain why, though both a plane mirror and a sheet of paper reflect light but we can see the image of our face in a plane mirror but not in a sheet of paper?
3. When a spherical mirror is held towards the Sun and its sharp image is formed on a piece of carbon paper for some time, a hole is burnt in the carbon paper.
   Why is a hole burnt in the carbon paper?
4. Explain why, a ray of light passing through the centre of curvature of a concave mirror gets reflected back along the same path.
5. Why can you not use a cancave mirror as a rear-view mirror in vehicles ?
6. A ray of light travelling in air enters obliquely into water. Does the ray of light bend towards the normal or away from the normal? Why?
7. Why does a beam of light bend when it enters glass at an angle? Why does it not bend if it enters the glass at right angles?
8. Explain why, a real image can be projected on a screen but a virtual image cannot?
9. Which causes more bending (or more refraction) of light rays passing throught it : a convex lens of long focal length or a convex lens of short focal length? Why?
10. Which has more power : a thick convex lens or a thin convex lens, made of the same glass? Give reason for your choice.

HOTS Questions

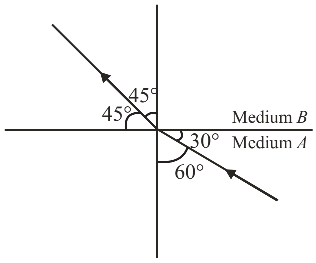
1. An object of 5 cm is placed 20 cm away from converging lens of focal length 10 cm. Draw the ray diagram to produce the image and find the position, size and the nature of the image formed.
2. An object 3 cm in height is placed 20cm from convex lens of focal length 12 cm. Find the nature, position and height of the image.
3. A concave lens has focal length of 15 cm. At what distance should the object from the lens be placed so that it forms an image at 10 cm from the lens ? Also, find the magnification produced by the lens.
4. A man standing in front of a spherical mirror, finds his image having a very small head, a fat body and legs of normal size. What types of mirrors are used in the small parts?

Case Based MCQs

1. **Read the following and answer any four questions from 1(i) to 1(v).**

Light travels through a vacuum at a speed $c = 3 \times 10^8$ m/s. It can also travel through many materials, such as air, water and glass. Atoms in the material absorb, reemit and scatter the light, however. Therefore, light travels through the material at a speed that is less than c, the actual speed depending on the nature of the material. To describe the extent to which the speed of light in a material medium differs from that in a vacuum, we use a parameter called the index of refraction (or refractive index).

(i) Figure shows a ray of light as it travels from medium *A* to

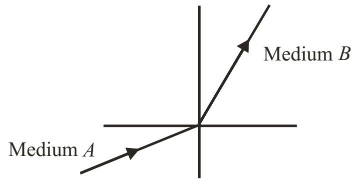


medium *B*. Retractive index of the medium B relative to medium A is

(a) $\frac{\sqrt{3}}{2}$ (b) $\frac{\sqrt{2}}{\sqrt{3}}$

(c) $\frac{1}{\sqrt{2}}$ (d) $\sqrt{2}$

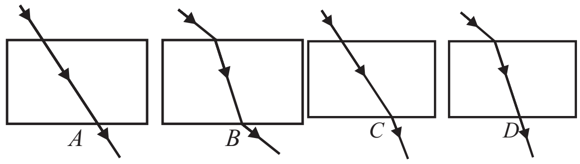
(ii) A light ray enters from medium *A* to medium *B* as shown



in the figure. The refractive index of medium *B* relative to *A* will be

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

(iii) The path of a ray of light coming from air passing through a rectangular glass slab traced by four students shown as *A, B, C* and *D* in the figure. Which one of them is correct?



(a) *A* (b) *B*
(c) *C* (d) *D*

(iv) You are given water, mustard oil, glycerine and kerosene. In which of these media, a ray of light incident obliquely at same angle would bend the most?

(a) Kerosene (b) Water
(c) Mustard oil (d) Glycerine

(v) A ray of light is incident in medium 1 on a surface that separates medium 1 from medium 2. Let v_1 and v_2 represent the velocity of light in medium 1 and medium 2 respectively. Also let n_{12} and n_{21} represent the refractive index of medium 1 with respect to medium 2 and refractive index of medium 2 with respect to medium 1, respectively. If *i* and *r* denote the angle of incidence and angle of refraction, then-

(a) $\frac{\sin i}{\sin r} = n_{21}\frac{v_1}{v_2}$ (b) $\frac{\sin i}{\sin r} = n_{21}\frac{v_2}{v_1}$

(c) $\frac{\sin i}{\sin r} = n_{12}\frac{v_1}{v_2}$ (d) $\frac{\sin i}{\sin r} = n_{12}\frac{v_2}{v_1}$

Exercise 2 Master NCERT (Textbook & Exemplar)

Text-Book Questions

1. Define the principal focus of a concave mirror.
2. The radius of curvature of a spherical mirror is 20 cm. What is its focal length ?
3. Name a mirror that can give an erect and enlarged image of an object.
4. Why do we prefer a convex mirror as a rear-view mirror in vehicles?
5. Find the focal length of a convex mirror whose radius of curvature is 32 cm.
6. A concave mirror produces three times magnified real image of an object placed at 10 cm in front of it. Where is the image located ?
7. A ray of light travelling in air enters obliquely into water. Does the light ray bend towards the normal or away from the normal? Why?
8. Light enters from air to glass having refractive index 1.50. What is the speed of light in the glass ? The speed of light in vaccum is 3×10^8 m / sec.
9. You are given kerosene, turpentine and water. In which of these does the light travel fastest?
10. Define 1 dioptre of power of a lens.
11. A convex lens forms a real and inverted image of a needle at a distance of 50 cm from it. Where is the needle placed in front of the convex lens if the image is equal to the size of the object ? Also, find the power of the lens.
12. Find the power of a concave lens of focal length 2 m.

Text-Book Exercise

1. Which one of the following materials cannot be used to make a lens?
   (a) Water (b) Glass (c) Plastic (d) Clay
2. The image formed by a concave mirror is observed to be virtual, erect and larger than the object. Where should be the position of the object?
   (a) Between the principal focus and the centre of curvature
   (b) At the centre of curvature
   (c) Beyond the centre of curvature
   (d) Between the pole of the mirror and its principal focus.
3. Where should an object be placed in front of a convex lens to get a real image of the size of the object?
   (a) At the principal focus of the lens
   (b) At twice the focal length
   (c) At infinity
   (d) Between the optical centre of the lens and its principal focus
4. A spherical mirror and a thin spherical lens have each a focal length of –15 cm. The mirror and the lens are likely to be –
   (a) both concave
   (b) both convex
   (c) the mirror is concave and the lens is convex
   (d) the mirror is convex but the lens is concave.
5. No matter how far you stand from a mirror, your image appears erect. The mirror is likely to be
   (a) plane (b) concave
   (c) convex (d) either planer or convex
6. Which of the following lenses would you prefer to use while reading small letters found in a dictionary?
   (a) A convex lens of focal length 50 cm
   (b) A concave lens of focal length 50 cm.
   (c) A convex lens of focal length 5 cm
   (d) A concave lens of focal length 5 cm
7. We wish to obtain an erect image of an object, using a concave mirror of focal length 15 cm. What should be the range of distance of the object from the mirror? What is the nature of the image? Is the image larger or smaller than the object? Draw a ray diagram to show the image formation in this case.
8. Name the type of mirror used in the following situations.
   (a) Headlights of a car.
   (b) Side/rear-view mirror of a vehicle.
   (c) Solar furnace.
   (d) Support your answer with reason.
9. An object 5 cm in length is held 25 cm away from a converging lens of focal length 10 cm. Draw the ray diagram and find the position, size and the nature of the image formed.
10. A concave lens of focal length 15 cm forms an image 10 cm from the lens. How far is the object placed from the lens? Draw the ray diagram.
11. An object is placed at a distance of 10 cm from a convex mirror of focal length 15 cm. Find the position and nature of the image.
12. The magnification produced by a plane mirror is +1. What does this mean?
13. An object 5 cm in length is placed at a distance of 20 cm in front of a convex mirror of radius of curvature 30 cm. Find the position of the image, its nature and size.
14. An object of size 7 cm is placed at 27 cm in front of a concave mirror of focal length 18 cm. At what distance from the mirror should a screen be placed, so that a sharp focussed image can be otained ? Find the size and nature of the image.