UNIT 3

Light

Learning Objectives

At the end of this unit the students will be able to

- describe the nature of images formed by plane mirrors
- explain why lateral inversion takes place
- apply the laws of reflection for plane mirrors and spherical mirrors
- draw ray diagrams to find the position and size of the image for spherical mirrors
- distinguish between real and virtual images
- apply the mirror equation to calculate position, size and nature of images and focal lengths for spherical mirrors
- identify situations in which refraction will occur
- identify the direction of bending when light passes from one medium to another
- solve problems using Snell's law
- predict whether light will be refracted or undergo total internal reflection
- recognize atmospheric conditions that cause refraction

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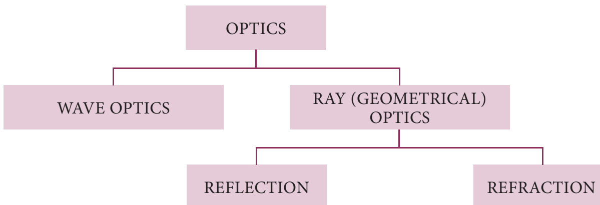
Introduction

In our day to day life we use number of optical instruments. Microscopes are inevitable in physics laboratory, biology laboratory and in medical laboratories. Also telescopes, binoculars, cameras and projectors are used in educational, scientific and entertainment fields. Do you know the basic components or parts used in these instruments? Mirrors and lenses! You can name some more optical instruments you have seen. Also, in our daily life we come across many optical illusions like mirage, rainbow, apparent bending of objects placed in liquids.

In this chapter, you will learn about the properties of plane mirror and spherical mirrors (concave and convex). Also you will learn about the properties of light, namely reflection and refraction and their applications.

Light is a form of energy and it travels in the form of electromagnetic waves. The branch of physics that deals with the properties and applications of light is called *optics*. The branch of optics that treats light as rays is named *ray optics* or *geometrical optics* and the branch of optics where the wave nature of light is considered is called *wave optics*.



3.1 Reflection of Light

You know that light is a form of energy. This energy travels from a source in all direction and the direction along which it travels is called a ray of light. Observe a bulb in your house, slightly closing your eye lids. You can see the light in the form of yellow lines. One such a line is called a ray. A bundle of such rays constitute a beam of light.

Light falling on any polished surface such as a mirror, is reflected. This reflection of light on polished surfaces follows certain laws and you might have studied about them in your lower classes. Let us study about them little elaborately.

3.1.1 Laws of reflection

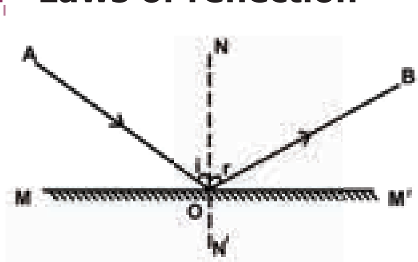


Figure 1 Plane mirror

Consider a plane mirror MM′ as shown in Figure 1. Let AO be the light ray incident on the plane mirror at O. The ray AO is called incident ray. The plane mirror reflects the incident ray along OB. The ray OB is called reflected ray. Draw a line ON at O perpendicular to MM′. This line ON is called **normal.**

The angle made by the incident ray with the normal (i = *angle* AON) is called angle of incidence. The reflected ray OB makes an angle (r = angle NOB) with the normal and this is called angle of reflection. From the figure you can observe that the angle of incidence is equal to the angle of reflection. (i.e) $\angle i = \angle r$. Also, the incident ray, the reflected ray and the normal at the point of incidence all lie in the same plane. These are called the laws of reflection.

Laws of reflection:

- The incident ray, the reflected ray and the normal at the point of incidence, all lie in the same plane.
- The angle of incidence is equal to angle of reflection.

Activity 1

The most common modern usage of mirror writing can be found on the front of ambulances, where the word "AMBULANCE" is often written in very large mirrored text, find out why it is written in such a way?

Reflection of light has many interesting facts. Let us look at some of them here.

How tall does a mirror have to be to fit your entire body?

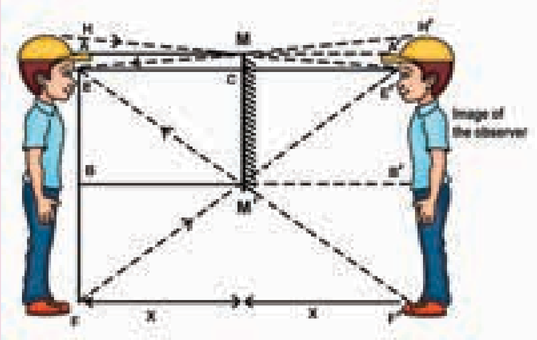
Can you see your entire body in a make-up mirror? Now, stand before the mirror in your dressing table or the mirror fixed in a steel almirah. Do you see your whole body now? What do you know from this? To see your entire body in a mirror, the mirror should be atleast half of your height. Height of the mirror= Your height/2

Find out

Using a metre scale, measure your height in centimetre. Now find out the height of the mirror to see your entire body.

More to Know

Let an observer *HF* stand at a distance '*x*' in front of a plane mirror *MM′*. The image *H′F′* of the observer is formed at the same distance '*x*' behind the plane mirror. The image *H′F′* of this observer will be of the same size as that of the observer.



A ray from the person's feet FM′, gets reflected as M′E. He observes this as virtual image at F′. Based on Law of reflection (2) and on the geometry of the triangles Δ FM′B and Δ BM′E,

the height of the person from feet to eye = FE
this is double that of EB (or) EB = $\frac{FE}{2}$.

Also EB = CM′ (1)

Similarly, a ray from the person's head HM, gets reflected as ME. He observes this as virtual image at H′. Based on the same law and geometry of the triangles Δ HMA and Δ H′MA′,

the height of the person from head to eye = HE
this is double that of AE (or) AE = $\frac{HE}{2}$.

Also AE = MC (2)

From the above figure,

total height of the person = HF = HE + EF (3)

total height of his image = H′F′ = H′E′ + E′F′ (4)
These two heights are the *same*. (Can you prove it?)

Moreover, from (1) and (2),

Height of mirror = CM′ + CM = $\frac{FE}{2}$ + $\frac{EH}{2}$ = $\frac{HF}{2}$. i.e., half of his height

Note: The requirement remains the same regardless of the distance *x* of the observer from the mirror.

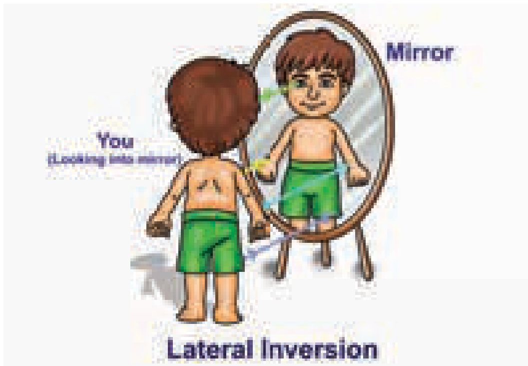
3.1.2 Lateral inversion

You might have heard about inversion. But what is lateral inversion?The word lateral comes from the Latin word *latus* which means side. Lateral inversion means sidewise inversion; it is the apparent inversion of left and right that occurs in a plane mirror.

Why do plane mirrors reverse left and right, but they do not reverse up and down?

Well the answer is surprising. Mirrors do not actually reverse left and right and they do not reverse up and down also. What actually mirrors do is reverse inside out.

Look at the image below and observe the arrows, which indicate the light ray from the object falling on the mirror. The arrow from object's head is directed towards the top of the mirror and the arrow from the feet is directed towards the bottom. The arrow from left hand goes to the left side of the mirror and the arrow from the right hand goes to the right side of the mirror. Here, you can see that there is no switching. It is an optical illusion.



The apparent lateral inversion we observe is not caused by the mirror but the result of our perception.

Note: You can try this activity with pencil or pen. What do you observe?

3.2 Curved Mirrors

We studied about laws of reflection. These laws are applicable to all types of reflecting surfaces including curved surfaces. Let us learn about image formation in curved surfaces in this part.

In your earlier classes, you have studied that there are many types of curved mirrors, such as spherical and parabolic mirrors. The most commonly used type of curved mirror is spherical mirror. The curved surfaces of a shining spoon could also be considered as a curved mirror.

Take a hemispherical spoon. It has an inner and outer surface like the inside and outside of the ball. See your face on these surfaces? How do they look?

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?

3.2.1 Spherical mirrors

In curved mirrors, the reflecting surface can be considered to form a part of the surface of a sphere. Such mirrors whose reflecting surfaces are spherical are called spherical mirrors.

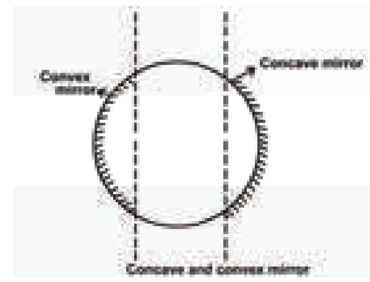


Figure 2 Concave and Convex mirror

In some spherical mirrors the reflecting surface is curved inwards, that is, it faces towards the centre of the sphere. It is called concave mirror. In some other mirrors, the reflecting surface is curved outward. It is called convex mirror and are shown in Figure 2.

In order to understand reflection of light at curved surfaces, we need to know the following.

Centre of curvature (C): The centre of the hollow sphere of which the spherical mirror forms a part.

Pole (P): The geometrical centre of the spherical mirror.

Principal axis (PC)**:** The perpendicular line joining the pole and the centre of curvature of the mirror.

Radius of curvature(R): The distance between the pole and the centre of curvature of the spherical mirror.

Principal focus (F): The point on the principal axis of the spherical mirror where the rays of light parallel to the principal axis meet or appear to meet after reflection from the spherical mirror.

Focal length(f): The distance between the pole and the principal focus.

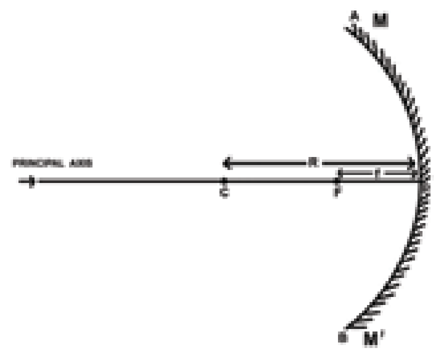


Figure 3 Concave mirror

Radius of curvature and focal length are related to each other by the formula: R=2f. All these are depicted in Figure 3.

Check yourself:

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1. Focal length of a concave mirror is 5 cm. Find its radius of curvature.
2. For a concave mirror the distance between P and C is 10 cm. Calculate it's the focal length.
3. A concave mirror has radius of curvature 20 cm. Find the focal length of the mirror.

3.3 Image Formed by Curved Mirrors

Activity 2

Hold a concave mirror in your hand (or placed in a stand). Direct its reflecting surface towards the sun. Direct the light reflected by the mirror onto a sheet of paper held not very far from the mirror. Move the sheet of paper back and forth gradually until you find a bright, sharp spot of light on the paper. **[Do this activity only under adult supervision]**. Position the mirror and the paper at the same location for few moments. What do you observe? Why does the paper catches fire?

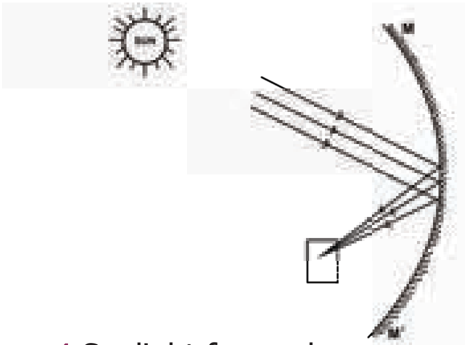


Figure 4 Sunlight focused on a concave mirror

We have seen that the parallel rays of sun light (Figure 4) could be focused at a point using a concave mirror. Now let us place a lighted candle and a white screen in front of the concave mirror. Adjust the position of the screen. Move the screen front and back. Note the size of the image and its shape. Is it inverted? Is it small?

Next, slowly bring the candle closer to the mirror. What do you observe? As you bring the object closer to the mirror the image becomes bigger. Try to locate the image when you bring the candle very close to the mirror. Are you able to see an image on the screen? Now look inside the mirror. What do you see? An erect magnified image of the candle is seen. In some positions of the object an image is obtained on the screen. However at some position of the object no image is obtained. It is clear that the behaviour of the concave mirror is much more complicated than the plane mirror.

However, with the use of geometrical technique we can simplify and understand the behaviour of the image formed by a concave mirror. In the earlier case of plane mirror, we used only two rays to understand how to get full image of a person. But for understanding the nature of image formed by a concave mirror we need to look at four specific rules.

3.3.1 Rules for the construction of image formed by spherical mirrors

From each point of an object, number of rays travel in all directions. To find the position and nature of the image formed by a concave mirror, we need to know the following rules.

Rule 1: A ray passing through the centre of curvature is reflected back along its own path (Figure 5).

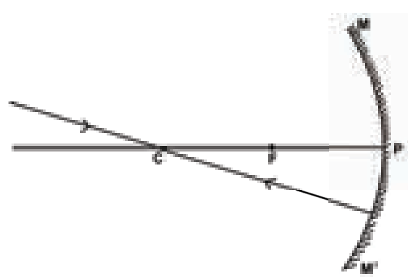


Figure 5 Ray passing centre of curvature

Rule 2: A ray parallel to the principal axis passes through the principal focus after reflection (Figure 6).

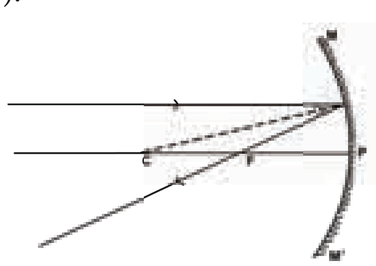


Figure 6 Ray parallel to prinicpal axis

Rule 3: A ray passing through the focus gets reflected and travels parallel to the principal axis (Figure 7).

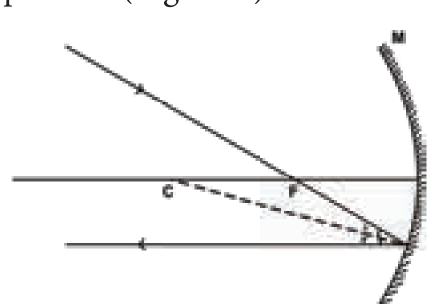


Figure 7 Ray travelling through the principal focus

Rule 4: A ray incident at the pole of the mirror gets reflected along a path such that the angle of incidence (APC) is equal to the angle of reflection (BPC) (Figure 8).

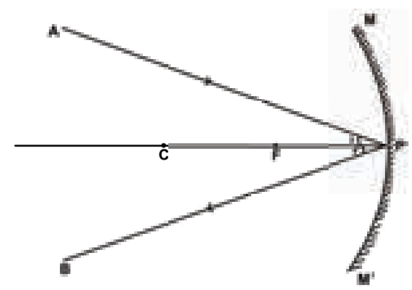


Figure 8 Angle of incidence equal to angle of reflection

3.4 Real and Virtual Image

If the light rays coming from an object actually meet, after reflection, the image formed will be a real image and it is always inverted. A real image can be produced on a screen. When the light rays coming from an object do not actually meet, but appear to meet when produced backwards,that image will be virtual image. The virtual image is always erect and cannot be caught on a screen (Figure 9).

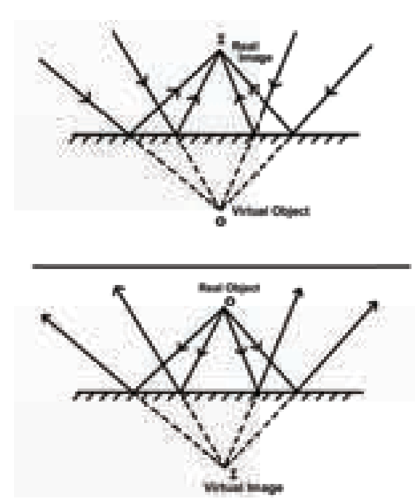


Figure 9 Real and virtual image

Activity 3

Keep a lighted candle between the principal focus (F) and pole (P) of a concave mirror. Can you see an enlarged image of the candle on the mirror? Now keep the candle away from P, beyond C. You can obtain an image of the candle on a screen.

What is the type of image formed by a plane mirror? Can you catch that image on a screen?

3.5 Concave Mirror

3.5.1 Ray diagrams for the formation of images

We shall now find the position, size and nature of image by drawing the ray diagram for a small linear object placed on the principal axis of a concave mirror at different positions.

Case–I: When the object is far away (at infinity), the rays of light reaching the concave mirror are parallel to each other (Figure 10).

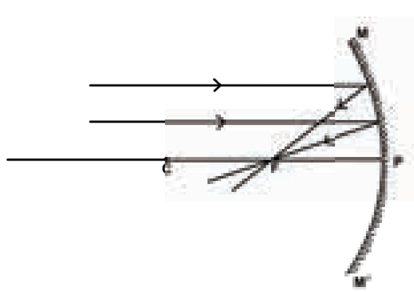


Figure 10 Object at inifinity

Position of the Image: The image is at the principal focus F.

Nature of the Image: It is (i) real, (ii) inverted and (iii) highly diminished in size.

Case–II: When the object is beyond the centre of curvature (Figure 11).

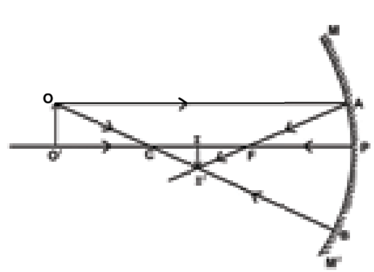


Figure 11 Object beyond the centre of curvature

Position of the image: Between the principal focus F and centre of curvature C.

Nature of the image: Real, inverted and smaller than object.

Case – III: When the object is at the centre of curvature (Figure 12).

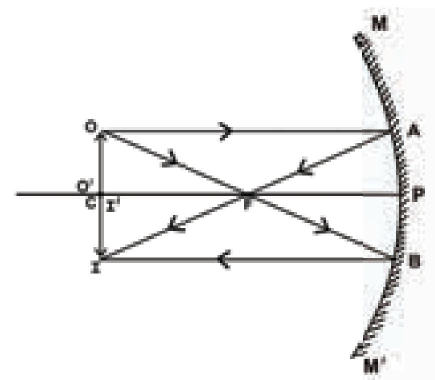


Figure 12 Object at the centre of curvature

Position of the image: The image is at the centre of curvature itself.

Nature of the image: It is i) Real, ii) inverted and iii) same size as the object.

Case – IV: When the object is in between the centre of curvature C and principal focus F (Figure 13).

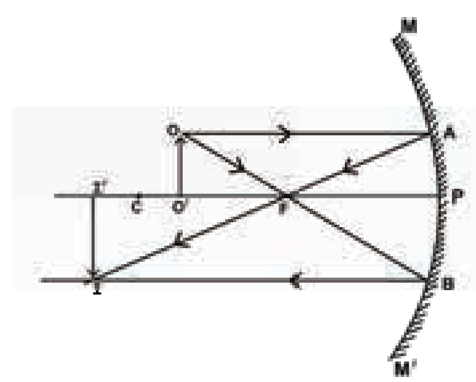


Figure 13 Object in between centre of curvature and principal focus

Position of the image: The image is beyond C

Nature of the image: It is i)Real ii) inverted and iii) magnified.

Case – V: When the object is at the principal focus F (Figure 14).

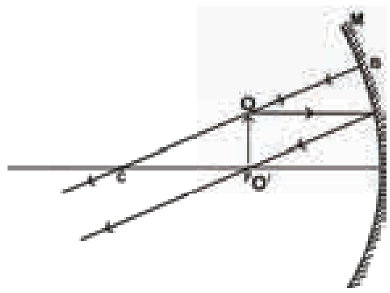


Figure 14 Object at principal focus

Position of the image: Theoretically, the image is at infinity.

Nature of the image: No image can be captured on a screen nor any virtual image can be seen.

Case – VI: When the object is in between the focus F and the pole P (Figure 15).

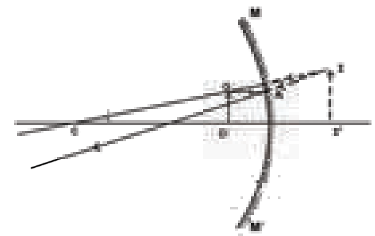
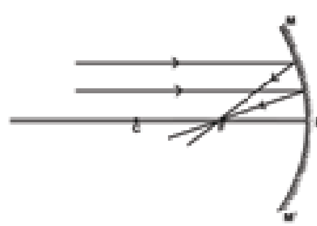
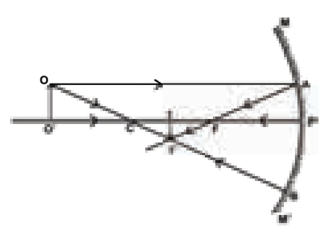
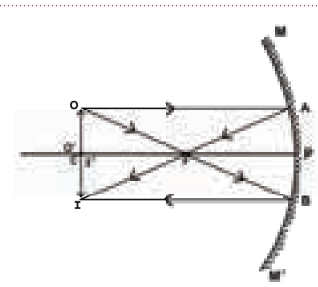
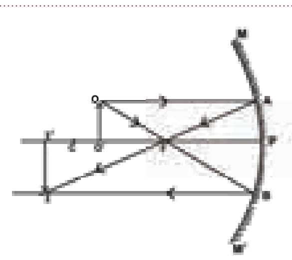
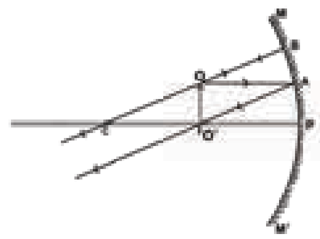
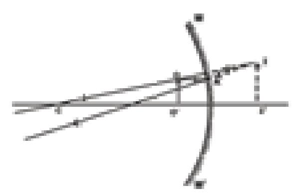


Figure 15 Object in between principal focus and pole

Position of the image: The image is behind the mirror.

Nature of the image: It is virtual,erect and magnified.

Sl. No.	Position of Object	Ray Diagram	Position of Image	Size of Image	Nature of Image
1.	At infinity		At the principal focus	Point size	Real and Inverted
2.	Beyond the Centre of Curvature C		Between F and C	Smaller than the object	Real and Inverted
3.	At the Centre of Curvature C		At C	Same size	Real and Inverted
4.	Between C and F		Beyond C	Magnified	Real and inverted

Sl. No.	Position of Object	Ray Diagram	Position of Image	Size of Image	Nature of Image
5.	At the principal focus F		At infinity	infinitely large	Real and Inverted
6.	Between the principal focus F and the pole P of the mirror		Behind the mirror	Magnified	Virtual and Erect

3.5.2 Sign convention for measurement of distances

We follow a set of sign conventions called the cartesian sign convention. In this convention the pole (P) of the mirror is taken as the origin. The principal axis is taken as the x axis of the coordinate system (Figure 16).

Figure 16 Sign convention for spherical mirrors

- The object is always placed on the left side of the mirror.
- All distances are measured from the pole of the mirror.
- Distances measured in the direction of incident light are taken as positive and those measured in the opposite direction are taken as negative.
- All distances measured perpendicular to and above the principal axis are considered to be positive.
- All distances measured perpendicular to and below the principal axis are considered to be negative.

3.5.3 Mirror equation

The expression relating the distance of the object u, distance of image v and focal length f of a spherical mirror is called the mirror equation. It is given as:

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

Type of mirror	u	v		f	R	Height of the Object	Height of the Image	
		real	virtual				real	virtual
Concave mirror	-	-	+	-	-	+	-	+
Convex mirror	-	No real image	+	+	+	+	No real image	+

Sign convention for measurement of distances

3.5.4 Linear magnification (m)

Magnification produced by a spherical mirror gives the how many times the image of an object is magnified with respect to the object size.

It can be defined as the ratio of the height of the image (h_i) to the height of the object (h_o).

$$m = \frac{h_i}{h_o}$$

The magnification can be related to object distance (u) and the image distance (v)

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

$$\therefore m = \frac{h_i}{h_o} = -\frac{v}{u}$$

Note: A negative sign in the value of magnification indicates that the image is real. A positive sign in the value of magnification indicates that the virtual image.

Sample Problem 1

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

1. Position of image

Object distance u = – 15 cm (to the left of mirror)

Image distance v =?

Focal length f = – 10 cm (concave mirror)

Using mirror formula

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

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

$$\frac{1}{v} - \frac{1}{15} = \frac{-1}{10}$$

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

$$= \frac{-3+2}{30}$$

$$\frac{1}{v} = \frac{-1}{30}$$

∴ Image distance v = −30cm (negative sign indicates that the image is on the left side of the mirror)

∴ Position of image is 30 cm in front of the mirror

2. Nature of image: Since the image is in front of the mirror it is real and inverted.
3. Size of image: To find the size of the image, we have to calculate the magnification.

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

Object distance u = – 15cm

Image distance v = – 30 cm

$$m = \frac{-(-30)}{(-15)}$$

$$m = -2$$

We know that, $m = \frac{h_2}{h_1}$

Here, height of the object h_1 = 1 cm

$$-2 = \frac{h_2}{1}$$

$$h_2 = -2 \times 1$$

$$= -2 \text{ cm}$$

The height of image is 2 cm (negative sign shows that the image is formed below the principal axis).

Sample Problem 2

An object 2 cm high is placed at a distance of 16 cm from a concave mirror which produces a real image 3 cm high. Find the position of the image.

Calculation of position of image

Height of object $h_1 = 2$ cm

Height of real image $h_2 = -3$ cm

Magnification $m = \frac{h_2}{h_1}$

$= \frac{-3}{2}$

$= -1.5$

We know that, $m = \frac{-v}{u}$

here, object distance $u = -16$ cm

Substituting the value, we get

$$-1.5 = -\frac{v}{(-16)}$$

$$-1.5 = \frac{v}{16}$$

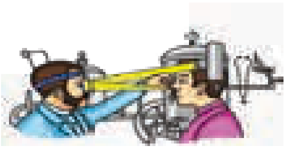
$$v = 16 \times (-1.5)$$

$$v = -24 \text{ cm}$$

The position of image is 24 cm in front of the mirror (negative sign indicates that the image is on the left side of the mirror).

3.5.5 Uses of concave mirror

As a dentist's head mirror: You would have seen a circular mirror attached to a band tied to the forehead of the dentist/ENT specialist. A parallel beam of light is made to fall on the concave mirror;this mirror focuses the light beam on a small area of the body (such as teeth, throat etc.).



As a make-up mirror: When a concave mirror is held near the face (between the pole and principal focus of the mirror), an upright and magnified image is seen. Here, our face will be seen magnified.

Other applications: Concave mirrors are also used as reflectors in torches, head lights in vehicles and search lights to get powerful beams of light. Concave reflectors are also used in room heaters. Large concave mirrors are used in solar heaters.

Think

Stellar objects are at an infinite distance; therefore the image formed by a concave mirror would be diminished, and inverted. Yet, why do astronomical telescopes use concave mirror?

3.6 Convex Mirror

3.6.1 Rules for the construction of image formed by spherical mirrors

We have studied the image formation by a concave mirror. Similarly, we can trace the path of light rays reflected by the convex mirrors using four 'rules'.

Rule 1: A ray of light which is parallel to the principal axis of a convex mirror appears to be coming from its principal focus, after reflection from the mirror (Figure 17).

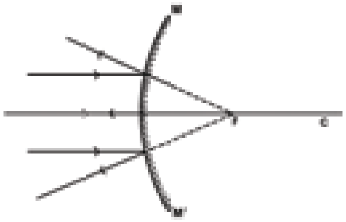


Figure 17 Rule 1

Rule 2: A ray of light going towards the centre of curvature is reflected back along the same path (Figure 18).

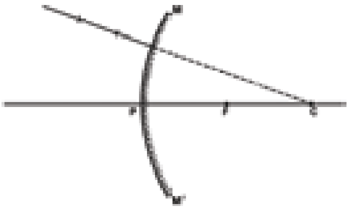


Figure 18 Rule 2

Rule 3: A ray of light going towards the principal focus of a convex mirror becomes parallel to the principal axis after reflection (Figure 19).

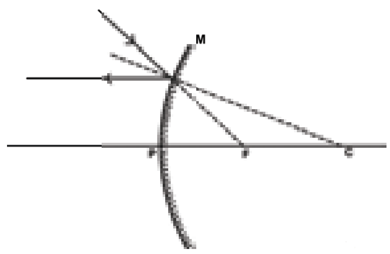


Figure 19 Rule 3

Rule 4: A ray of light which is incident at the pole of a convex mirror is reflected back making the same angle with the principal axis (Figure 20).

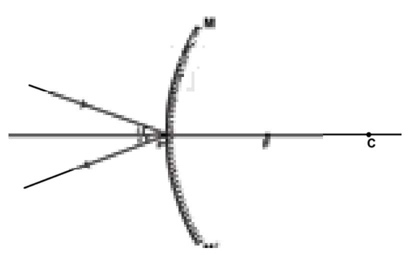


Figure 20 Rule 4

3.6.2 Image formation in a convex mirror

Any two rays can be chosen to draw the position of the image in a convex mirror (Figure 21).

1st ray: the ray that is parallel to the principal axis (rule 1) and

2nd ray : the ray that appears to pass through the centre of curvature (rule 2).

Note: All rays behind the convex mirror shall be shown with dotted lines.

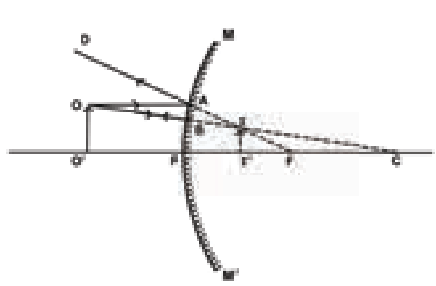


Figure 21 Image formation in a convex mirror

The ray OA parallel to the principal axis is reflected along AD. The ray OB retraces its path. The two reflected rays diverge but they appear to intersect at I when produced backwards. Thus II′ is the virtual image of the object OO′. It is virtual, erect and smaller than the object.

Activity 4

Draw a ray diagram with the object at different positions in front of the convex mirror. Observe the size, nature and positions of image in each case. What do you conclude?

Activity 5

Take a convex mirror. Hold it in one hand. Hold a pencil close to the mirror in the upright position in the other hand. Observe the image of the pencil in the mirror. Is the image erect or inverted? Is it diminished or enlarged? Move the pencil slowly away from the mirror. Does the image become smaller or larger? What do you observe?

ELP3FH

Sample Problem 3

A car is fitted with a convex mirror of focal length 20 cm. Another car is 6 m away from the first car.

a) Find the position of the second car as seen in the mirror of the first

b) What is the size of the image if the second car is 2 m broad and 1.6 m high?

Focal length = 20 cm (convex mirror)

Object distance = –6m

= –600 cm

Image distance v =?

Calculation for position of image using mirror equation

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

$$\frac{1}{20} = \frac{1}{-600} + \frac{1}{v}$$

$$\frac{1}{v} = \frac{1}{20} - \frac{1}{-600}$$

$$= \frac{1}{20} + \frac{1}{600}$$

$$\frac{1}{v} = \frac{30+1}{600} = \frac{31}{600}$$

$$v = \frac{600}{31}$$

$$= 19.35 \text{ cm}$$

b) Size of the image

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

$$= -\frac{v}{(-u)} = \frac{-600}{31} \times \frac{1}{-600}$$

$$m = \frac{1}{31}$$

$$\text{Breadth of image} = \frac{1}{31} \times 200 \text{ cm} = 6.45 \text{ cm}$$

$$\text{Height of image} = \frac{1}{31} \times 160 \text{ cm} = 5.16 \text{ cm}$$

3.6.3 Uses of convex mirrors

Convex mirrors are used as rear-view mirrors in vehicles. It always forms a virtual, erect, small-sized image of the object. As the vehicles approach the driver from behind the size of the image increases. When the vehicles are moving away from the driver, then image size decreases. A convex mirror provides a much wider field of view* compared to plane mirror.

(* field of view – it is the observable area as seen through eye / any optical device such as mirror)

DO YOU KNOW?

Convex mirrors are installed on public roads as traffic safety device. They are used in acute bends of narrow roads such as hairpin bends in mountain passes where direct view of oncoming vehicles is restricted. It is also used in blind spots in shops.

More to know by observation

1) Have you ever seen the dish antenna used at your home? What is the shape of the antenna? Is it convex or concave? Why?
2) Look around your environment. Observe all the spherical objects (having reflecting surfaces) and record your observation (for example soap bubble).

> **DO YOU KNOW?**
>
> In the rear view mirror, the following sentence is written. "Objects in the mirror are closer than they appear" Why?

Crossword puzzle

		1												
					2						12			
				3										
4							5							
							11							
				6			7		8					
							9				10			

Across

3. Kind of image formed when rays from the mirror converge.

4. Rays from an object at infinity.

6. Converging mirror.

9. Line perpendicular to the surface at the point of incidence.

11. Diameter of circular rim of spherical mirror.

Down

1. Reflection of light into many directions by rough objects.

2. The turning back of light at the shining surface of substance.

5. _______ of reflection: angle of incidence (i) = angle of reflection (r).

7. Centre of curvature is on the side opposite to the reflecting surface of mirror.

8. Image of an object in a plane mirror.

10. _______ of reflection angle between the reflected ray and the normal at thepoint of contact.

12. Nature of image formed by convex mirror.

3.7 Speed of light

In early seventeenth century, the Italian scientist Galileo Galilee (1564-1642) tried to measure the speed of light as it travelled from a lantern on a hill top about a mile (1.6 km) away from where he stood. His attempt was bound to fail, because he had no accurate clocks or timing instruments.

In 1665 the Danish astronomer Ole Roemer first estimated the speed of light by observing one of the twelve moons of the planet Jupiter. As these moons travel around the planet, at a set speed, it would take 42 hours to revolve around Jupiter. Roemer made a time schedule of the eclipses for the whole year. He made first observation in June and second observation in December. Roemer estimated the speed of light to be about 220,000 km per second.

In 1849 the first land based estimate was made by Armand Fizeau. Today the speed of light in vacuum is known to be almost exactly 300,000 km per second.

3.7.1 Refraction of light

Activity 6

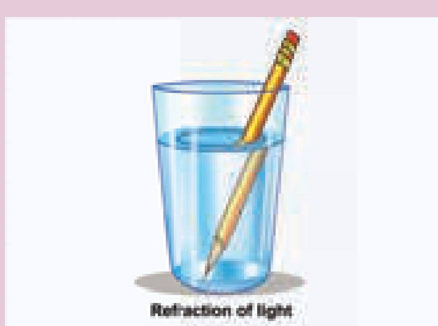
Refraction of light at air – water interface

a) Coin in a cup

Put a small coin, for example a five-rupee coin at the nearside of the cup and keep it at a distance so you/or your friend cannot see the coin; now gently pour water in the cup (without disturbing the coin). At some point, the coin comes in sight.

b) The bent pencil

Put a straight pencil into a tank of water or beaker of water at an angle of 45° and look at it from one side and above. How does the pencil look now? The pencil appears to be bent at the surface of water.



Both the above activities are the result of refraction of light. The bending of light rays when they pass obliquely from one medium to another medium is called refraction of light.

3.7.2 Cause of refraction

Light rays get deviated from their original path while entering from one transparent medium to another medium of different optical density. This deviation (change in direction) in the path of light is due to the change in velocity of light in the different medium. The velocity of light depends on the nature of the medium in which it travels. Velocity of light in a rarer medium (low optical density) is more than in a denser medium (high optical density).

3.7.3 Refraction of light from a plane transparent surface

When a ray of light travels from optically rarer medium to optically denser medium, it bends towards the normal. (Figure 22)

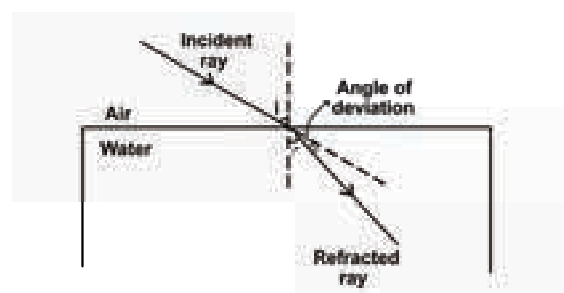


Figure 22 Light ray travelling from rarer to denser medium

When a ray of light travels from an optically denser medium to an optically rarer medium it bends away from the normal. (Figure 23)

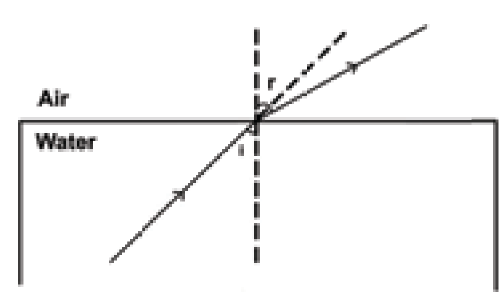


Figure 23 Light ray travelling from denser to rarer medium

A ray of light incident normally on a denser medium, goes without any deviation. (Figure 24).

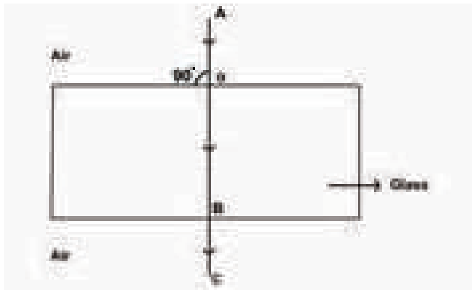


Figure 24 Incident of light ray in denser medium

3.7.4 The laws of refraction of light

The incident ray, the refracted ray and the normal to the interface of two transparent media at the point of incidence, all lie in the same plane.

The ratio of the sine of the angle of incidence to the sine of the angle of refraction is a constant for a light of a given colour and for the given pair of media. This law is also known as Snell's law of refraction.

If i is the angle of incidence and r is the angle of refraction, then

$$\frac{\sin i}{\sin r} = \text{constant}$$

This constant is called the refractive index of the second medium with respect to the first medium. It is generally represented by the Greek letter, ${}_1\mu_2$ (mew)

Note: The refractive index has no unit as it is the ratio of two similar quantities

3.7.5 Verification of laws of refraction

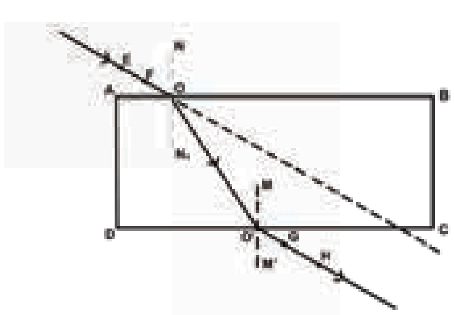


Figure 25 Verification of laws of refraction

Activity 7

Fix a sheet of white paper on a drawing board using drawing pins.

Place a rectangular glass slab over the sheet in the middle

Draw the outline of the slab with a pencil. Let us name the outline as ABCD

Take four identical pins.

Fix two pins. Say E and F, vertically such that the line joining the pins is inclined to the edge AB.

Look for the images of the pins E and F through the opposite edge. Fix two other pins, say G and H, such that these pins and the images of E and F lie on a straight line.

Remove the pins and the slab.

Join the prints of the pins E and F and let it meet AB at O. Let EF meet AB at O. Similarly, join the prints of the pins G and H and Let it meet HG at O′. Join O and O′. Also produce EF as shown by a dotted line in Figure 25.

Draw a perpendicular NN′ to AB at O and another perpendicular MM′ to CD at O′. In this activity, you will note that, the light ray has changed its direction at points O and O′. Note that both the points O and O′ lie on surfaces separating two transparent media. The light ray has entered from air to glass and has bent towards the normal that is from a rarer to denser medium.

The light ray has emerged from glass to air that is from a denser medium to a rarer medium. The light here has bent away from the normal. Compare the angle of incidence with the angle of refraction at both refracting surfaces AB and CD.

In Figure 25 EO is the incident ray OO′ the refracted ray and O′H the emergent ray. You may observe that the emergent ray is parallel to the direction of the incident ray. Why does it happen so? The extent of bending of the ray of light at the opposite parallel faces AB (air-glass interface) and CD (glass-air-interface) of the rectangular glass slab is equal and opposite. This is why the ray emerges parallel to the incident ray. However, the light ray is shifted sideward slightly. What happens when a light ray is incident normally to the interface of two media? Try and find out.

Refraction through Rectangular glass slab:

http://www.freezeray.com/flashFiles/Refraction2.htm

3.7.6 Speed of light in different media

Light has the maximum speed in vacuum and it travels with different speeds in different media. The speed of light in some media is given below.

Substance	Speed of light(ms^{-1})	Refractive index(μ)
Water	2.25×10^8	1.33
glass	2×10^8	1.5
diamond	1.25×10^8	2.41
Air	3×10^8	1.00

Note: The refractive index of a medium is also defined in terms of speed of light in different media

$$\mu = \frac{\text{speed of light in vacuum or air } (c)}{\text{speed of light in the medium } (v)}$$

In general $_1\mu_2 = \dfrac{\text{Speed of light in medium 1}}{\text{Speed of light in medium 2}}$

Sample problem 4

The speed of light in air is $3 \times 10^8 ms^{-1}$ and in glass it is $2 \times 10^8 ms^{-1}$ what is the refractive index of glass.

$$_a\mu_g = \frac{3 \times 10^8}{2 \times 10^8} = \frac{3}{2} = 1.5$$

Sample problem 5

Light travels from a rarer medium to a denser medium. The angles of incidence and refraction are respectively 45° and 30°. Calculate the refractive index of the second medium with respect to the first medium.

Angle of incidence i = 45°

Angle of refraction r = 30°

$$_1\mu_2 = \frac{\sin i}{\sin r}$$

$$_1\mu_2 = \frac{\sin 45^\circ}{\sin 30^\circ}$$

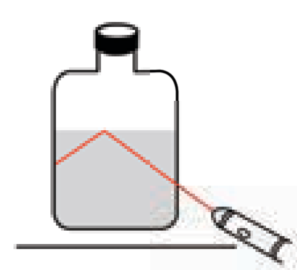
$$= \frac{1/\sqrt{2}}{1/2} = \sqrt{2}$$

$$_1\mu_2 = 1.414$$

3.8 Total Internal Reflection

A demonstration for total internal reflection

Apparatus: Small transparent bottle, Few drops of Dettol (or some salt); Pointer laser



- Take some water in a bottle; add a few drops of Dettol or some salt.

- Point the laser pointer at different angles and note its path
- At some angle, you will see that the light gets reflected within the water itself. This is called total internal reflection.

Total internal reflection: https://www.youtube.com/watch?v=axwDkA9PrgI

3.8.1 When does total internal reflection takes place?

When light travels from denser medium into a rarer medium, it gets refracted away from the normal. We know this. While the angle of incidence in the denser medium increases the angle of refraction also increases and it reaches a maximum value of r = 90° for a particular angle of incidence value. This angle of incidence is called critical angle (Figure 26). Now the refracted ray grazes the surface of separation between the two media.

The angle of incidence at which the angle of refraction is 90° is called the critical angle.

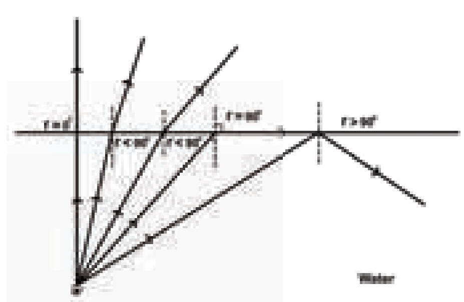


Figure 26 Critical angle

When the angle of incidence exceeds the value of critical angle, the refracted ray is not possible, since r > 90° the ray is totally reflected back to the same medium. This is called as total internal reflection.

3.8.2 Conditions to achieve total internal reflection

- Light must travel from denser medium to rarer medium. Example from water to air.
- The angle of incidence inside the denser medium must be greater than that of the critical angle.

Recall

1. Write the relation between the angle of incidence and the angle of refraction.
2. What is the unit of refractive index?
3. Which has higher refractive index: water or glass?
4. When does refraction take place?
5. When does total internal reflection take place?

3.8.3 Total internal reflection in nature

Mirage: On hot summer days, when you are travelling on a straight road have you seen the patch of water on the road which keeps moving ahead as you approach it? This is an illusion sometimes in the desert or over hot roads. Especially in summer, the air near the ground becomes hotter than the air at higher levels. The refractive index of air increases with its density. Hotter air is less dense, and has smaller refractive index than the cooler air. If the air currents are small, that is, the air is still, the optical density of different layers of air increases with height. As a result, light from an object such as a car (See Photo), passes through a medium whose refractive index decreases towards the ground. Thus, a ray of light from such an object successively bends away from the normal and undergoes total internal reflection, if the angle of incidence for the air near the ground exceeds the critical angle.

Diamond: Diamonds are known for their spectacular brilliance. Do you know the reason for their brilliance? It is mainly due to the total internal reflection of light inside them. The critical angle for diamond – air interface (θ_c =24.4°) is very small; therefore once light enters a diamond, it is very likely to undergo total internal reflection inside it. Diamonds faces in nature rarely exhibit the brilliance for which they are known. It is the technical skill of a diamond cutter which makes diamonds to sparkle so brilliantly. By cutting the diamond suitably, multiple total internal reflections can be made to occur.

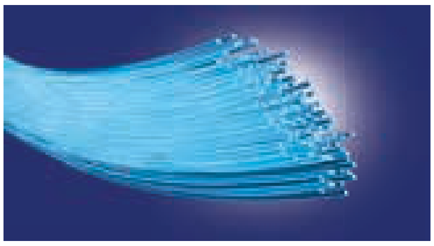
Why do stars twinkle?

Stars are very far away from us (so appear as point-like objects); light from the star passes through our atmosphere before it reaches our eyes. This light bends (refracts) due to the varying densities and temperature of atmosphere. Moreover, the atmosphere is not stable; it is very turbulent. Therefore, the light which reaches us appears to come from different points. This gives the impression that stars are twinkling. If you go above the atmosphere and see(!), stars do not twinkle. Can you find why do planets not twinkle?

Optical fibres

Optical fibres are bundles of high-quality composite glass/quartz fibres. Each fibre consists of a core and cladding. The refractive index of the material of the core is higher than that of the cladding. Optical fibres work on the phenomenon of total internal reflection. When a signal in the form of light is directed at one end of the fibre at a suitable angle, it undergoes repeated total internal reflection along the length of the fibre and finally comes out at the other end.

Optical fibres are extensively used for transmitting audio and video signals through long distances. Moreover, due to their flexible nature, optical fibers enable physicians to look and work inside the body through tiny incisions without having to perform surgery.



DO YOU KNOW?

We must be proud that an Indian-born physicist **Narinder Kapany** is regarded as the *Father of Fibre Optics*. Kapany used optical fibres to transmit and get back good images. In addition, Kapany's work is now used in lasers, biomedical instrumentation, solar energy and pollution monitoring. He is the one to have coined the name Fibre Optics.

Optical Fiber You tube Video: https://www.youtube.com/watch?v=llI8Mf_faVo

Recall

1. What are the examples of total internal reflection in nature?
2. What are the uses of total internal reflection?

Key words

Spherical mirror
Concave mirror
Convex mirror
Centre of curvature
Radius of curvature
Pole
Principal axis
Principal focus
Focal length
Magnification
Refraction of light
Laws of refraction
Total internal reflection

A-Z GLOSSARY

1. **Light** Light is a form of energy which produces the sensation of sight
2. **Ray of Light** Line drawn in the direction of propagation of light
3. **Laws of reflection**
   i) Angle of incidence is equal to the angle of reflection
   ii) The incident ray, the normal to the point of incidence and the reflected ray, all lie in the same plane
4. **Plane Mirror** Mirror with a flat (planar) reflective surface
5. **Spherical Mirror** A reflecting surface which is a part of a sphere whose inner or outer surface is reflecting
6. **Concave Mirror** Part of a hollow sphere whose outer part is silvered and/or inner part is the reflecting surface
7. **Convex Mirror** Part of the hollow sphere whose inner part is silvered and/or outer part is the reflecting surface
8. **Centre of curvature** The centre of the hollow sphere of which the spherical mirror forms a part is called centre of curvature
9. **Radius of curvature** The radius of the hollow sphere of which the spherical mirror forms a part is called radius of curvature
10. **Pole** The midpoint of the spherical mirror is called the pole
11. **Aperture** The diameter of the circular rim of the mirror is called the aperture of the mirror
12. **Principal axis** The normal to the centre of the mirror is called the principal axis
13. **Principal focus** The point on the principal axis of the spherical mirror where the rays of light parallel to the principal axis meet or appear to meet after reflection from the spherical mirror
14. **Focal length** The distance between the pole and the principal focus of the spherical mirror is called focal length. $f = \frac{R}{2}$; Where R is the radius of curvature of the mirror

15. **Mirror equation** The relation between u, v and f of a spherical mirror is known as mirror formula $\frac{1}{u}+\frac{1}{v}=\frac{1}{f}$

16. **Magnification** $m = \frac{\text{height of the image } h_2}{\text{height of the object } h_1}$

$$= \frac{-\text{image distance } v}{\text{object distance } u}$$

$$\text{so } m = \frac{h_2}{h_1} = \frac{-v}{u}$$

17. **Refraction of light** the bending of light when it passes obliquely from transparent medium to another is called refraction

18. **Laws of refraction**

The incident ray, the refracted ray and the normal to the surface separating two medium lie in the same plane

The ratio of the sine of the incident angle (∠i) to the sine of the refracted angle (∠r) is constant

i.e. $\mu = \frac{\sin i}{\sin r}$ = constant

19. **Total internal reflection** When the angle of incidence exceeds the value of critical angle the refracted ray is impossible, since r > 90° refraction is impossible the ray is totally reflected back to the same medium (denser medium). This is called as total internal reflection

ICT CORNER

LIGHT - REFRACTION

Refraction is bending of light when travel from one medium to another

This activity enable the students to learn about the different mediums and its role in refraction of light

B121_9_SCI_EM

Step 1. Type the following URL in the browser or scan the QR code from your mobile. Youcan see"**Bending light**" on the screen. Click intro

Step 2. Now you can see light beam from the torch. Options are there in the four corners. Select options of your choice and then press the button in the torch. You can see the phenomeno of refraction. The angles of refraction differ for different medium. You can check it with the protractor

Step 3. Next select prism. Now explore with given tools and different mediums and come out with different results

https://phet.colorado.edu/sims/html/bending-light/latest/bending-light_en.html

EXERCISE

I. Multiple Choice Questions

1. The field of view * is maximum for ______________
   a) plane mirror
   b) concave mirror
   c) convex mirror
   (*FOV is the extent of the observable area that is seen at any given instant)

2. When a ray of light passes from one medium to another medium, refraction takes place when angle of incidence is
   a) 0°   b) 45°   c) 90°

3. __________ is used as reflectors in torchlight
   a) concave mirror
   b) convex mirror
   c) plane mirror

4. We can create enlarged, virtual images with
   a) concave mirror
   b) convex mirror
   c) plane mirror

5. When the reflecting surface is curved outwards the mirror formed will be
   a) concave mirror
   b) convex mirror
   c) plane mirror

6. The focal length of a concave mirror is 5cm. Its radius of curvature is
   a) 5 cm   b) 10 cm   c) 2.5 cm

7. When a beam of white light passes through a prism it gets
   a) Reflected
   b) deviated and dispersed
   c) only deviated

8. The speed of light is maximum in
   a) vacuum
   b) glass
   c) diamond

9. A real and enlarged image can be obtained by using a
   a) convex mirror
   b) plane mirror
   c) concave mirror

10. Which of the following statements about total internal reflection is true?
    a) angle of incidence should be greater than critical angle
    b) light must travel from a medium of higher refractive index to a medium of lower refractive index
    c) both (a) and (b)

II. True or False – If false give the correct answer

1. The angle of deviation depends on the refractive index of the glass.
2. If a ray of light passes obliquely from one medium to another, it does not suffer any deviation.
3. If the object is at infinity in front of a convex mirror the image is formed at infinity.
4. An object is placed at distance of 3 cm from a plane mirror. The distance of the object and image is 3 cm.

5. The convex mirror always produces a virtual, diminished and erect image of the object.
6. The distance from centre of curvature of the mirror to the pole is called the focal length of the mirror.
7. When an object is at the centre of curvature of concave mirror the image formed will be virtual and erect.
8. Light is one of the slowest travelling energy with a speed of 3×10^{-8} ms^{-1}
9. The angle of incidence at which the angle of refraction is 0° is called the critical angle.
10. The reason for brilliance of diamonds is mainly due to total internal reflection of light.

III. Fill in the blanks / complete the Sentence

1. In going from a rarer to denser medium, the ray of light bends ______________.
2. The ratio of sine of the angle of incidence to the sine of ____________ is a constant.
3. The mirror used in search light is ______________.
4. The angle of deviation of light ray in a prism depends on the angle of ______________.
5. The radius of curvature of a concave mirror whose focal length is 5cm is __________________.
6. A spherical mirror whose reflecting surface is curved outwards is called ____________ mirror
7. Large __________ mirrors are used to concentrate sunlight to produce heat in solar furnaces
8. All distances parallel to the principal axis are measured from the ______________ of the mirror
9. A negative sign in the value of magnification indicates that the image is _____________
10. Light is refracted or bent while going from one medium to another because its ___________ changes.

IV. Match the following

i) List I	List II
1. Ratio of height of image to height of object.	1. concave mirror
2. Used in hairpin bends in mountains	2. total internal reflection
3. Coin inside water appearing slightly raised	3. magnification
4. Mirage	4. convex mirror
5. Used as Dentist's mirror	5. refraction

ii) Position of object	Position of image	Size and nature of image
1. Within focus	a) Between F and C	A) Magnified , Real, inverted
2. At focus F	b) At C	B) Magnified, virtual, erect
3. Between F and C	c) Behind the mirror	C) Diminished, Real, inverted
4. At C	d) Infinity	D) Highly Diminished, Real, inverted
5. Beyond C	e) At F	E) Highly Magnified , Real, inverted
6. At infinity	f) Beyond C	F) Same size, Real, inverted

V. Assertion & Reason

In the following questions, the statement of assertion is followed by a reason. Mark the correct choice as:

a) If both assertion and reason are true and reason is the correct explanation

b) If assertion is true but reason is false.

c) If assertion is false but reason is true.

1. Assertion: For observing the traffic at a hairpin bend in mountain paths a plane mirror is preferred over convex mirror and concave mirror.

   Reason: A convex mirror has a much larger field of view than a plane mirror or a concave mirror.

2. Assertion: Incident ray is directed towards the centre of curvature of spherical mirror. After reflection it retraces its path.

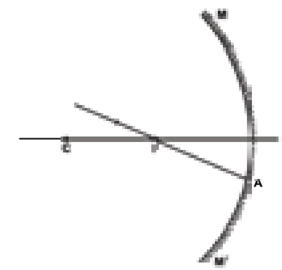
   Reason: Angle of incidence i = Angle of reflection $r = 0^o$.

VI. Very short answer type

1. Give two examples of transparent medium that are denser than air.
2. According to cartesion sign convention, which mirror and which lens has negative focal length?
3. A coin in a glass beaker appears to rise as the beaker is slowly filled with water, why?
4. Name the mirror(s) that can give (i) an erect and enlarged image, (ii) same sized, inverted image
5. Name the spherical mirror(s) that has/have

   i) Virtual principal focus

   ii) Real principal focus
6. If an object is placed at the focus of a concave mirror, where is the image formed?
7. Copy this figure in your answer book and show the direction of the light ray after reflection

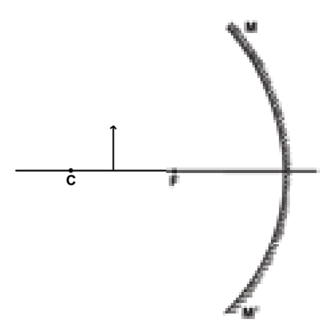


8. Why does a ray of light bend when it travels from one medium to another?
9. What is speed of light in vacuum? Who first measured the speed of light?
10. Concave mirrors are used by dentists to examine teeth. Why?

VII. Short answer type

1. a) Complete the diagram to show how a concave mirror forms the image of the object.

   b) What is the nature of the image?



2. Pick out the concave and convex mirrors from the following and tabulate them

   Rear-view mirror, Dentist's mirror, Torch-light mirror, Mirrors in shopping malls, Make-up mirror.
3. State the direction of incident ray which after reflection from a spherical mirror retraces its path. Give reason for your answer.

4. What is meant by magnification? Write its expression. What is its sign for the

   a) real image b) virtual image

5. Write the spherical mirror formula and explain the meaning of each symbol used in it.

VIII. Long answer type

1. a) Draw ray diagrams to show how the image is formed, using a concave mirror when the position of object is i) at C ii) between C and F iii) between F and P of the mirror.

   b) Mention in the diagram the position and nature of image in each case.

2. Explain with diagrams how refraction of incident light takes place from

   a) rarer to denser medium b) denser to rarer medium c) normal to the surface separating the two media.

3. State and verify laws of refraction using a glass slab.

4. Draw a ray diagram to show the formation of image by a concave mirror for an object placed between its pole and Principal focus and state three characteristics of the image.

IX. Numerical problems

1. The radius of curvature of a convex mirror is 40 cm. Find its focal length (Ans: 20 cm)

2. An object of height 2 cm is placed at a distance 20 cm in front of a concave mirror of focal length 12 cm. Find the position, size and nature of the image.

   (Ans: 30 cm in front of the mirror 3 cm high, real, inverted and magnified)

3. A concave mirror produces three times magnified real image of an object placed at 7 cm in front of it. Where is the image located?

   (Ans: 21 cm in front of the mirror)

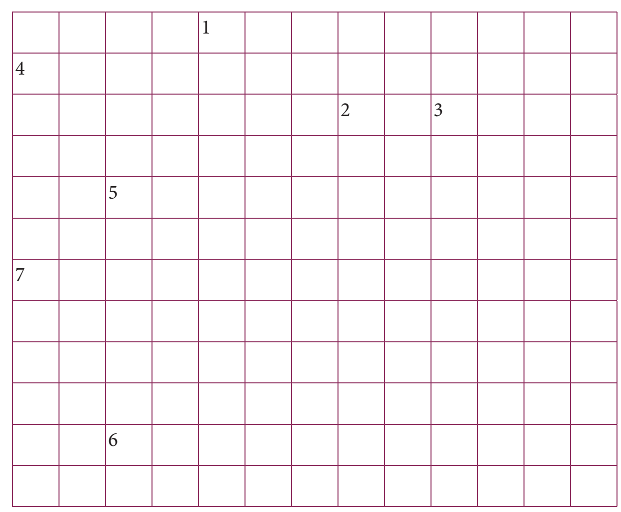
4. Light enters from air into a glass plate having refractive index 1.5. What is the speed of light in glass?(Speed of light in vacuum is 3×10^8 ms^{-1})

   (Ans: 2×10^8 ms^{-1})

5. The speed of light in water is 2.25×10^8 ms^{-1}. If the speed of light in vacuum is 3×10^8 ms^{-1}, calculate the refractive index of water.

   (Ans:1.33)

X. Cross word puzzle



Across

2. Optical illusion due to refraction
4. A type of mirror that diverge the light rays
6. The nature of image formed when object is near the pole of concave mirror
7. Electromagnetic radiation visible to us

Down

1. The light ray sent back from a surface into the same medium
3. When magnification is negative, the nature of the image is _________
5. For concave mirror u and f are always ___________

HOTS

1. Light ray emerges from water into air. Draw a ray diagram indicating the change in its path in water.
2. When a ray of light passes from air into glass, is the angle of refraction greater than or less than the angle of incidence?
3. What do you conclude about the speed of light in diamond if you are told that the refractive index of diamond is 2.41?

Amazing fact

Did you know that some organisms can make their own light too? This ability is called bioluminescence. Worms, fish, squid, starfish and some other organisms that live in the dark sea habitat glow or flash light to scare off predators.

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INTERNET RESOURCES

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II. https://elearning.cpp.edu/learning-objects/optics/spherical-mirrors/
III. https://www.geogebra.org/m/aJuUDA9Z
IV. https://www.edumedia-sciences.com/en/media/362-concave-mirror
V. http://www.animations.physics.unsw.edu.au/light/geometrical-optics/
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