TEST – 8 Part - 1

Light & Laser	8th term 1	Unit-3. Light
	9 th book	Unit - 6 –LIGHT
	10th book	Unit 2- Optics

8th term 1 Unit-3. Light

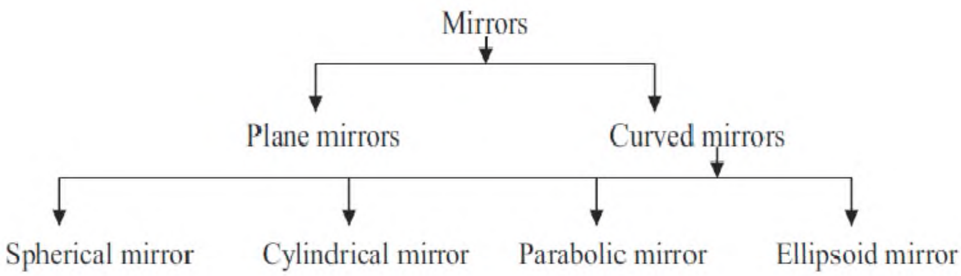
Introduction

Lofty mountains covered with greenish vegetation, magnificent trees reaching up to the clouds, beautiful streams drifting down the valleys, bluish sea water roaring towards the coast and the radiant sky in the morning being filled with golden red color, all give delight to our eyes and peace to our mind. But, can we see them all without light? No, because, we can see things around us only when the light reflected by them reaches our eyes.

Light is a form of energy and it travels in a straight line. You have studied in your lower classes, how it is reflected by the polished surfaces such as plane mirrors. In this lesson, you will study about other types of mirrors like the spherical mirrors and parabolic mirrors and their applications in our daily life. You will also study about the laws of reflection and the laws of refraction and some of the optical instruments, such as periscope and kaleidoscope, which work on these principles.

Types of Mirrors

We use mirrors in our daily life for various purposes. We use them for decoration. In vehicles, they are used as rear view mirrors. They are also used in scientific apparatus, like telescope. The mirror is an optical device with a polished surface that reflects the light falling on it. A typical mirror is a glass sheet coated with aluminium or silver on one of its sides to produce an image. Mirrors have a plane or curved surface. Curved mirrors have surfaces that are spherical, cylindrical, parabolic and ellipsoid. The shape of a mirror determines the type of image it forms. Plane mirrors form the perfect image of an object. Whereas, curved mirrors produce images that are either enlarged or diminished. You would have studied about plane mirrors in your lower classes. In this section, you will study about spherical and parabolic mirrors.



Do You Know?

Method of coating a glass plate with a thin layer of reflecting metals was in practice during the 16th century in Venice, Italy. They used an amalgam of tin and mercury for this purpose. Nowadays, a thin layer of molten aluminium or silver is used for coating glass plates that will then become mirrors.

Spherical mirrors

Spherical mirrors are one form of curved mirrors. If the curved mirror is a part of a sphere, then it is called a ‘spherical mirror’. It resembles the shape of a piece cut out from a spherical surface. One side of this mirror is silvered and the reflection of light occurs at the other side.

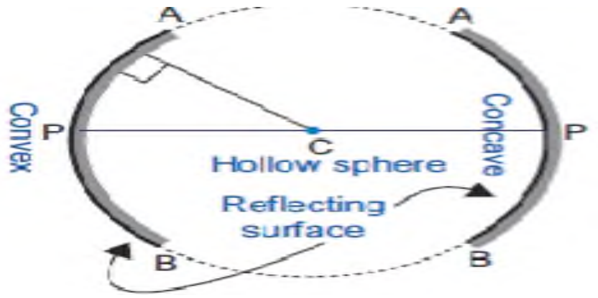


Figure 3.1 Spherical mirror

Concave mirrors

A spherical mirror, in which the reflection of light occurs at its concave surface, is called a concave mirror. These mirrors magnify theobject placed close to them. The most common example of a concave mirror is the make-up mirror.

Convex mirror

A spherical mirror, in which the reflection of light occurs at its convex surface, is called a convex mirror. The image formed by these mirrors is smaller than the object. Most common convex mirrors are rear viewing mirrors used in vehicles.

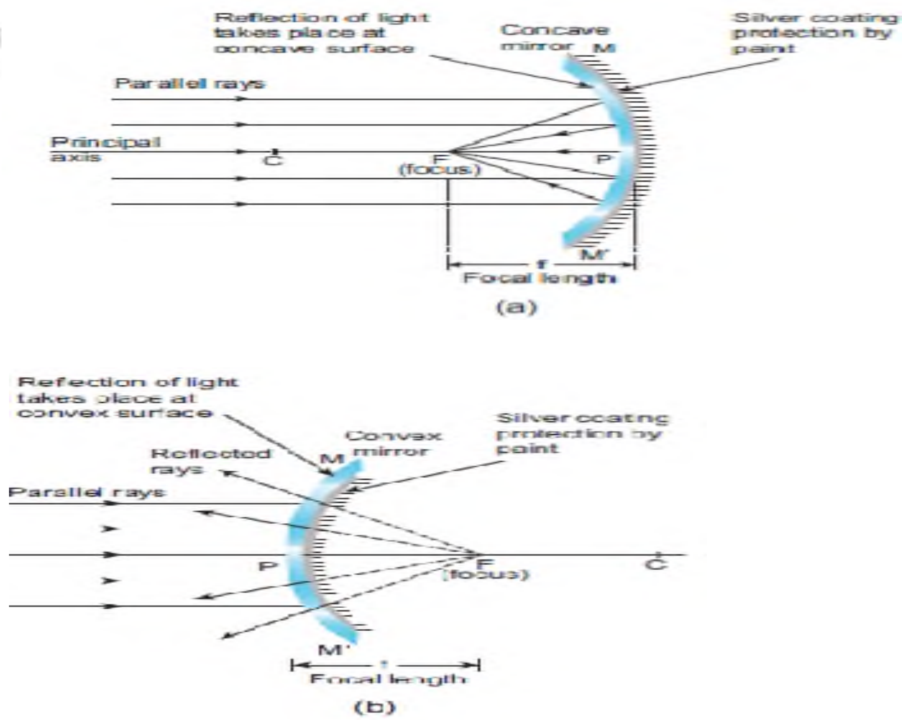


Figure 3.2 Concave and Convex mirrors

Do You Know?
Convex mirrors used in vehicles as rear-view mirrors are labeled with the safety warning: ‘Objects in the mirror are closer than they appear’ to warn the drivers. This is because inside the mirrors, vehicles will appear to be coming at a long distance.

Parabolic mirrors

A parabolic mirror is one type of curved mirror, which is in the shape of a parabola. It has a concave reflecting surface and this surface directs the entire incident beam of light to converge at its focal point.

In the same way, light rays generated by the source placed at this focal point will fall on this surface and they will be diverged in a direction, which is parallel to the principal axis of the parabolic mirror. Hence, the light rays will be reflected to travel a long distance, without getting diminished.

Parabolic mirrors, also known as parabolic reflectors, are used to collect or project energy such as light, heat, sound and radio waves. They are used in reflecting telescopes, radio telescopes and parabolic microphones. They are also used in solar cookers and solar water heaters.

Do You Know?
The principle behind the working of a parabolic mirror has been known since the Greco-Roman times. The first mention of these structures was found in the book, ‘On Burning Mirrors’, written by the mathematician Diocles. They were also studied in the 10th century, by a physicist called IbnSahl. The first parabolic mirrors were constructed by Heinrich Hertz, a German physicist, in the form of reflector antennae in the year 1888.

TERMS RELATED TO SPHERICAL MIRRORS

In order to understand the image formation in spherical mirrors, you need to know about some of the terms related to them.

Center of Curvature: It is the center of the sphere from which the mirror is made. It is denoted by the letter C in the ray diagrams. (A ray diagram represents the formation of an image by the spherical mirror. You will study about them in your next class).

Pole: It is the geometric centre of the spherical mirror. It is denoted by the letter P. Radius of Curvature: It is the distance between the center of the sphere and the vertex. It is shown by the letter R in ray diagrams. (The vertex is the point on the mirror's surface where the principal axis meets the mirror. It is also called as 'pole'.)

Principal Axis: The line joining the pole of the mirror and its center of curvature is called principal axis.

Focus: When a beam of light is incident on a spherical mirror, the reflected rays converge (concave mirror) at or appear to diverge from (convex mirror) a point on the principal axis. This point is called the 'focus' or 'principal focus'. It is also known as the focal point. It is denoted by the letter F in ray diagrams.

Focal length: The distance between the pole and the principal focus is called focal length (f) of a spherical mirror. There is a relation between the focal length of a spherical mirror and its radius of curvature. The focal length is half of the radius of curvature.

That is, focal length= $\frac{Radiusofcurvature}{2}$

Figure 3.4 Terms related to spherical mirror

PROBLEM 1 The radius of curvature of a spherical mirror is 20cm. Find its focal length Solution: Radius of curvature =20cm Focal length (f0 = $\frac{Radiusofcurvature}{2}$

$= \frac{R}{2} = \frac{20}{2} = 10cm$

PROBLEM 2

Focal length of a spherical mirror is 7 cm. What is its radius of curvature?

Solution:

Focal length = 7 cm

Radius of curvature (R) = 2 × focal length = 2 × 7 = 14 cm

IMAGES FORMED BY SPHERICAL MIRRORS

Images formed by spherical mirrors are of two types: i) real image and ii) virtual image. Real images can be formed on a screen, while virtual images cannot be formed on a screen.

Image formed by a convex mirror is always erect, virtual and diminished in size. As a result, images formed by these mirrors cannot be projected on a screen.

The characteristics of an image are determined by the location of the object. As the object gets closer to a concave mirror, the image gets larger, until attaining approximately the size of the object, when it reaches the centre of curvature of the mirror. As the object moves away, the image diminishes in size and gets gradually closer to the focus, until it is reduced to a point at the focus when the object is at an infinite distance from the mirror.

The size and nature of the image formed by a convex mirror is given in Table 3.1.

Concave mirrors form a real image and it can be caught on a screen. Unlike convex mirrors, concave mirrors show different image types. Depending on the position of the object in front of the mirror, the position, size and nature of the image will vary. Table 3.2 provides a summary of images formed by a concave mirror.

Table 3.1 Image formed by a convex mirror

POSITION OF THE OBJECT	POSITION OF THE IMAGE	IMAGE SIZE	NATURE OF THE IMAGE
At infinity	At F	Highly diminished, point sized	Virtual and erect
Between infinity the pole (P)	Between P and F	Diminished	Virtual erect

Table 3.2 Image formed by a concave mirror

POSITION OF THE OBJECT	POSITIOIN OF THE IMAGE	IMAGE SIZE	NATURE OF THE IMAGE
At infinity	At F	Highly diminished	Real and inverted
Beyond C	Between C and F	Diminished	Real and inverted
At C	At C	Same size as the object	Real and inverted
Between C and F	Beyond C	Magnified	Real and inverted
At F	At infinity	Highly magnified	Real and inverted
Between F and P	Behind the mirror	Magnified	Virtual and erect

You can observe from the table that a concave mirror always forms a real and inverted image except when the object is placed between the focus and the pole of the mirror. In this position, it forms a virtual and erect image.

Application of curved Mirrors

Concave mirrors

1. Concave mirrors are used while applying make-up or shaving, as they provide a magnified image.

2. They are used in torches, search lights and head lights as they direct the light to a long distance.

3. They can collect the light from a larger area and focus it into a small spot. Hence, they are used in solar cookers.

4. They are used as head mirrors by doctors to examine the eye, ear and throat as they provide a shadow-free illumination of the organ.

5. They are also used in reflecting telescopes. Figure 3.3 Concave mirrors

Convex mirrors

1. Convex mirrors are used in vehicles as rear view mirrors because they give an upright image and provide a wider field of view as they are curved outwards.

2. They are found in the hallways of various buildings including hospitals, hotels, schools and stores. They are usually mounted on a wall or ceiling where hallways make sharp turns.

3. They are also used on roads where there are sharp curves and turns.

Not all the objects can produce the same effect as produced by the plane mirror. A ray oflight, falling on a body having a shiny, polished and smooth surface alone is bounced back. This bouncing back of the light rays as they fall on the smooth, shiny and polished surface is called reflection.

Reflection involves two rays: i) incident ray and ii) reflected ray. The incident ray is the light ray in a medium falling on the shiny surface of a reflecting body. After falling on the surface, this ray returns into the same medium. This ray is called the reflected ray. An imaginary line perpendicular to the reflecting surface, at the point of incidence of the light ray, is called the normal.

The relation between the incident ray, the reflected ray and the normal is given as the law of reflection. The laws of reflection are as follows:

- The incident ray, the reflected ray and the normal at the point of incidence, all lie in the same plane.

- The angle of incidence and the angle of reflection are always equal.

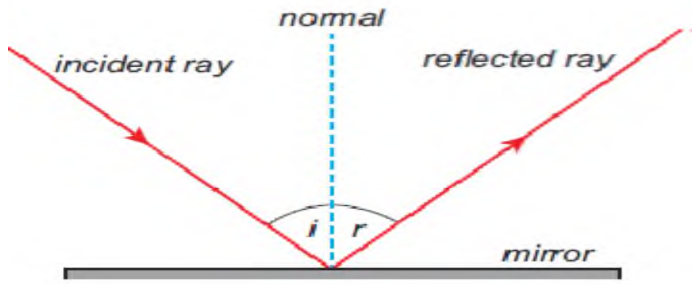


Figure 3.7Reflection of light

> Do You Know?
> Silver metal is the best reflector of light. That's why a thin layer of silver is deposited on the side of materials like plane glass sheets, to make mirrors.

TYPES OF REFLECTION

You have learnt that not all bodies can reflect light rays. Th e amount of reflection depends on the nature of the reflecting surface of a body. Based on the nature of the surface, reflection can be classified into two types namely, i) regular reflection and ii) irregular reflection.

Regular reflection

When a beam of light (collection of parallel rays) falls on a smooth surface, it gets reflected. After reflection, the reflected rays will be parallel to each other. Here, the angle of incidence and the angle of reflection of each ray will be equal. Hence, the law of reflection is obeyed in this case and thus a clear image is formed. This reflection is called 'regular reflection' or 'specular reflection'. Example: Reflection of light by a plane mirror and reflection of light from the surface of still water.

Irregular reflection

In the case of a body having a rough or irregular surface, each region of the surface is inclined at different angles. When light falls on such a surface, the light rays are reflected at different angles. In this case, the angle of incidence and the angle of reflection of each ray are not equal. Hence, the law of reflection is not obeyed in this case and thus the image is not clear. Such a reflection is called 'irregular reflection' or 'diff used reflection'. Example: Reflection of light from a wall.

MULTIPLE REFLECTIONS

You can see three images. How is it possible to have three images with two mirrors? In the activity given above, you observed that for a body kept in between two plane mirrors, which were inclined to each other, you could see many images. Th is is because, the 'image' formed by one mirror acts as an 'object' for the other mirror. Th e image formed by the first mirror acts as an object for the second mirror and the image formed by the second mirror acts as an object for the first mirror. Th us, we have three images of a single body. Th is is known as multiple reflection. This type of reflections can be seen in show rooms and saloons.

The number of images formed, depends on the angle of inclination of the mirrors. If the angle between the two mirrors is a factor of 360°, then the total number of reflections is finite. If θ (Theta) is the angle of inclination of the plane mirrors, the number of images formed = $\frac{360}{0}$-1. As you decrease this angle, the number of images formed increases. When they are parallel to each other, the number of images formed becomes infinite.

Problem.3

If two plane mirrors are inclined to each other at an angle of 90°, find the number of images formed.

Solution:

Angle of inclination = 90°

Number of images formed =

$\frac{360^0}{q} - \frac{360^o}{90^o} - 1 = -1 = 4 - 1 = 3$

Kaleidoscope

It is a device, which functions on the principle of multiple reflection of light, to produce numerous patterns of images. It has two or more mirrors inclined with each other. It can be designed from inexpensive materials and the colourful image patterns formed by this will be pleasing to you. This instrument is used as a toy for children.

Periscope

It is an instrument used for viewing bodies or ships, which are over and around another body or a submarine. It is based on the principle of the law of reflection of light. It consists of a long outer case and inside this case mirrors or prisms are kept at each end, inclined at an angle of 45°. Light coming from the distant body, falls on the mirror at the top end of the periscope and gets reflected vertically downward. This light is reflected again by the second mirror kept at the bottom, so as to travel horizontally and reach the eye of the observer. In some complex periscopes, opticfibre is used instead of mirrors for obtaining a higher resolution. Th e distance between the mirrors also varies depending on the purpose of using the periscope.

Uses

• It is used in warfare and navigation of the submarine.
• In military it is used for pointing and firing guns from a 'bunker'. • Photographs of important places can be taken through periscopes without trespassing restricted military regions.
• Fibre optic periscopes are used by doctors as endoscopes to view internal organs of the body.

REFRACTION OF LIGHT

We know that when a light ray falls on a polished surface placed in air, it is reflected into the air itself. When it falls on a transparent material, it is not reflected completely, but a part of it is reflected and a part of it is absorbed and most of the light passes through it. Th rough air, light travels with a speed of 3 x10^8 m s-1, but it cannot travel with the same speed in water or glass, because, optically denser medium such as water and glass offer some resistance to the light rays.

So, light rays travelling from a rarer medium like air into a denser medium like glass or water are deviated from their straight line path. Th is bending of light about the normal, at the point of incidence; as it passes from one transparent medium to another is called refraction of light.

When a light ray travels from the rarer medium into the denser medium, it bends towards the normal and when it travels from the denser medium into the rarer medium, it bends away from the normal. You can observe this phenomenon with the help of the activity given below.

In this activity, the light rays actually travel from the water (a denser medium) into the air (a rarer medium). As you saw earlier, when a light ray travels from a denser medium to a rarer medium, it is deviated from its straight line path. So, the pencil appears to be bent when you see it through the glass of water.

Refractive Index

Refraction of light in a medium depends on the speed of light in that medium. When the speed of light in a medium is more, the bending is less andwhen the speed of light is less, the bending is more.

The amount of refraction of light in a medium is denoted by a term known as refractive index of the medium, which is the ratio of the speed of light in the air to the speed of light in that particular medium. It is also known as the absolute refractive index and it is denoted by the Greek letter 'μ' (pronounced as 'mew').

$$\mu = \frac{Speedoflighinair(c)}{Speedoflight\,\mathrm{int}\,hemedium(v)}$$

Refractive index is a ratio of two similar quantities (speed) and so, it has no unit. Since, the speed of light in any medium is less than its speed in air, refractive index of any transparent medium is always greater than 1.
Refractive indices of some common substances are given in Table 3.3.

Substances	Refractive Index
Air	1.0
Water	1.33
Ether	1.36

Kerosene	1.41
Ordinary Glass	1.5
Quartz	1.56
Diamond	2.41

In general, the refractive index of one medium with respect to another medium is given by the ratio of their absolute refractive indices.

$$\mu_2 \frac{Absoluterefactiveindexofthe\sec ondmedium}{Absoluterefactiveindexofthefivemedum}$$

$$_1\mu_2 = \frac{\frac{c}{v_2}}{\frac{c}{v_1}} \quad \text{or} \quad _1\mu_2 = \frac{v_1}{v_2}$$

Thus, the refractive index of one medium with respect to another medium is also given by the ratio of the speed of light in first medium to its speed in the second medium.

PROBLEM 4

Speed of light in air is 3 × 108 m s-1 and the speed of light in a medium is 2 ×108 ms-1. Find the refractive index of the medium with respect to air.

Solution:

Refractive index (μ)= $\frac{Speedoflightinair(c)}{Speedoflight\operatorname{int}hemedum(v)}$

$$\mu = \frac{3C10^8}{2C10^8} = 1.5$$

PROBLEM 5

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

Solution:

$$_w\mu_g = \frac{\text{Refractive index of glass}}{\text{Refractive index of water}} = \frac{\frac{3}{2}}{\frac{4}{3}} = \frac{9}{8} = 1.125$$

Snell's Law of Refraction

Refraction of light rays, as they travel from one medium to another medium, obeys two laws, which are known as Snell's laws of refraction. They are:

I) The incident ray, the refracted ray and the normal at the point of intersection, all lie in the same plane.
II) The ratio of the sine of the angle of incidence (i) to the sine of the angle of refraction (r) is equal to the refractive index of the medium, which is a constant.

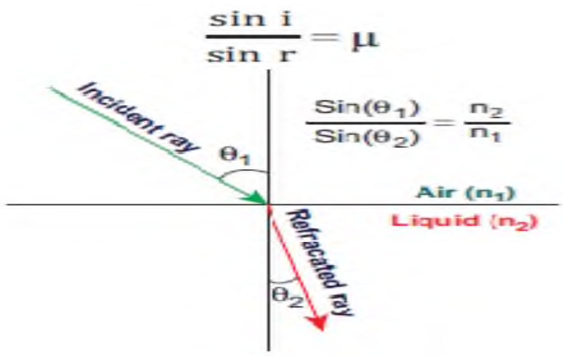


Figure 3.12 Snell's Law

In the above activity, you can see that the first prism splits the white light into seven coloured light rays and the second prism recombines them into white light, again. Thus, it is clear that white light consists of seven colours. You can also recall the Newton's disc experiment, which you studied in VII standard.

Splitting of white light into its seven constituent colours (wavelength), on passing through a transparent medium is known as dispersion of light.

Why does dispersion occur? It is because, light of different colours present in white light have different wavelength and they travel at different speeds in a medium. You know that refraction of a light ray in a medium depends on its speed. As each coloured light has a different speed, the constituent coloured lights are refracted at different extents, inside the prism. Moreover, refraction of a light ray is inversely proportional to its wavelength.

Thus, the red coloured light, which has a large wavelength, is deviated less while the violet coloured light, which has a short wavelength, is deviated more.

9 th book
UNIT- 6 –LIGHT

Introduction

Light is a form of energy which travels as electromagnetic waves. The branch of physics that deals with the properties and applications of light is called optics. In our day to day life we use number of optical instruments. Microscopes are inevitable in science laboratories. Telescopes, binoculars, cameras and projectors are used in educational, scientific and entertainment fields. In this lesson, you will learn about spherical mirrors (concave and convex). Also, you will learn about the properties of light, namely reflection and refraction and their applications.

Reflection 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 have studied about them in your lower classes. Let us study about them little elaborately here.

Laws of reflection

Consider a plane mirror MM′ as shown in Figure 6.1. 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., i = 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 are given as: 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.

The most common usage of mirror writing can be found on the front of ambulances, where the word "AMBULANCE" is often written in very large mirrored text.

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 (Figure 6.2) and observe the arrows, which indicate the light ray from the object falling on the mirror. The arrow from the 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. Thus, the apparent lateral inversion we observe is not caused by the mirror but the result of our perception.

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
binoculars, cameras and projectors are used in educational, scientifi c and entertainment fields.

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

Curved Mirrors

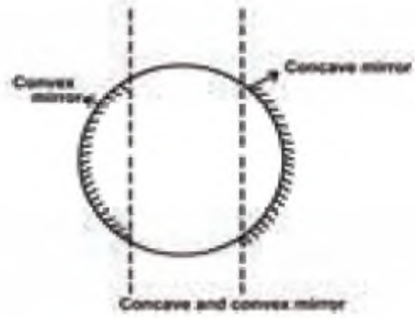
We studied about laws of reflection. These laws are applicable to all types of reflecting surfaces including curved surfaces. Let us learn about image formation in curved surfaces in this part.

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?

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.



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

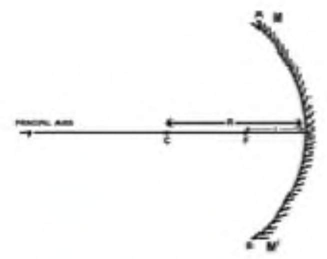


Figure 3 Concave mirror

Image Formed by Curved Mirrors

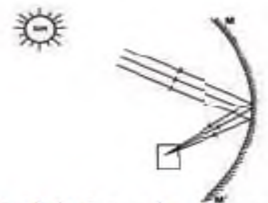


Figure 4 Sunlight focused on a concave mirror

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 formedby a concave mirror we need to look at four specific rules.

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).

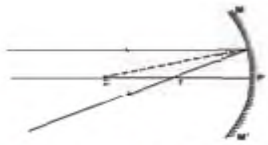


Figure 6 Ray parallel to prinicpal axis

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

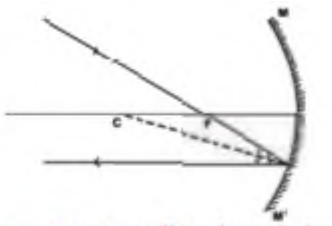


Figure 7 Ray travelling through the principal focus

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).

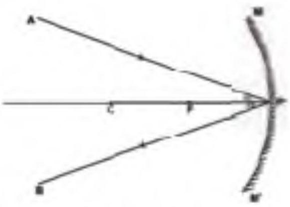


Figure 8 Angle of incidence equal to angle of reflection

Concave Mirror

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).

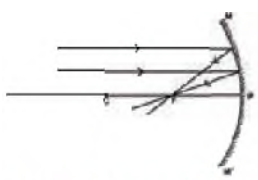


Figure 10 Object at Infinity

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

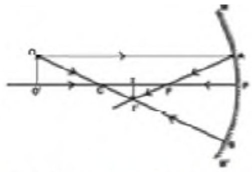


Figure 11 Object beyond the centre of curvature

Nature of the image: Real, inverted and smaller than object.
Case – III: When the object is at the centre of curvature (Figure 12).
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.

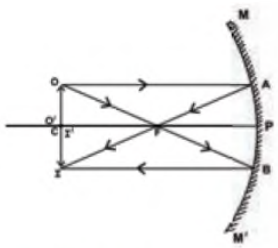


Figure 12 Object at the centre of curvature

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

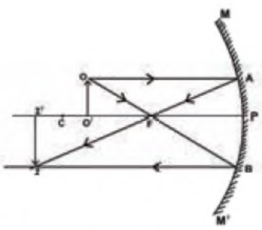


Figure 13 Object in between centre of curvature and principal focus

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).
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.

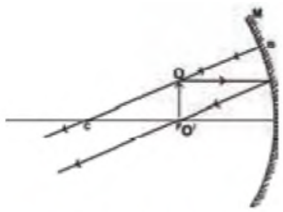
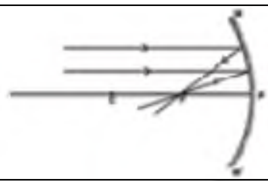
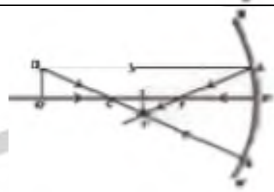
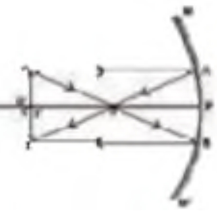
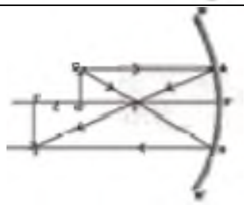
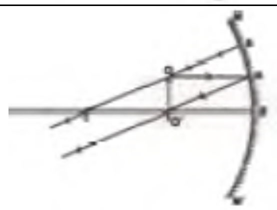
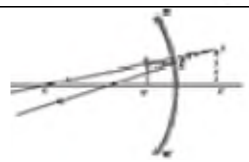


Figure 14 Object at principal focus

Case – VI: When the object is in between the focus F and the pole P (Figure 15). Position of the image: The image is behind the mirror. Nature of the image: It is virtual,erect and magnified.

S. 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		A to C	Same size	Real and Inverted
4.	Between C and F		Beyond C	Magnified	Real and inverted
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

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).The object is always placed on the left side of the mirror.
All distances are measured from the pole of the mirror.

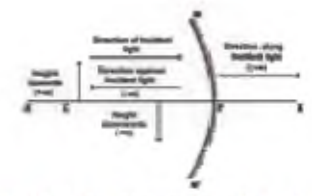


Figure 16 Sign convention for spherical mirrors

- 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.

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

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:

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

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 (/ /.) to the height of the object (h).

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

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.

Uses of concave mirror

Dentist's head mirror:

In dentist's head mirror, 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.).

Make-up mirror:

When a concave mirror is held near the face, 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. Large concave mirrors are used in solar heaters.

Stellar objects are at an infinite distance. Therefore, the image formed by a concave mirror would be diminished, and inverted. Yet, astronomical telescopes use concave mirrors

Convex Mirror

Image Formation

Any two rays can be chosen to draw the position of the image in a convex mirror (Figure 6.10): a ray that is parallel to the principal axis (rule 1) and a 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.

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 image of the object OO′. It is virtual, erect and smaller than the object.

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 (it is the observable area as seen through eye / any optical device such as mirror) compared to plane mirror. 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 ofoncoming vehicles is restricted. It is also used in blind spots in shops.

In the rear view mirror, the following sentence is written. “Objects in the mirror are closer than they appear”. Why?

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.

Refraction of light

This activity explains the refraction of light. The bending of light rays when they pass obliquely from one medium to another medium is called refraction of light.

Cause of refraction

Light rays get deviated from their original path while entering from one transparentmedium 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).

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)

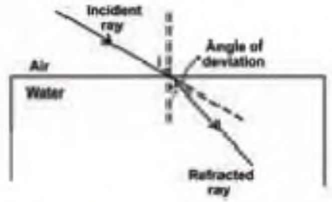


Figure 22 Light ray travelling from rarer to denser medium

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

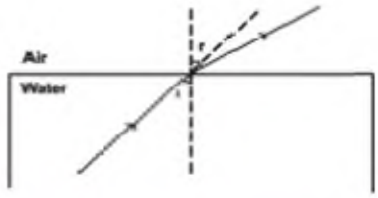


Figure 23 Light ray travelling from denser to rarer medium

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

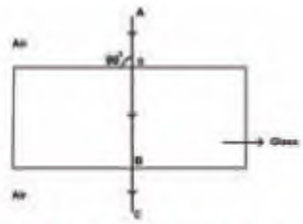


Figure 24 Incident of light ray in denser medium

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

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

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

Verification of laws of refraction

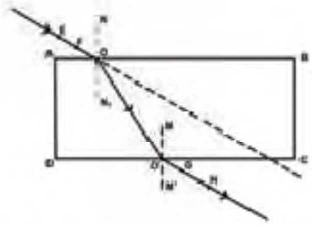


Figure 25 Verification of laws of refraction

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.

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

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

in general,$1\mu2 = \frac{speed of light in medium\ 1}{\text{speed of light in medium 2}}$

Total internal reflection

When light travels from denser medium into a rarer medium, it gets refracted away from the normal. While the angle of incidence in the denser medium increases the angle of refraction also increases and it reaches a maximum value of r = 90º for a particular value. This angle of incidence is called critical angle (Figure 6.12). The angle of incidence at which the angle of refraction is 90º is called the critical angle. At this angle, the refracted ray grazes the surface of separation between the two media.

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

Conditions to achieve total internal reflection

In order to achieve total internal refelection the following conditions must be met.

- 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.

Total internal reflection in nature

Mirage:

On hot summer days, patch of water may be on the road. This is an illusion. In summer, the air near the ground becomes hotter than the air at higher levels. Hotter air is less dense, and has smaller refractive index than the cooler air. Thus, a ray of light bends away from the normal and undergoes total internal reflection. Total internal reflection is the main cause for the spectacular brilliance of diamonds and twinkling of stars.

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.

An Indian-born physicist NarinderKapany is regarded as the Father of Fibre Optics.

Points to Remember

- Light is a form of energy which produces the sensation of sight.

- 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.

- The distance between the pole and the called focal length. f= $\frac{R}{2}$ where R is the radius of curvature of the mirror.

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

- Magnification: m= $\frac{height\ of\ the\ image\ h2}{height\ of\ the\ object\ h1}$ ...

- 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. (
$u = \frac{\sin i}{\sin r}$= constant

- The bending of light when it passes obliquely from transparent medium to another is called refraction.

- When the angle of incidence exceeds the value of critical angle the refracted ray is impossible. Since r > 90º refraction is impossible and the ray is totally reflected back to the same medium (denser medium). This is called as total internal reflection

10th Standard
Unit 2: Optics

INTRODUCTION

Light is a form of energy which travels in the form of waves. Th e path of light is called ray of light and group of these rays are called as beam of light. Any object which gives out light are termed as source of light. Some of the sources emit their own light and they are called as luminous objects. All the stars, including the Sun, are examples for luminous objects. We all know that we are able to see objects with the help of our eyes. But, we cannot see any object in a dark room. Can you explain why? If your answer is 'we need light to see objects', the next question is 'if you make the light from a torch to fall on your eyes, will you be able to see the objects?'Definitely, 'NO'. We can see the objects only when the light is made to fall on the objects and the light reflected from the objects is viewed by our eyes. You would have studied about the reflection and refraction of light elaborately in your previous classes. In this chapter, we shall discuss about the scattering of light, images formed by convex and concave lenses, human eye and optical instruments such as telescopes and microscopes.

PROPERTIES OF LIGHT

Let us recall the properties of light and the important aspects on refraction of light.

- Light is a form of energy.
- Light always travels along a straight line.
- Light does not need any medium for its propagation. It can even travel through vacuum.
- The speed of light in vacuum or air is, $c = 3 \times 10^8 ms^{-1}$.

- Since, light is in the form of waves, it is characterized by a wavelength (λ) and a frequency (ν), which are related by the following equation: $c = \nu \lambda$ (c - velocity of light).

- Different coloured light has different wavelength and frequency.

- Among the visible light, violet light has the lowest wavelength and red light has the highest wavelength.

- When light is incident on the interface between two media, it is partly reflected and partly refracted.

REFRACTION OF LIGHT

When a ray of light travels from one transparent medium into another obliquely, the path of the light undergoes deviation. This deviation of ray of light is called refraction. Refraction takes place due to the difference in the velocity of light in different media. The velocity of light is more in a rarer medium and less in a denser medium. Refraction of light obeys two laws of refraction.

First law of refraction:

The incident ray, the refracted ray of light and the normal to the refracting surface all lie in the same plane.

Second law of refraction:

The ratio of the sine of the angle of incidence and sine of the angle of refraction is equal to the ratio of refractive indices of the two media. This law is also known as Snell's law.

$$\frac{\sin i}{\sin r} = \frac{\mu_2}{\mu_1} \quad \cdots\cdots\cdots\cdots \quad (2.1)$$

- Refractive index gives us an idea of how fast or how slow light travels in a medium. The ratio of speed of light in vacuum to the speed of light in a medium is defined as refractive index 'μ' of that medium.

- The speed of light in a medium is low if the refractive index of the medium is high and vice versa.
- When light travels from a denser medium into a rarer medium, the refracted ray is bent away from the normal drawn to the interface.
- When light travels from a rarer medium into a denser medium, the refracted ray is bent towards the normal drawn to the interface.

REFRACTION OF A COMPOSITE LIGHT-DISPERSION OF LIGHT

We know that Sun is the fundamental and natural source of light. If a source of light produces a light of single colour, it is known as a monochromatic source. On the other hand, a composite source of light produces a white light which contains light of different colours. Sun light is a composite light which consists of light of various colours or wavelengths. Another example for a composite source is a mercury vapour lamp. What do you observe when a white light is refracted through a glass prism?

When a beam of white light or composite light is refracted through any transparent media such as glass or water, it is split into its component colours. This phenomenon is called as 'dispersion of light'.

The band of colours is termed as spectrum. This spectrum consists of following colours: Violet, Indigo, Blue, Green, Yellow, Orange, and Red. These colours are represented by the acronym "VIBGYOR". Why do we get the spectrum when white light is refracted by a transparent medium? This is because, different coloured lights are bent through different angles. That is the angle of refraction is different for different colours.

Angle of refraction is the smallest for red and the highest for violet. From Snell's law, we know that the angle of refraction is determined in terms of the refractive index of the medium. Hence, the refractive index of the medium is different for different coloured lights.

This indicates that the refractive index of a medium is dependent on the wavelength of the light.

SCATTERING OF LIGHT

When sunlight enters the Earth's atmosphere, the atoms and molecules of different gases present in the atmosphere refract the light in all possible directions. This is called as 'Scattering of light'. In this phenomenon, the beam of light is redirected in all directions when it interacts with a particle of medium. The interacting particle of the medium is called as 'scatterer'.

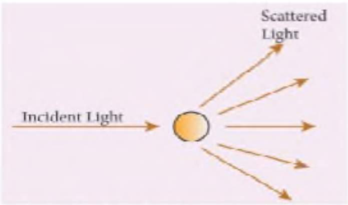


Figure 2.1 Scattering of light

Types of scattering

When a beam of light, interacts with a constituent particle of the medium, it undergoes many kinds of scattering. Based on initial and final energy of the light beam, scattering can be classified as,

Elastic scattering

- If the energy of the incident beam of light and the scattered beam of light are same, then it is called as 'elastic scattering'.

Inelastic scattering

- If the energy of the incident beam of light and the scattered beam of light are not same, then it is called as 'inelastic scattering'. The nature and size of the scatterer results in different types of scattering. They are

1) Rayleigh scattering
2) Mie scattering

3) Tyndall scattering
4) Raman scattering

Rayleigh scattering

The scattering of sunlight by the atoms or molecules of the gases in the earth's atmosphere is known as Rayleigh scattering.

Rayleigh's scattering law

Rayleigh's scattering law states that, "The amount of scattering of light is inversely proportional to the fourth power of its wavelength".

$$\text{Amount of scattering 'S'} \propto \frac{1}{\lambda^4}$$

According to this law, the shorter wavelength colours are scattered much more than the longer wavelength colours.

When sunlight passes through the atmosphere, the blue colour (shorter wavelength) is scattered to a greater extent than the red colour (longer wavelength). This scattering causes the sky to appear in blue colour.

At sunrise and sunset, the light rays from the Sun have to travel a larger distance in the atmosphere than at noon. Hence, most of the blue lights are scattered away and only the red light which gets least scattered reaches us. Therefore, the colour of the Sun is red at sunrise and sunset.

Mie scattering

Mie scattering takes place when the diameter of the scatterer is similar to or larger than the wavelength of the incident light. It is also an elastic scattering. The amount of scattering is independent of wave length.

Mie scattering is caused by pollen, dust, smoke, water droplets, and other particles in the lower portion of the atmosphere.

Mie scattering is responsible for the white appearance of the clouds. When white light falls on the water drop, all the colours are equally scattered which together form the white light.

Tyndall Scattering

When a beam of sunlight, enters into a dusty room through a window, then its path becomes visible to us. This is because, the tiny dust particles present in the air of the room scatter the beam of light. This is an example of Tyndall Scattering

The scattering of light rays by the colloidal particles in the colloidal solution is called Tyndall Scattering or Tyndall Effect.

> Do you Know: Colloid is a microscopically small substance that is equally dispersed throughout another material. Example: Milk, Ice cream, muddy water, smoke

Raman scattering

When a parallel beam of monochromatic (single coloured) light passes through a gas or liquid or transparent solid, a part of light rays are scattered.

The scattered light contains some additional frequencies (or wavelengths) other than that of incident frequency (or wavelength). This is known as Raman scattering or Raman Effect.

Raman Scattering is defined as "The interaction of light ray with the particles of pure liquids or transparent solids, which leads to a change in wavelength or frequency."

The spectral lines having frequency equal to the incident ray frequency is called 'Rayleigh line' and the spectral lines which are having frequencies other than the incident ray frequency are called 'Raman lines'. The lines having frequencies lower than the incident frequency is called stokes lines and the lines having frequencies higher than the incident frequency are called Antistokes lines.

You will study more about Raman Effect in higher classes.

LENSES

A lens is an optically transparent medium bounded by two spherical refracting surfaces or one plane and one spherical surface.

Lens is basically classified into two types. They are: (i) Convex Lens (ii) Concave Lens

- Convex or bi-convex lens: It is a lens bounded by two spherical surfaces such that it is thicker at the centre than at the edges. A beam of light passing through it, is converged to a point. So, a convex lens is also called as converging lens.

- (ii) Concave or bi-concave Lens: It is a lens bounded by two spherical surfaces such that it is thinner at the centre than at the edges. A parallel beam of light passing through it, is diverged or spread out. So, a concave lens is also called as diverging lens.

Other types of Lenses

- Plano-convex lens: If one of the faces of a bi-convex lens is plane, it is known as a plano-convex lens.

- Plano-concave lens: If one of the faces of a bi-concave lens is plane, it is known as a plano-concave lens.

All these lenses are shown in Figure 2.2 given below:

IMAGES FORMED DUE TO REFRACTION THROUGH A CONVEX AND CONCAVE LENS

When an object is placed in front of a lens, the light rays from the object fall on the lens. Th e position, size and nature of the image formed can be understood only if we know certain basic rules.

Rule-1: When a ray of light strikes the convex or concave lens obliquely at its optical centre, it continues to follow its path without any deviation (Figure 2.3).

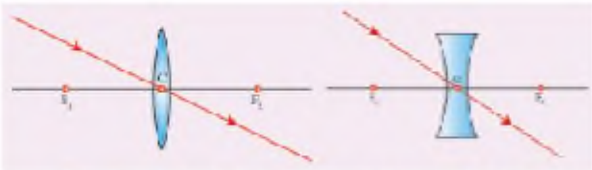


Figure 2.3 Rays passing through the optical centre

Rule-2: When rays parallel to the principal axis strikes a convex or concave lens, the refracted rays are converged to (convex lens) or appear to diverge from (concave lens) the principal focus (Figure 2.4).

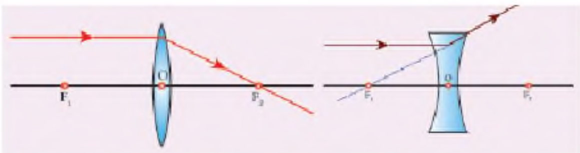


Figure 2.4 Rays passing parallel to the optic axis

Rule-3: When a ray passing through (convex lens) or directed towards (concave lens) the principal focus strikes a convex or concave lens, the refracted ray will be parallel to the principal axis (Figure 2.5).

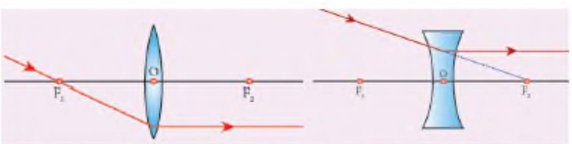


Figure 2.5 Rays passing through or directed towards the principal focus

REFRACTION THROUGH A CONVEX LENS

Let us discuss the formation of images by a convex lens when the object is placed at various positions.

Object at infinity

When an object is placed at infinity, a real image is formed at the principal focus. Th e size of the image is much smaller than that of the object (Figure 2.6).

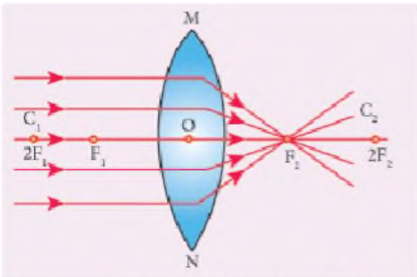


Figure 2.6 Object at infinity

Object placed beyond C (>2F)

When an object is placed behind the center of curvature(beyond C), a real and inverted image is formed between the center of curvature and the principal focus. Th e size of the image is the same as that of the object (Figure 2.7).

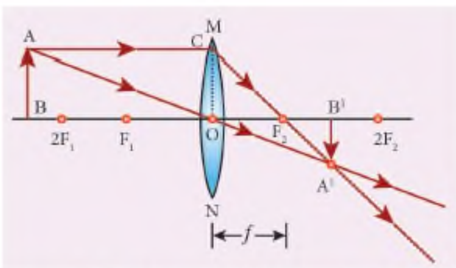


Figure 2.7 Object placed beyond C (>2F)

Object placed at C

When an object is placed at the center of curvature, a real and inverted image is formed at the other center of curvature. Th e size of the image is the same as that of the object (Figure 2.8).

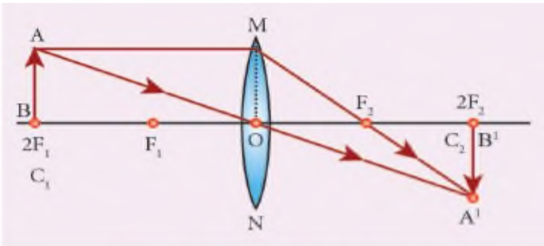


Figure.2.8 Object placed at C

Object placed between F and C

When an object is placed in between the center of curvature and principal focus, a real and inverted image is formed behind the center of curvature. The size of the image is bigger than that of the object (Figure 2.9).

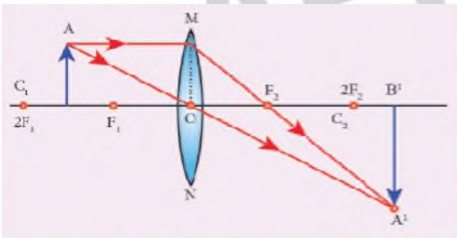


Figure 2.9 Object placed between F and C

Object placed at the principal focus F

When an object is placed at the focus, a real image is formed at infinity. The size of the image is much larger than that of the object (Figure 2.10).

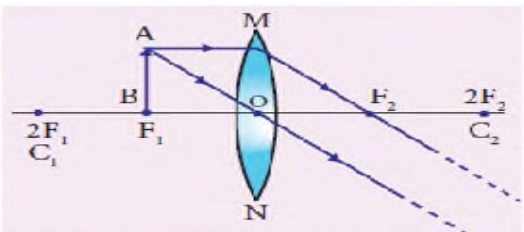


Figure 2.10 Object placed at the principal focus F

Object placed between the principal focus F and optical centre O

When an object is placed in between principal focus and optical centre, a virtual image is formed. The size of the image is larger than that of the object (Figure 2.11).

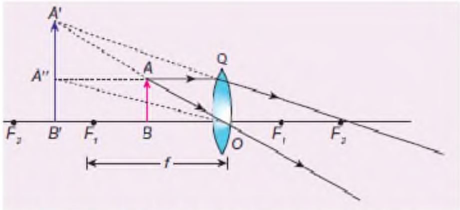


Figure 2.11 Object placed between the principal focus F and optical centre O

APPLICATIONS OF CONVEX LENSES

- Convex lenses are used as camera lenses
- They are used as magnifying lenses
- They are used in making microscope, telescope and slide projectors
- They are used to correct the defect of vision called hypermetropia

REFRACTION THROUGH A CONCAVE LENS

Let us discuss the formation of images by a concave lens when the object is placed at two possible positions.

Object at Infinity

When an object is placed at infinity, a virtual image is formed at the focus. The size of the image is much smaller than that of the object (Figure 2.12).

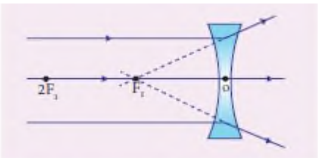


Figure 2.12 Concave lens-Object at infinity

Object anywhere on the principal axis at a finite distance

When an object is placed at a finite distance from the lens, a virtual image is formed between optical center and focus of the concave lens. The size of the image is smaller than that of the object (Figure 2.13).

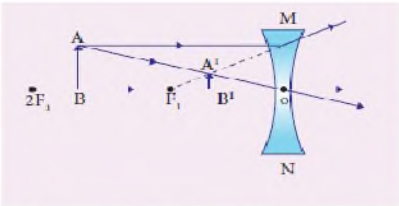


Figure 2.13 Concave lens Object at a finite distance

But, as the distance between the object and the lens is decreased, the distance between the image and the lens also keeps decreasing. Further, the size of the image formed increases as the distance between the object and the lens is decreased. This is shown in (figure 2.14).

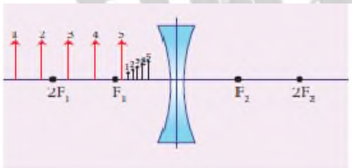


Figure 2.14 Concave lens-Variation in position and size of image with object distance

APPLICATIONS OF CONCAVE LENSES

- Concave lenses are used as eye lens of 'Galilean Telescope'
- They are used in wide angle spy hole in doors.
- They are are used to correct the defect of vision called 'myopia'

LENS FORMULA

Like spherical mirrors, we have lens formula for spherical lenses. The lens formula gives the relationship among distance of the object (u), distance of the image (v) and the focal length (f) of the lens. It is expressed as

$$\frac{1}{f}=\frac{1}{v}-\frac{1}{u}\ldots\ldots\ldots\ldots\ 2.2$$

It is applicable to both convex and concave lenses. We need to give an at most care while solving numerical problems related to lenses in taking proper signs of different quantities.

SIGN CONVENTION

Cartesian sign conventions are used for measuring the various distances in the ray diagrams of spherical lenses. According to cartesian sign convention,

- The object is always placed on the left side of the lens.
- All the distances are measured from the optical centre of the lens.
- The distances measured in the same direction as that of incident light are taken as positive.
- The distances measured against the direction of incident light are taken as negative.
- The distances measured upward and perpendicular to the principal axis is taken as positive.
- The distances measured downward and perpendicular to the principal axis is taken as negative.

MAGNIFICATION OF A LENS

Like spherical mirrors, we have magnification for spherical lenses. Spherical lenses produce magnification and it is defined as the ratio of the height of the image to theheight of an object. Magnification is denoted by the letter 'm'. If height of the object is *h* and height of the image is *h ´*, the magnification produced by lens is,

$$m = \frac{height\ of\ the\ image}{height\ of\ the\ object} = \frac{h'}{h} \quad \ldots\ldots (2.3)$$

Also it is related to the distance of the object (*u*) and the distance of the image (*v*) as follows:

$$m = \frac{Distance\ of\ the\ image}{Distance\ of\ the\ object} = \frac{v}{u} \quad \ldots\ldots (2.4)$$

If the magnification is greater than 1, then we get an enlarged image. On the other hand, if the magnification is less than 1, then we get a diminished image.

LENS MAKER'S FORMULA

All lenses are made up of transparent materials. Any optically transparent material will have a refractive index. The lens formula relates the focal length of a lens with the distance of object and image. For a maker of any lens, knowledge of radii of curvature of the lens is required. This clearly indicates the need for an equation relating the radii of curvature of the lens, the refractive index of the given material of the lens and the required focal length of the lens. The lens maker's formula is one such equation. It is given as

$$\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \ldots\ldots\ldots (2.5)$$

where μ is the refractive index of the material of the lens; $R1$ and $R2$ are the radii of curvature of the two faces of the lens; f is the focal length of the lens.

POWER OF A LENS

When a ray of light falls on a lens, the ability to converge or diverge these light rays depends on the focal length of the lens. This ability of a lens to converge (convex lens) or diverge (concave lens) is called as its power. Hence, the power of a lens can be defined as the degree of convergence or divergence of light rays. Power of a lens is numerically defined as the reciprocal of its focal length.

$$P = \frac{1}{f} \cdots\cdots\cdots\cdots\cdots\cdots (2.6)$$

The SI unit of power of a lens is dioptre. It is represented by the symbol D. If focal length is expressed in 'm', then the power of lens is expressed in 'D'. Thus 1D is the power of a lens, whose focal length is 1metre. $1D = 1m^{-1}$.

By convention, the power of a convex lens is taken as positive whereas the power of a concave lens is taken, as negative.

More to Know: The lens formula and lens maker's formula are applicable to only thin lenses. In the case of thick lenses, these formulae with little modifications are used.

Table 2.1 Differences between a Convex Lens and a Concave Lens

S.No	Convex Lens	Concave Lens
1	A convex lens is thicker in the middle than at edges.	A concave lens is thinner in the middle than at edges.
2	It is a converging lens.	It is a diverging lens.
3	It produces mostly real images.	It produces virtual images.
4	It is used to treat hypermeteropia.	It is used to treat myopia.