Chapter 9

Ray Optics and Optical Instruments

Types of Mirrors, Mirror Formula & Magnification

What is a Mirror?

A mirror is a smooth and highly polished reflecting surface and can be explained by the law of reflection, which states that when a ray of light is made to fall on the reflecting surface, the reflected ray has its angle of reflection, incident ray, and the reflected ray are normal to the surface at a point of incidence.

1. Plane Mirror

A highly polished plane surface is called a plane mirror.
Different properties of image formed by plane mirror:

- Size of image = Size of object
- Magnification = Unity
- Distance of image = Distance of object

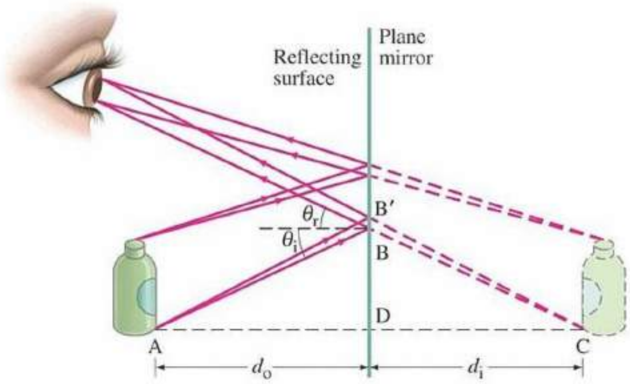


Image formed by a plane mirror

- A plane mirror may form a virtual as well as a real image. A man may see his full image in a mirror of half-height of a man.
- When two plane mirrors are held at an angle θ, the number of images of an object placed between them is given below:
  (a) n = [(360° / θ) – 1], where 360° / θ is an integer.
  (b) n = integral part of 360° / θ, when 360° is not an integer.
- A plane mirror may form a real image when the pencil of light incident on the mirror is convergent. Children, during their play, form an image of the sun as a wall by a strip of a plane mirror.
- Kaleidoscope and periscope employ the principle of image formation by a plane mirror. If keeping an object fixed a plane mirror is rotated in its plane by an angle θ, then the reflected ray rotates in the same direction by an angle 2 θ.

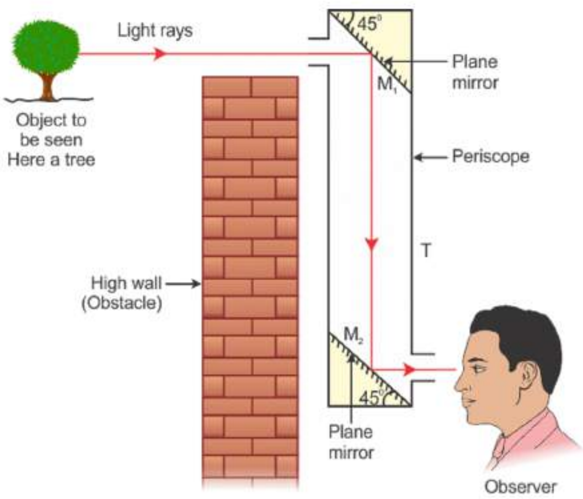


Image formed by a Periscope

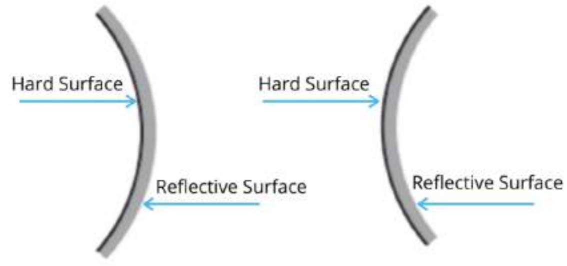
- Focal length, as well as the radius of curvature of a plane mirror, is infinity. The power of a plane mirror is zero.
- An image formed by a plane mirror is **virtual, erect, laterally inverted, of the same size** as that of the object, and **at the same distance** as the object from the mirror.

2. Spherical Mirror

A highly polished curved surface whose reflecting surface is a cut part of a hollow at glass sphere is called a spherical mirror.

Spherical mirrors are of two types:

(i) Concave Mirror: A spherical mirror whose bent surface is reflecting surface, is called a concave mirror.

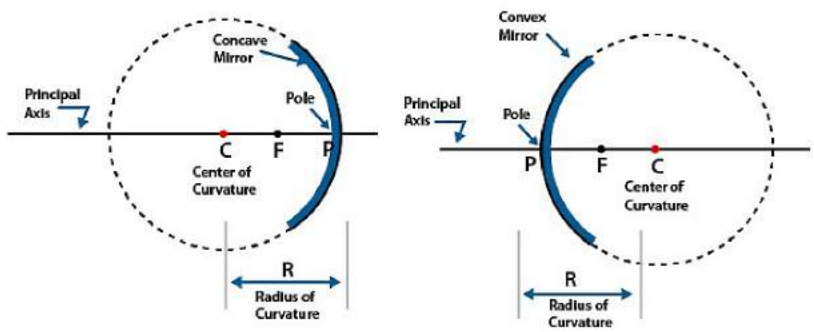


(a) Concave mirror (b) Convex mirror

(ii) Convex Mirror: A spherical mirror whose bulging out surface is reflecting surface, is called a convex mirror.

Some Terms Related to Spherical Mirrors are Given Below:

- **Centre of Curvature:** It is the center of the sphere of which the mirror or lens is a part.
- **The radius of Curvature (R):** The radius of the hollow sphere of which the mirror is a part, is called the radius of curvature.
- **Pole:** The central point of the spherical mirror is called its pole (P).
- **Focus:** When a parallel beam of light rays is incident on a spherical mirror, then after reflection it meets or appears to meet at a point on the principal axis, which is called the focus of the spherical mirror.
- **Focal Length:** The distance between the pole and the focus is called the focal length (f).
  The relation between focal length and radius of curvature is given by:
  $f=R/2$
  The power of a mirror is given as $P = 1/f$ (meter)

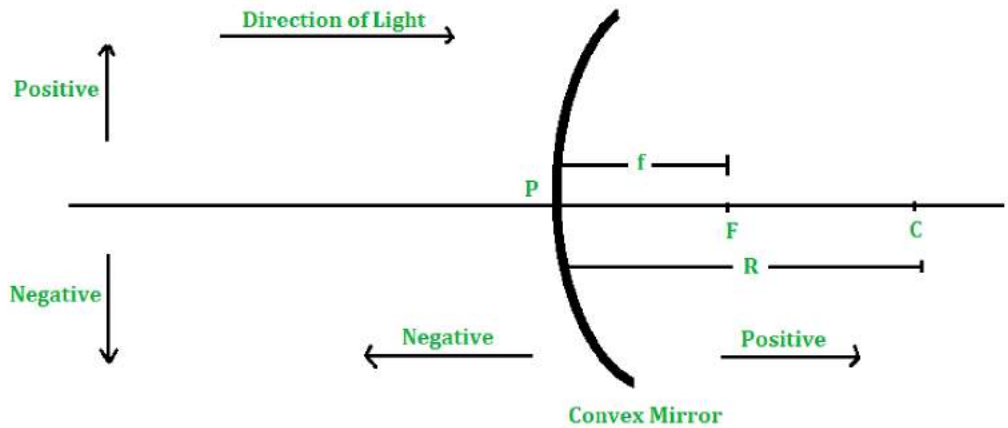


Terms Related to Spherical Mirrors

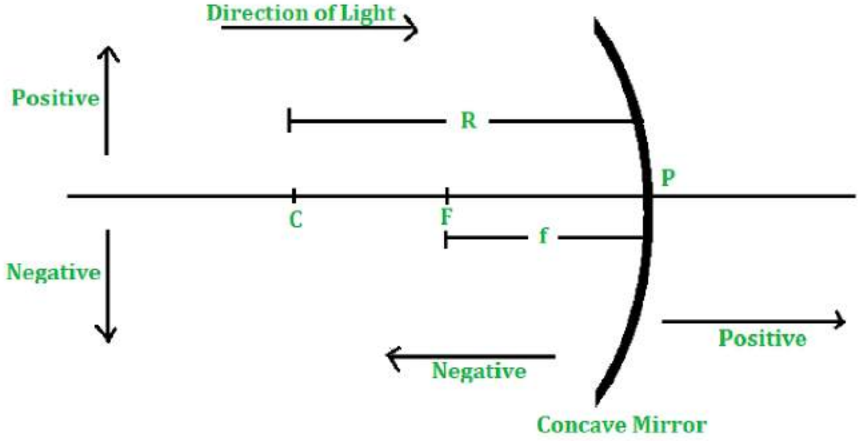
- **Mirror Formula:** $1/f = 1/v + 1/u$
  where, f = focal length of the mirror, u = distance of the object, and v = distance of the image.
- Newton's formula for a concave mirror:
  $$f = \sqrt{x_1 x_2}$$
  $$\Rightarrow f^2 = x_1 x_2$$
  where x_1 and x_2 are the distances of the object and image from the focus.

➢ Sign Convention for Spherical Mirrors

- All distances are measured from the pole of the mirror.
- Distances measured in the direction of incident light rays are taken as positive.
- Distances measured in opposite direction to the incident light rays are taken as negative.
- Distances measured above the principal axis are positive.
- Distances measured below the principal axis are negative.



Sign Convention for Convex Mirror



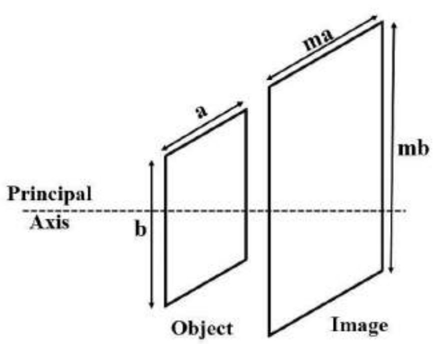
Sign Convention for Concave Mirror

Magnification1. Linear Magnification

- The ratio of the height of the image (I) formed by a mirror to the height of the object (O) is called **linear magnification (m)**.
- Linear magnification (m) = I/O = -v/u

2. Areal and Axial Magnification

- The ratio of the area of an image to the area of an object is called **areal magnification**.
- Areal magnification = $= m^2 = \frac{\text{Area of image}}{\text{Area of object}} = \frac{v^2}{u^2}$



Areal Magnification

- When a small-sized object is placed linearly along the principal axis, then its longitudinal or axial magnification is given by
- Axial magnification $= -\frac{dv}{du} = \left(\frac{v}{u}\right)^2 = \left(\frac{f}{f-u}\right)^2 = \left(\frac{f-v}{f}\right)^2$

Lateral Inversion

- In the image formed by a plane mirror the right side of the object appears as the left side and vice-versa. This phenomenon is called lateral inversion.

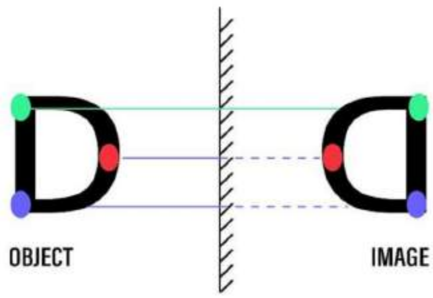


Image formed by a plane mirror

- When an object is placed between the pole and the focus of a concave mirror, then its virtual, erect, and magnified image is formed.

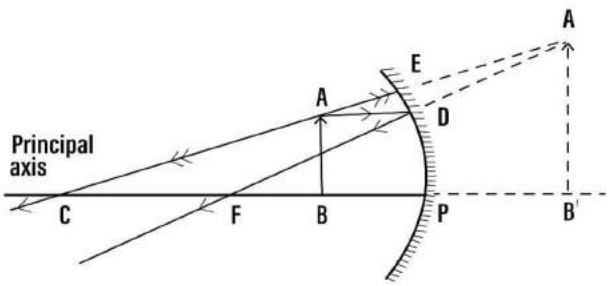


Image formed by a concave mirror

- A convex mirror forms a virtual, erect, and diminished image for all conditions of the object.

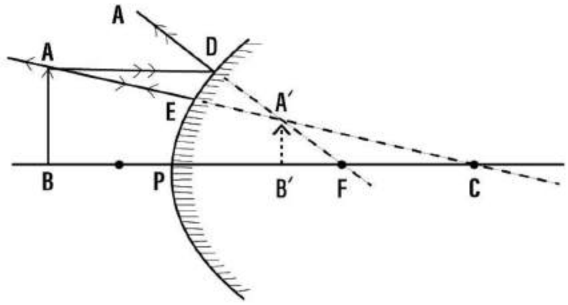


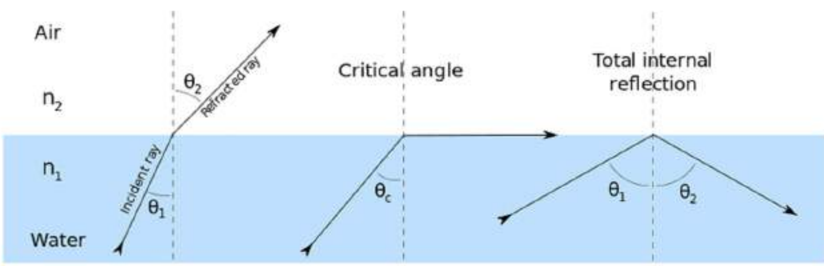
Image formed by a convex mirror

- The focal length of a concave mirror is taken as negative and of a convex mirror is taken as positive.

Total Internal Reflection

What is Total Internal Reflection?

- When a light ray travelling from a denser medium towards a rarer medium is incident at the interface at an angle of incidence greater than the critical angle, then light rays get reflected back into the denser medium. This phenomenon is called Total Internal Reflection.



Total Internal Reflection

- Consider the following situation. A ray of light passes from a medium of water to that of air. Lightray will be refracted at the junction separating the two media.
- Since it passes from a medium of a higher refractive index to that having a lower refractive index, the refracted light ray bends away from the normal.
- At a specific angle of incidence, the incident ray of light is refracted in such a way that it passes along the surface of the water. This particular angle of incidence is called the critical angle. Here the angle of refraction is 90 degrees.
- When the angle of incidence is greater than the critical angle, the incident ray is reflected back to the medium. We call this phenomenon total internal reflection.
- The refractive index is maximum for the violet colour of light and minimum for the red colour of light. i.e., $\mu_v > \mu_R$ therefore, critical angle is maximum for red colour of light and minimum for the violet colour of light, i.e., $C_v < C_R$

<u>Following are the two conditions of total internal reflection:</u>

1. The light ray moves from a moredense medium to a less dense medium.
2. The angle of incidence must be greater than the critical angle.

Note: The critical angle increases with temperature.

Formula of Total Internal Reflection

Total Internal Reflection: $\frac{n_1}{n_2} = \frac{sinr}{sini}$

Critical Angle, θ: $\sin\theta = n_2/n_1$ $(n_1 > n_2)$

- r is the angle of refraction
- i is the angle of incidence
- n_1 is the refractive index in medium 1
- n_2 is the refractive index in medium 2
- θ is the critical angle

Examples of Total Internal Reflection

➢ **Diamond**

- When the incident ray falls on every face of the diamond such that the angle formed, the ray is greater than the critical angle. The critical value of the diamond is 23°.
- This condition is responsible for the total internal reflection in a diamond which makes it shine.

➢ **Mirage**

- It is an optical illusion that is responsible for the appearance of the water layer at short distances in a desert or on the road.
- Mirage is an example of total internal reflection which occurs due to atmospheric refraction.

➢ **Optical Fibre**

- When the incident ray falls on the cladding, it suffers total internal reflection as the angle formed by the ray is greater than the critical angle.
- Optical fibres have revolutionized the speed with which signals are transferred, not only across cities but across countries and continents making telecommunication one of the fastest modes of information transfer.
- Optical fibers are also used in endoscopy.

Solved Examples

Example.1 An optical fibre made up the glass with refractive index n1 = 1.5 which is surrounded by another glass of refractive index n2. Find the refractive index n2 of the cladding such that the critical angle between the two cladding is 80°.

Solution.

Critical angle, $\theta = 80°$

Refractive index, $n_1 = 1.5$

Refractive index $n_2 = ?$

Using the below formula, we can calculate n_2:

$\sin\theta = n_2/n_1$

$\sin 80^\circ = (n_2 / 1.5)$

$n_2 = 1.5 * \sin 80^\circ$

$\mathbf{n_2 = 1.48}$

Example.2 Find the refractive index of the medium whose critical angle is 40°.

Solution.

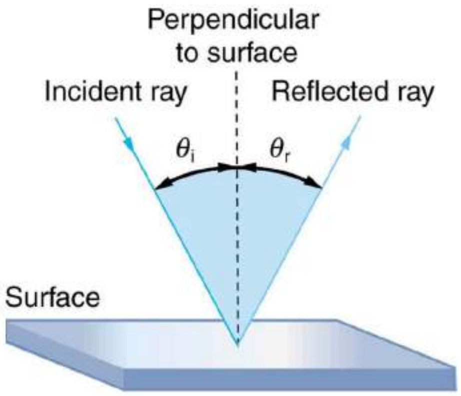
Critical angle, θ = 40°
Refractive index of the medium, μ =?
$\mu = 1/\sin\theta$
$\mu = 1/\sin 40^\circ$
$\mu = 1/0.65$
$\mu = 1.6$

Reflection of Light in Spherical Mirrors

What is Reflection?

- When a ray of light falls on any object (polished, smooth, shiny object), light from the object bounces back those rays of light to our eyes and this phenomenon is known as "Reflection" or "Reflection of Light".
- This phenomenon is what enables us to look at the world around us and is based on the property that light travels in a straight line. For example, the twinkling of stars or light reflected by a mirror.

Laws of Reflection



- In the diagram given above, the ray of light that approaches the mirror is known as the "Incident Ray". The ray that leaves the mirror is known as the "Reflected Ray".
- At the point of incidence where the incident ray strikes the mirror, a perpendicular line is drawn known as the "Normal". This normal is what divides the incident ray and the reflected ray equally and gives us the "Angle of Incidence" (Qi) and "Angle of Reflection" (Qr).
- Hence the above information gives us the "Laws of Reflection of Light" which state that:
  a. The angle of incidence is equal to the angle of reflection.
  b. The incident ray, the normal ray and the reflected ray, all lie in the same plane.

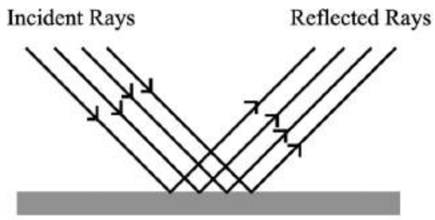
Types of Reflection

There are majorly two types of reflection:

- Specular/ Regular reflection
- Diffused/ Irregular reflection

(i) Specular/Regular reflection

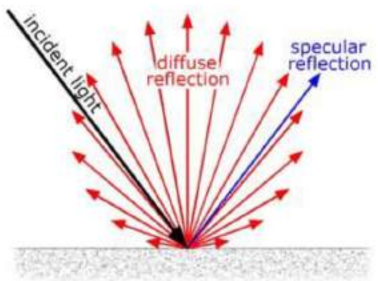
- A specular or regular reflection is a mirror-like reflection of rays of light. Here the rays of light which are reflected from a smooth and shiny object such as a mirror, are reflected at a definitive angle and each incident ray which is reflected along with the reflected ray has the same angle to the normal as the incident ray.
- Thus, this type of phenomenon causes the formation of an image.



Regular Reflection

(ii) Diffused/Irregular reflection

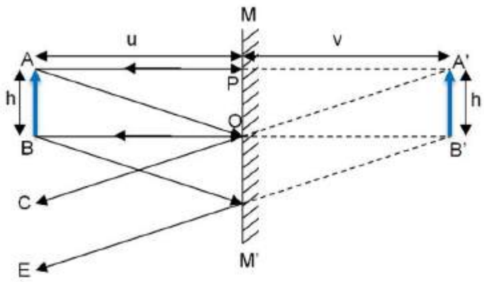
- A diffuse or irregular reflection is a non-mirror-like reflection of light. In this type of reflection rays of light that hit an irregular object with a rough surface, are reflected back in all directions.



Diffuse Reflection

- Here, the incident ray which is reflected along with the reflected ray doesn't have the same angle to the normal as the incident ray.
- Thus, this type of reflection doesn't form an image.

Image Formation by a Plane Mirror



- Let us take a mirror MM' as shown in the diagram given above. Let us suppose an object AB of size 'h' on the left-hand side of the mirror at a distance 'u'.
- An incident ray of light AP from point A of the object AB falls on the mirror MM' at point P. This incident ray AP is reflected back along the same path PA. Another ray OC falls on the mirror MM' at a point O and is reflected along the path OC.
- Now, since reflected rays PA and OC are diverging and therefore cannot meet each other in front of the mirror, hence we extend these rays PA and OC behind the mirror by dotted lines.
- On extending these rays behind the mirror, we see that these rays meet at point A' at a distance of V'. Therefore, A' is the virtual image of point A of the object AB.
- Similarly, a virtual image of point B will be formed behind the mirror as B' from the incident rays BO and BE.
- Now, to get a complete image of the object AB, we join points A and B to points A' and B' by a dotted line. In doing so, we find that the image A'B' being formed is virtual, erect and of the same shape and size as the object AB; thereby giving us the characteristics of images formed by the plane mirror.

Characteristics of Images formed by Plane Mirror

(i) Images formed by a plane mirror are "Always Virtual".
(ii) Images formed by a plane mirror are "Erect/Upright".

(iii) Images formed by a plane mirror are of the "same shape and size" as that of an object.

Natural Phenomena due to Sunlight & Optical Instruments

What is Scattering of Light?

- Light can be examined entirely from its source. When light passes from one medium to any other medium say air, a glass of water then a part of the light is absorbed by particles of the medium preceded by its subsequent radiation in a particular direction. This phenomenon is termed as a scattering of light.

- The intensity of scattered light depends on the size of the particles and the wavelength of the light.
- Shorter wavelength and high frequency scatter more due to the waviness of the line and its intersection with a particle. The wavier the line, the more are the chances of it intersecting with a particle.
- On the other hand, longer wavelengths have low frequency, and they are straighter and chances of colliding with the particle are less so the chances are less.
- The bending of multicoloured light can be seen in the afternoon due to the refraction and total internal reflection of light. The wavelength of the sunlight forms different colours in different directions.
- Rayleigh scattering theory is reasoned for the red colour of the sun in the morning and blue colour of the sky. Let p be considered as the probability of scattering and λ is the wavelength of radiation, then it is given as:
  $P \propto 1\lambda^4$
- The probability for scattering will give a high rise for shorter wavelength and it is inversely proportional to the fourth power of the wavelength of radiation.

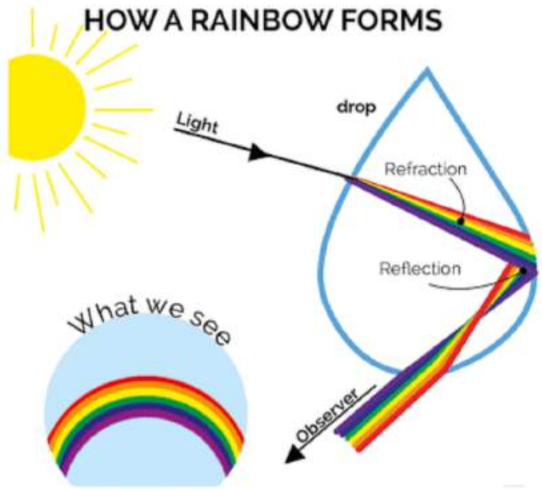
Examples of Scattering of Light

- Molecules with a larger size than the wavelength of light, experience the scattering effect differently, the phenomenon is known as Mie effect.
- Due to the largeness of particles, the light appears white. That is why the clouds, which are made of droplets of water are white. The blue colour is present in the major percentage among the lower wavelengths.
- With the wavelength of the light, the scattering efficiency of the small molecules in the atmosphere decreases. Sun radiates its light and its rays fall into the earth's envelope thus, sunlight gets scattered in the atmosphere.
- There are some examples that also show scattering, particles like dust, and smoke can also scatter radiation. In the same manner, we can explain the red colour appearance of the sun.
- For red light, the wavelength is more, and it is easy to go through the atmosphere as the scattering is less for the red light. When the light is on any other object, it gets scattered depending on its properties as different light has different intensity and each particle has different characteristics.

The Rainbow

Everyone must have seen the rainbow. The rainbow that appears in the sky is the most beautiful optical phenomenon. The sunlight passing through the water droplets present in the atmosphere undergo reflection and refraction to form a rainbow. Sometimes after the rains two rainbows are seen. The two rainbows are the primary rainbow and secondary rainbow.

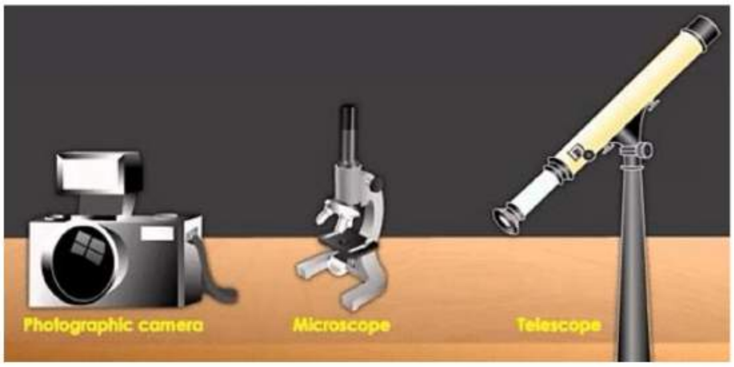
If the sunlight undergoes one internal reflection in the raindrops before emerging than the rainbow formed is the primary rainbow. Primary rainbow is brighter and narrow. It has red color at the outer edge and violet at the inner edge. The red light has a longer wavelength and is bent at least. The violet with a shorter wavelength is bent most.



While forming a secondary rainbow, light rays undergo two internal reflections inside the water drops and due to this, it appears to be faint. The colors are reversed in the secondary rainbow with red at the inner edge and violet at the outer edge.

Optical Instruments

An optical instrument can be defined as a device that either process light waves to enhance an image for viewing or analyzes light waves to determine one of a number of characteristic properties.



Optical Instruments

➢ Camera

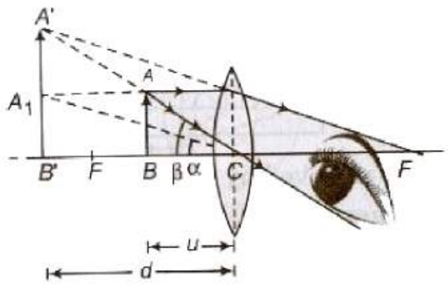
A photograph camera consists of a light proof box, at one end of which a converging lens system is fitted. A light-sensitive film is fixed at the other end of the box, opposite to the lens system. A real inverted image of the object is formed on the film by the lens system.

f-Number for a Camera: The f-number represent the size of the aperture.

f-number =Focal length of the lens (F) / Diameter of the lens(d)
Generally 2, 2.8, 4, 5.6, 8, 11, 22, 32 are f-numbers.
The amount of light (L) entering the camera is directly proportional to the area (A) of the aperture, i.e.,
$L \propto A \propto d^2$
Brightness of Image $\propto$ (d2/f2)
where, d = diameter of the lens and F = focal length of the lens.
Exposure time is the time for which light is incident of photographic film.

➢ Simple Microscope

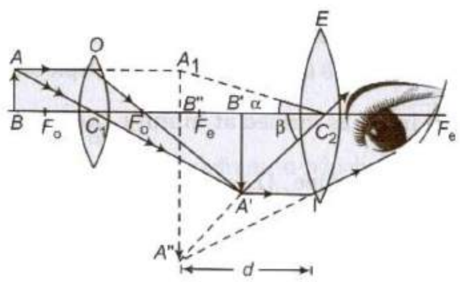
It is used for observing magnified images of objects. It is consists of a converging lens of small focal length.



Magnifying Power
(i) When final image is formed at least distance of distinct vision (D), then M=1+d/f
where, f= focal length of the lens.
(ii) When final image is formed at infinity, then M = D/f

➢ Compound Microscope

It is a combination of two convex lenses called objective lens and eye piece separated by a distance. Both lenses are of small focal lengths but $f_o < f_e$, where f_o and f_e are focal lengths of objective lens and eye piece respectively

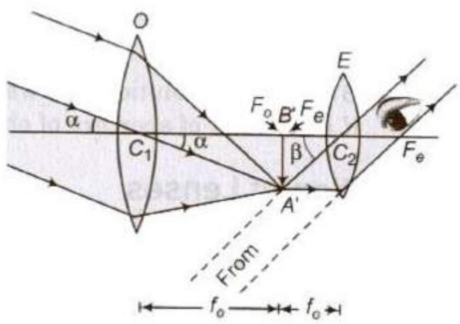


Magnifying Power
$M = v_o / u_o \{1 + (D/f_o)$

Where v_o= distance of image, formed by objective lens and
u_o = distance of object from the objective
(ii) When final image is formed at infinity, then
$M = v_o/u_o . D/f_e$

➢ **Astronomical Telescope**

It is also a combination of two lenses, called objective lens and eye piece, separated by a distance. It is used for observing distinct images of heavenly bodies like stars, planets etc.



Magnifying Power

(i) When final image is formed at least distance of distinct vision (D), then $M = f_o/f_e \{1+ (D/f_e)\}$ where f_o and f_e are focal lengths of objective and eyepiece respectively.
Length of the telescope (L) = $(f_o + u_e)$
where, u_e = distance of object from the eyepiece.
(ii) When final image is formed at infinity, then $M = f_o/f_e$
Length of the telescope (L) = $f_o + f_e$
For large magnifying power of a telescope f_o should be large and f_e should be small.
For large magnifying power of a microscope; $f_o < f_e$ should be small.

Resolving Power

The ability of an optical instrument to produce separate and clear images of two near by objects, is called its resolving power.

Limit of Resolution

The minimum distance between two near by objects which can be just resolved by the instrument, is called its limit of resolution (d).
Resolving power of a microscope = $1/d = 2 \mu \sin \theta / \lambda$

where, d = limit of resolution, λ = wavelength of light used.
μ = refractive index of the medium between the objects and objective lens and θ = half of the cone angle.
Resolving power of a telescope = $1/d\theta = d/1.22\lambda$
where, $d\theta$ = limit of resolution, A = wavelength of light used and
d = diameter of aperture of objective

Aberration of Lenses

The image formed by the lens suffer from following two main drawbacks:

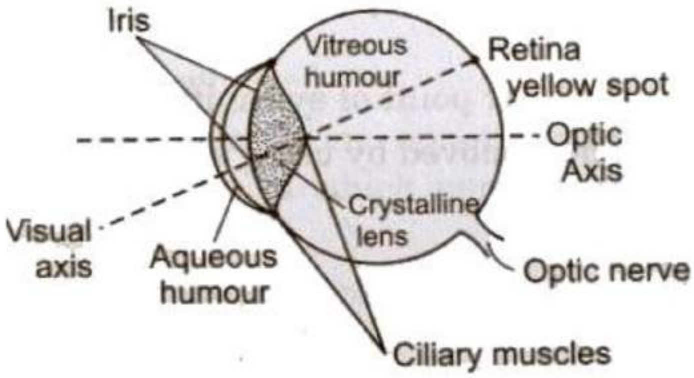
(i) Spherical Aberration: Aberration of the lens due to which the rays passes through the lens are not focussed at a single and the image of a point object placed on the axis is blurred. called spherical aberration.
It can be reduced by using

- lens of large focal lengths
- plano-convex lenses
- crossed lenses
- combining convex and concave lens

(ii) Chromatic Aberration: The image of a white object formed by lens is usually coloured and blurred. This defect of the image produced by lens is called chromatic aberration.

➢ **Human Eye**

Human eye is an optical instrument which forms real image of the objects on retina. Retina colours contains lakhs of cone and rod cells which of light and intensities of light respectively.

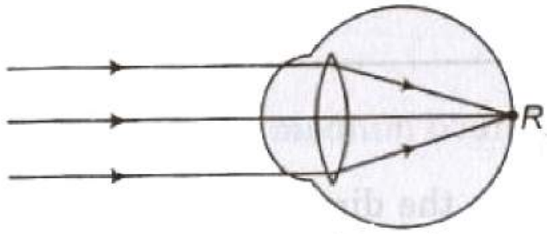


Ciliary muscles change the focal length of eye lens. This power of eye is called power of accommodation of eye.

Different defects of vision of human eye are described below:

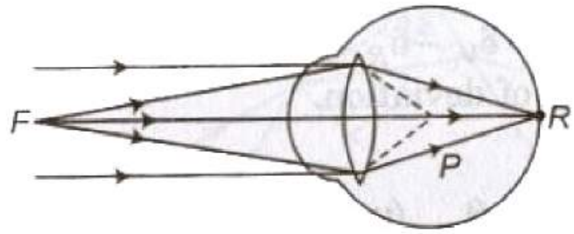
(i) **Myopia or Short-Sightedness** It is a defect of eye due to which a person can see near by objects clearly but cannot see far away objects clearly.
In this defect, the far point of eye shifts from infinity to a nearer distance.
This defect can be removed by using a concave lens of appropriate power.

(a)



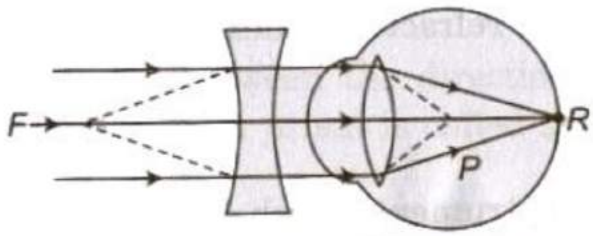
Normal eye

(b)



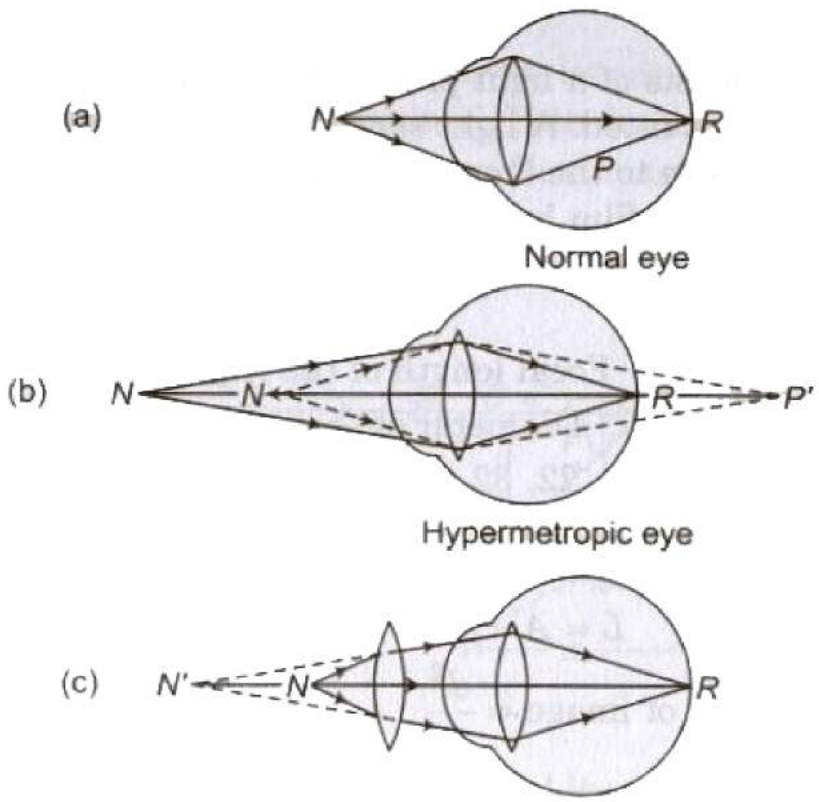
Myopic eye

(c)



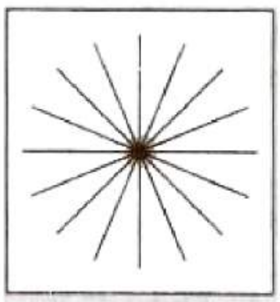
Corrected eye

(ii) **Hypermetropia or Long-Sightedness** In this defect, a person can see far away objects clearly but cannot see near by objects clearly.
In this defect the near point of eye shifts away from the eye.
This defect can be removed by using a convex lens of appropriate power.



Normal eye
Hypermetropic eye
Corrected eye

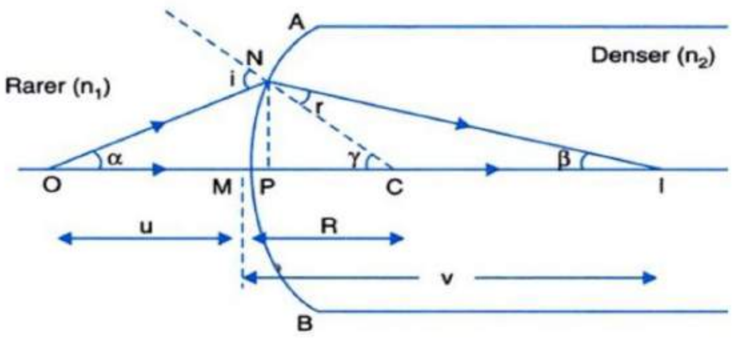
(iii) **Astigmatism-** In this defect, a person cannot focus on horizontal and vertical lines at the same distance at the same time.



This defect can be removed by using suitable cylindrical lenses.
(iv) **Colour Blindness** In this defect, distinguish between few colours. a person is unable to The reason of this defect is the absence few colours. of cone cells sensitive for
This defect cannot be removed.
(v) Cataract In this defect. an opaque white membrane is developed on cornea due to which person lost power of vision partially on completely.
This defect can be removed by removing this membrane through surgery.

Refraction at Spherical Surface & Lenses

Refraction at a Spherical Surface



- Let us now see the refraction of light at the spherical surface. Now, the change in direction or bending of a light wave passing from one transparent medium to another caused by the change in wave's speed is the Refraction.
- Suppose the above figure is a spherical surface. There is one medium with refractive index n_1 and the second medium with refractive index n_2.
- There is an object O and a ray of light from the object O is incident on the spherical mirror. Since it is moving from a rarer medium to a denser medium, the ray bends towards the normal.
- An image is formed and the radius of curvature of a spherical surface is R with the center C of the spherical surface.

<u>Now as we know that:</u>

- n_1 is the refractive index of a medium from which rays are incident.
- n_2 is the refractive index of another medium

<u>We get:</u>

► $\tan\alpha = MN / OM$
► $\tan\gamma = MN / MC$
► $\tan\beta = MN / MI$

Now, for Δ NOC, i is the exterior angle.

$i = \angle NOM + \angle NCM$

$i = MN / OM + MN / MC$ ...(1)

Similarly,

$r = MN / MC - MN / MI$ ...(2)

Now by using Snell's law we get:

$n_1 \sin i = n_2 \sin r$

Substituting i and r from Eq. (1) and (2), we get

$n_1 / OM + n_2 / MI = (n_2 - n_1) / MC$
As, $OM = -u$, $MI = +v$, $MC = +R$
Hence, the equation becomes:

$$\frac{n_2}{v} - \frac{n_1}{u} = \frac{n_2 - n_1}{R}$$

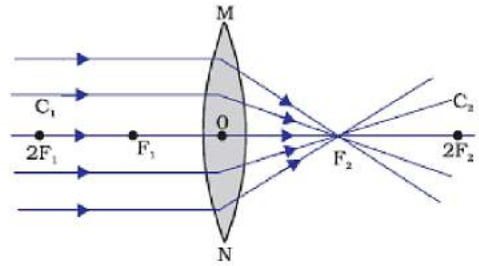
Lens
A lens is a uniform transparent medium bounded between two spherical or one spherical and one plane surface.
Here are some terms related to Lens:

- **Centre of Curvature:** The centre of the actual glass sphere, of which your lens forms a part
- **Principal Axis:** When two spheres are part of your lens, it is the imaginary line joining the centres of curvatures of both spheres.
- **Principal Focus:** It is point on the principal axis, where light rays parallel to principal axis meet in case of a convex lens (or appear to meet after extrapolation in case of a concave lens).
- **Optical Centre:** It is a point within the lens where the diameter of the lens and the principal axis meet
- **Focal Length:** The distance between the focus and the optical centre

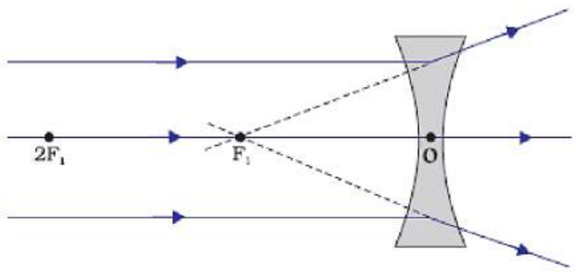
Types of Lens

1. **Convex Lens**
   A lens that is thinner at the edges and thicker at the middle is called a convex or converging lens. A convex lens is also referred to as a converging lens since it "converges" light rays that are incident on it.

Concave Lens
A lens which is thicker at edges and thinner at middle, is called a concave or diverging lens. A concave lens is also referred to as a diverging lens since it "diverges" light rays that are incident on it.



(a) Converging action of convex lens



(b) Diverging action of concave lens

Convex and Concave Lens

➢ **Lens Formula**

$1/f = 1/v - 1/u$

where, f = focal length of the lens, U = distance of object, U = distance of image.

Lens Maker's formula

$1/f = (\mu - 1)(1/R_1 - 1/R_2)$

where, μ = refractive index of the material of the lens and R_1 and R_2 are radii of curvature of the lens.

➢ **Power of a Lens**

The reciprocal of the focal length of a lens, when it is measured in metre, is called power of a lens.

Power of a lens, (P)= 1/f(metre)

Its unit is dioptre (D).

The power of a convex (converging) lens is positive and for a concave (diverging) lens it is negative.

➢ **Focal Length of a Lens Combination**

(i) When lenses are in contact $1/F - 1/f_1 + 1/f_2$

Power of the combination $P = P_1 + P_2$

(ii) When lenses are separated by a distance d

$1/F = 1/f_1 + 1/f_2 - d/f_1f_1$

Power of the combination:
$P = P_1 + P_2 - dP_1P_2$

➢ Linear Magnification

$m = I/O = v/u$

For a small sized object placed linearly along the principal axis, its axial (longitudinal) magnification is given by

Axial magnification $= - dv/du = (v/u)^2$

$= (f / f+u)^2 = (f - v/f)^2$

➢ Focal Length of a Convex Lens by Displacement Method

Focal length of the convex lens $f = (a^2 - d^2) / 4a$

where, a = distance between the image pin and object pin and

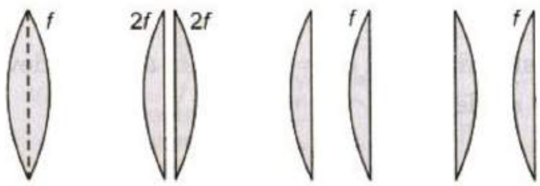
d = distance between two positions of lens.

The distance between the two pins should be greater than four times the focal length of the convex lens, i.e., $a > 4f$.

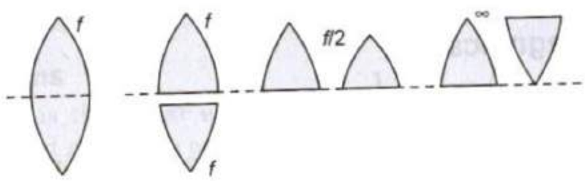
Height of the object $O = \sqrt{I_1 I_2}$

➢ Cutting of a Lens

- If a symmetrical convex lens of focal length f is cut into two parts along its optic axis, then focal length of each part (a plane convex lens) is 2f. However, if the two parts are joined as shown in figure, the focal length of combination is again f.



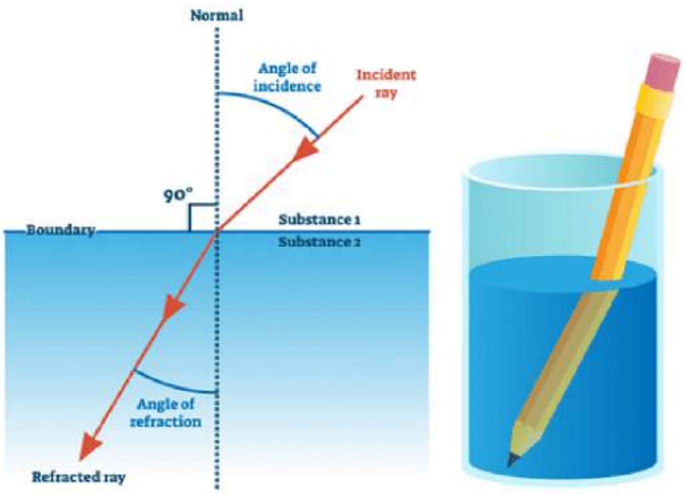
- If a symmetrical convex lens of focal length f is cut into two parts along the principal axis, then focal length of each part remains unchanged as f. If these two parts are joined with curved ends anone side, focal length of the combination is f/2. But on joining two 2 parts in opposite sense the net focal length becomes



Refraction of Light

What is Refraction?

- Refraction is the bending of a wave when it passes from one medium to another. The bending is caused due to the differences in density between the two substances.



Refraction

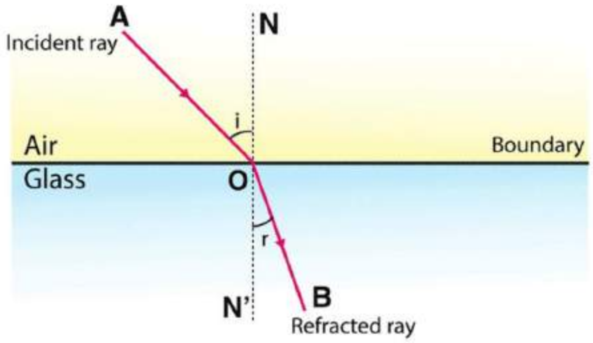
- Refraction of light is one of the most commonly observed phenomena, but other waves like sound waves and water waves also experience refraction.
- Refraction makes it possible for us to have optical instruments such as magnifying glasses, lenses and prisms. It is also because of the refraction of light that we are able to focus light on to our retina.

Why do stars twinkle?

Did you know that the twinkling effect of stars is due to atmospheric refraction? The starlight undergoes several refractions while reaching the Earth. This atmospheric refraction occurs in a medium of gradually changing refractive index.

Causes of Refraction

- A light ray refracts whenever it travels at an angle into a medium of different refractive index. This change in speed results in a change in direction. As an example, consider air travelling into water. The speed of light decreases as it continues to travel at a different angle.



- The refraction of light in glass is shown in the figure above. When light travels from air into glass, the light slows down and changes direction slightly. When light travels from a less dense substance to a denser substance, the refracted light bends more towards the normal line.
- If the light wave approaches the boundary in a direction that is perpendicular to it, the light ray doesn't refract in spite of the change in speed.

Laws of Refraction of Light

Laws of refraction state that:

1. The incident ray refracted ray, and the normal to the interface of two media at the point of incidence all lie on the same plane.
2. The ratio of the sine of the angle of incidence to the sine of the angle of refraction is a constant. This is also known as Snell's law of refraction.

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

What is Refractive Index?

- The Refractive index, also called the index of refraction describes how fast light travels through the material.
- Refractive Index is dimensionless. For a given material, the refractive index is the ratio between the speed of light in a vacuum (c) and the speed of light in the medium (v). If the refractive index for a medium is represented by n, then it is given by the following formula:

$$n = \frac{c}{v}$$

- Based on the refractive index of the medium, the light ray changes its direction, or it bends at the junction separating the two media. If the light ray travels from a medium to another of a higher refractive index, it bends towards the normal, else it bends away from the normal.

Refraction of Light in Real Life

- Mirage and looming are optical illusions which are a result of refraction of light.
- A swimming pool always looks shallower than it really is because the light coming from the bottom of the pool bends at the surface due to refraction of light.
- Formation of a rainbow is an example of refraction as the sun rays bend through the raindrops resulting in the rainbow.
- When white light passes through a prism it is split into its component colours – red, orange, yellow, green, blue and violet due to refraction of light.

Applications of Refraction of Light

Refraction has many applications in optics and technology. A few of the prominent applications are listed below:

1. A lens uses refraction to form an image of an object for various purposes, such as magnification.
2. Spectacles worn by people with defective vision use the principle of refraction.
3. Refraction is used in peepholes of house doors, cameras, movie projectors and telescopes.