APPLIED PHYSICS II - MODULE II

OPTICS

CO2: Compute the power of lens.

Introduction to Optics:

Optics is a branch of physics which deals with the study of light. Light is a form of energy that produces a sensation of sight. Light travels with constant velocity in a medium. The velocity of light in free space or vacuum is 3×10^8 m/s. It is the luminous objects that can emit light of their own. Sun, stars, candles, bulbs, etc. are some luminous sources. Sun is the primary source of light on earth.

Optics is classified into ray optics (geometrical optics) and wave optics. The property of light traveling in a straight line is called rectilinear propagation of light. Ray optics deals with the reflection of light from plane surfaces, spherical mirrors, refraction of light in a medium, refraction of light through prisms, and curved surfaces such as lenses. The direction along which light energy is propagated is known as the 'ray of light'. A collection of a large number of rays of light is called a 'beam of light'. There are three kinds of beams of light.

a) When a large number of rays are parallel to each other, they are called a parallel beam of light

b) When rays of light coming from different directions meet at a point is called a convergent beam of light.

c) When the rays of light starting from a point, travel in various directions, is called a divergent beam of light.

Reflection of light:

When a ray of light, travelling from one optical medium to another optical medium, strikes the surface of separation of two media, the following situations can arise: a) Reflection b) Absorption c) Refraction.

The phenomenon due to which a ray of light, travelling from one optical medium to another, optical medium, bounces off from its surface with a change of angle, is called reflection of light.

Reflection of light from surfaces can be classified into the following categories:

a) Regular reflection: When a beam of light on striking some smooth and polished surface, is reflected as a parallel beam of light.

Eg: Reflection takes place from mirrors, polished metals, etc.

b) Irregular reflection(diffused reflection): When a beam of light, on striking some rough surface, is reflected in different directions.

Eg: Reflections from walls, stones, trees, etc.

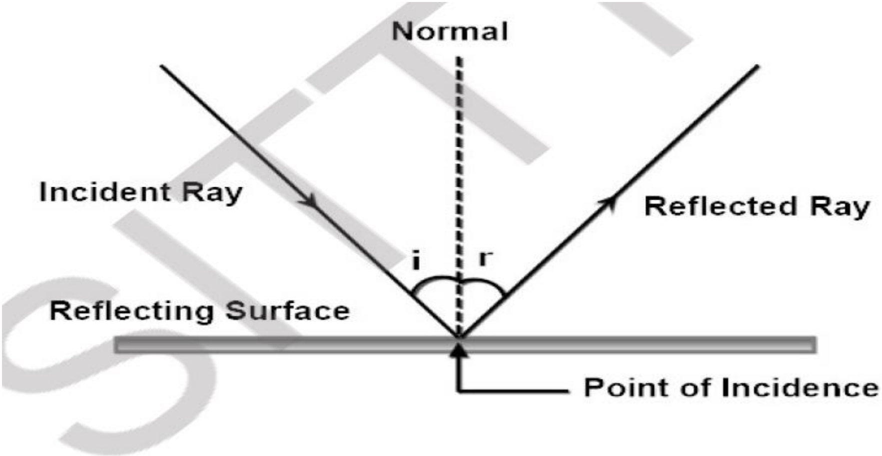


Fig. 2.1 Reflection of light from a plane surface

Fig. 2.1 shows the reflection of light from a smooth surface. We can define some terms related to the reflection of light from a surface as follows:

a) Incident ray: A ray of light which travels towards a reflecting surface.

b) Reflected ray: A ray of light bounces off the reflecting surface into the same optical medium.

c) Point of incidence: The point on the reflecting surface, where incident ray strikes.

d) Normal: The perpendicular drawn at the point of incidence to the reflecting surface.

e) Angle of incidence (i): The angle between the incident ray and normal.

f) Angle of reflection (r): The angle between the reflected ray and normal.

Laws of reflection:

A light ray is reflected from a plane smooth surface according to two laws of reflection:

a) The incident ray, the reflected ray, and the normal to the surface lie in the same plane at the point of incidence.

b) The angle of incidence is always equal to the angle of reflection.

i.e. ***i = r***

Spherical mirrors:

A mirror which is made from a part of a hollow sphere is called a spherical mirror. Spherical mirrors are constructed using glass and one surface of the glass is silvered. Spherical mirrors are mainly classified into convex mirrors and concave mirrors. If the inner surface of the spherical surface reflects light, then it is called a concave mirror. If the outer surface of the spherical surface reflects light, then it is called a convex mirror.

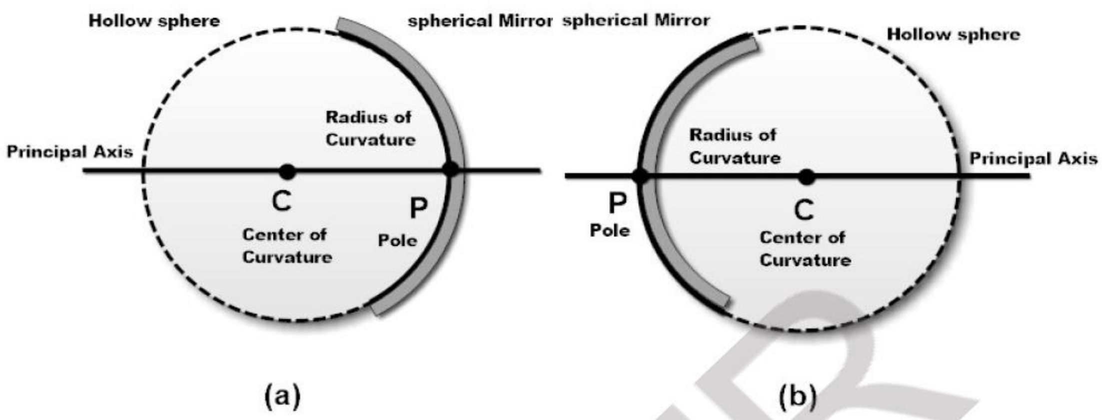


Fig. 2.2 Spherical mirrors as a part of a sphere (a) Concave mirror (b) Convex mirror

Fig. 2.2 shows both concave mirror and convex mirror as a part of the sphere. Now, we can define a few parameters related to spherical mirrors as follows:

a) Centre of curvature (C): It is the center of the sphere of which the mirror is a part.

b) Radius of curvature (R): It is the radius of the sphere of which the mirror is a part.

c) Pole (P): Geometrical center of the mirror. By convention, all distances are measured from the pole of the mirror.

d) Principal axis (PA): It is the straight line passing through the pole and the center of curvature of the mirror.

e) Principal focus (F): A narrow beam of light parallel to the principal axis after reflection converges to a point on the principal axis in the case of a concave mirror and appears to diverge from a point on the principal axis in the case of a concave mirror. This point is called the principal focus.

f) Focal length(f): It is the distance between the pole and the principal focus. For a spherical mirror, focus lie on the principal axis at the midpoint between pole and center of curvature. Hence the focal length of the spherical mirror is exactly half its radius of curvature.

$$f = \frac{R}{2}$$

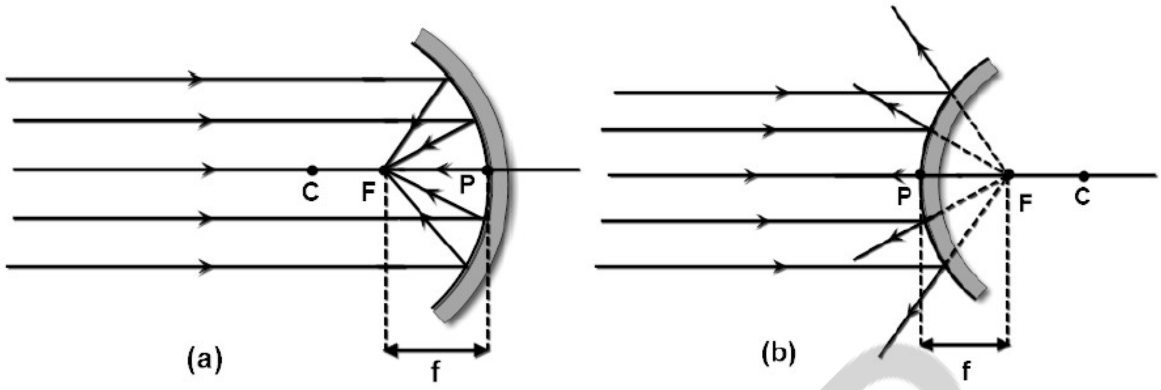


Fig 2.3 Principal focus and focal length of (a) concave mirror and (b) convex mirror

Mirror formula:

Mirror formula is a quantitative relation between object distance (u), image distance (v), and focal length (f) of a spherical mirror. The distance between the object and pole of the mirror is called object distance. The distance between the image and the pole of the mirror is called image distance. The mirror formula for the spherical mirror is given by,

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

Uses of spherical mirrors:

a) Concave mirror is used as shaving mirrors.

b) Parabolic mirrors are used in astronomical telescopes and searchlights.

c) Convex mirrors are used in vehicles to see the rear side.

d) Convex mirrors are used as streetlight reflectors.

Refraction of light:

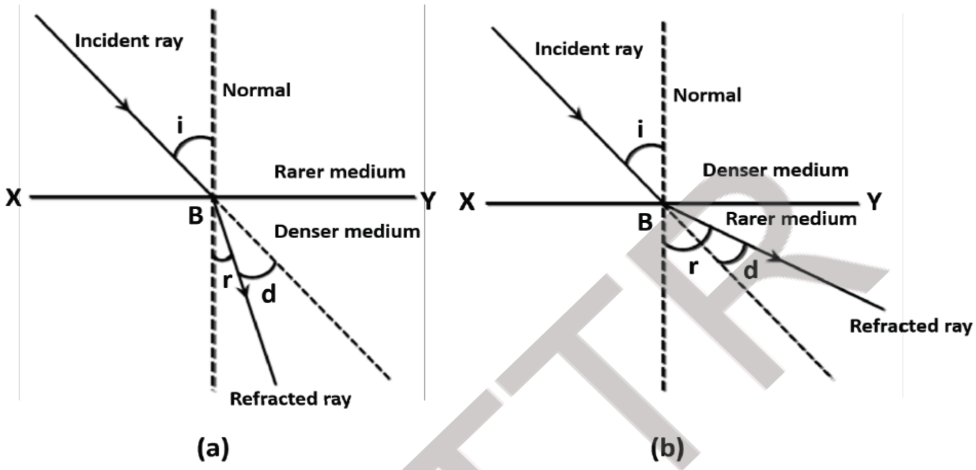


Fig. 2.4 Refraction of light when light travels from
(a) Rarer medium to denser medium and
(b) Denser medium to rarer medium

When light travels from one medium to another medium in an oblique direction, it deviates from its path. This is known as the refraction of light. ***The phenomenon of bending of light when it travels from one medium to another is known as refraction.*** When light travels from a rarer medium to a denser medium (Eg. From air to glass), light bends towards the normal at the point of incidence as shown in Fig. 2.4 (a). When light travels from a denser medium to a rarer medium, light bends away from the normal as shown in Fig. 2.4 (b). The angle between the incident ray and the normal is known as angle incidence (i). The angle between the refracted ray and the normal is known as the angle of refraction (r). The angle between the incident ray and the refracted ray is called the angle of deviation (d).

Laws of refraction:

Refraction of light occurs due to a change in the speed of the light as it enters from one transparent medium to another. It is experimentally observed that refraction of light at the interface of two media occurs according to certain laws called laws of refraction. The two laws of refraction are:

a) The incident ray, the refracted ray, and the normal at the point of incidence, all lie in the same plane.

b) The ratio of the sine of the angle of incidence to the sine of the angle of refraction is a constant for a given pair of media. This law is known as ***Snell's law of refraction*** *and it is mathematically expressed as*

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

where 'i' is the angle of incidence in the first medium and 'r' the angle of refraction in the second medium and the constant is known as the refractive index of the second medium with respect to the first medium denoted as n_{21}. Then by Snell's law,

$$\frac{\sin i}{\sin r} = n_{21}$$

Refractive index:

Refractive index is a physical quantity related to the speed of propagation of light in different media. Refractive index of a medium is defined as the ratio of the speed of the light in vacuum (c) to the speed of the light in the medium (v).The refractive index of the medium (n) is given by,

$$Refractive\ indexof\ the\ medium = \frac{speed\ of\ light\ in\ vaccum}{speed\ of\ light\ in\ the\ medium}$$

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

Light travels fastest in a vacuum with a speed of 3 × 10^8 m/s. The speed of the light in the air is only slightly less than that in the vacuum. Here n is the absolute refractive index of the medium defined with respect to air (vacuum).The Refractive index of the air (vacuum) is taken as 1. We can also define the refractive index of the medium using Snell's law of refraction. The refractive index of a medium is defined as the ratio of the sine of the angle of incidence to the sine of the angle of refraction when light travels from air to the medium. Medium of high refractive index is called a denser medium and medium of low refractive index is called a rarer medium. When light travels from medium 1 to medium 2, then

$$\frac{\sin i}{\sin r} = n_{21} = \frac{velocity\ of\ light\ in\ medium\ 1}{velocity\ of\ light\ in\ medium\ 2}$$

$$n_{21} = \frac{velocity\ of\ light\ in\ medium\ 1}{velocity\ of\ light\ in\ vaccum} \text{ X } \frac{velocity\ of\ light\ in\ vaccum}{velocity\ of\ light\ in\ medium\ 2}$$

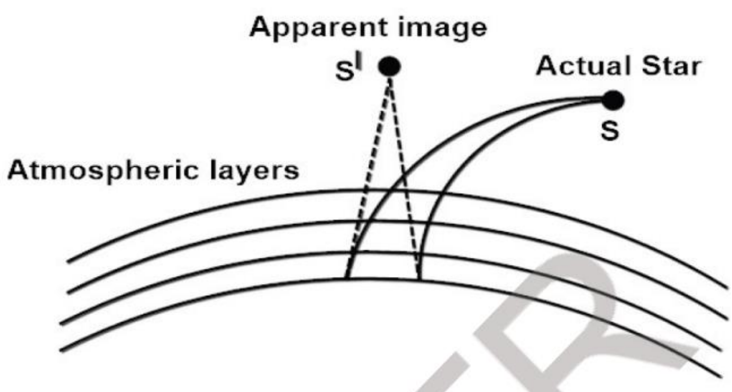
$$\therefore \quad n_{21} = \frac{n_2}{n_1}$$

Table 2.1 Refractive index of some transparent media

Substance	Refractive index
Air (vacuum)	1
Ice	1.31
Water	1.33
Ethyl alcohol	1.36
Paraffin oil	1.44
Crown glass	1.48 to 1.62
Flint glass	1.54 to 1.80
Diamond	2.42

Some practical examples of refraction:

a) **Twinkling of stars**: The twinkling of stars is due to the refraction of light from the star at different layers of the atmosphere. The density of different layers of the atmosphere continuously changes. So due to the refraction of light at these layers, the apparent image of the star appears to be at S^1. The position of S^1 also changes with time. Thus, the star appears to be twinkling.



b) **Apparent depth and real depth**: Consider an object kept in a medium at a depth D. When it is viewed from a rarer medium (air) apparent depth (d) seems to be less than the actual depth as shown in fig. 2.6. The apparent depth of an object depends on the refractive index of the medium. If n is the refractive index of the denser medium with respect to the rarer medium then,

$$n = \frac{D}{d}$$

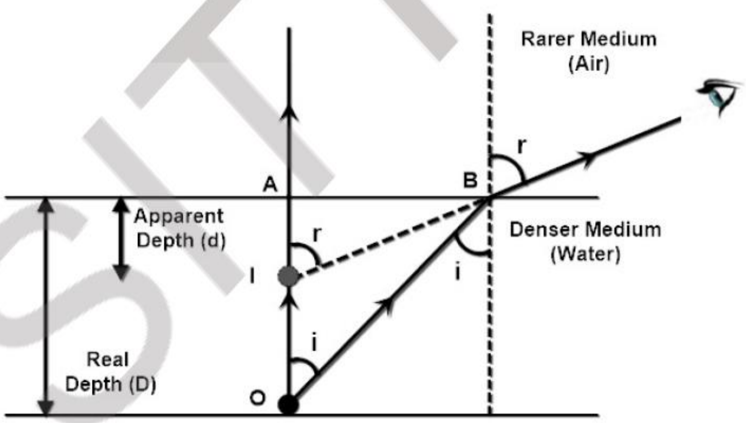


Fig. 2.6 Apparent depth of an object in denser medium as viewed from a rarer

c) **Apparent shift in the position of the sun at sunrise and sunset:** Sun is visible before sunrise and after sunset because of atmospheric refraction. The density of atmospheric air decreases as we go up. So, the rays coming from the sun deviate towards the normal after refraction at each layer. If the sun is below the horizon at S, light appears to come from S^1 as shown in fig. 2.7. For an observer on earth. So, the observer can see the sun before sunrise. Similarly, we can explain the same phenomenon at sunset. Therefore, due to refraction, the sun appears to rise early by 2 minutes and set late by 2 minutes. The day thus becomes longer by about 4 minutes.

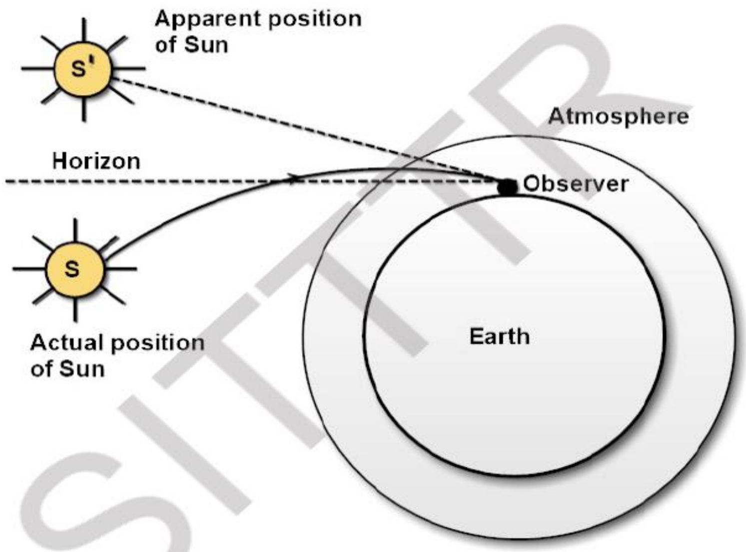


Fig. 2.7Apparent Shift in the position sunrise due to atmospheric refraction

Conceptual Learning 1:

A tank filled with water to a height of 12.5 cm. The apparent depth of a needle lying at the bottom of the tank is measured by a microscope to be 9.4 cm. If the water is replaced by a liquid of refractive index 1.63 up to the same height. What distance would the microscope have to be raised to focus the needle?

Spherical lenses:

A lens is made of transparent materials bound by two refracting surfaces. If the two surfaces are curved, they are known as spherical lenses. They are mainly divided into two; convex and concave. If the middle part of the lens is thicker than the edges it is s convex lens. If the middle part of the lens is thinner than the edges it is a concave lens. Now, we define some quantities related to spherical lenses.

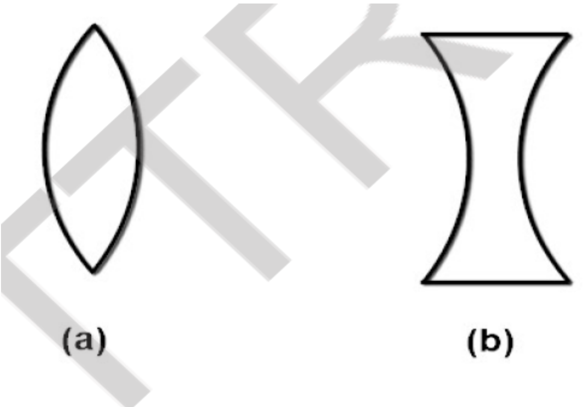


Fig. 2.8 (a) Convex lens and (b) Concave lens

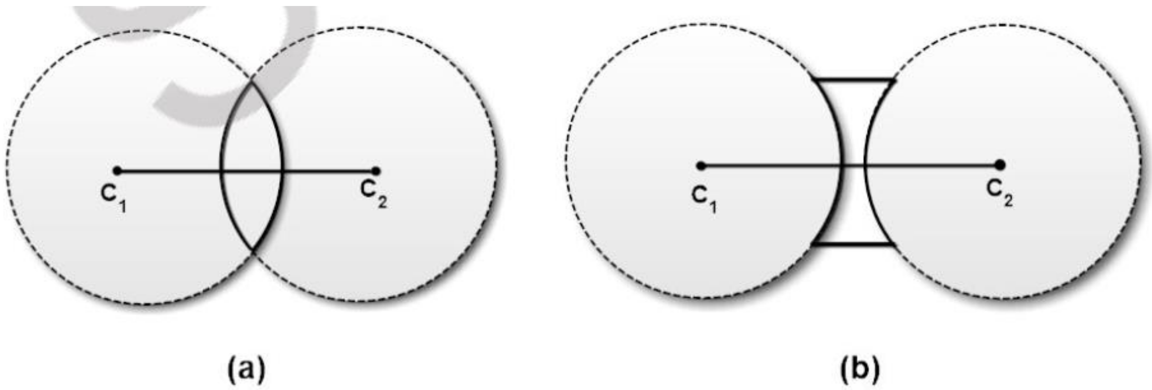


Fig. 2.9 Principal axis and centre of curvatures of (a) a convex lens and (b) a concave lens

a) Optic center: The geometric center of the lens is called the optic center.

b) Principal axis: There are two centers of curvatures for a lens as shown in fig. 2.9.The principal axis of a lens is the line joining the centers of curvature.

c) Principal focus: There are two principal foci each on either side of the lens. The definition of principal focus is different for the two types of spherical lenses.

i. Convex lens: A parallel beam of light parallel to the principal axis after refraction converges to a fixed point on the principal axis. This fixed point is called the principal focus.

ii. Concave lens: A parallel beam of light parallel to the principal axis after refraction diverges from a fixed point on the principal axis. This fixed point is called the principal focus.

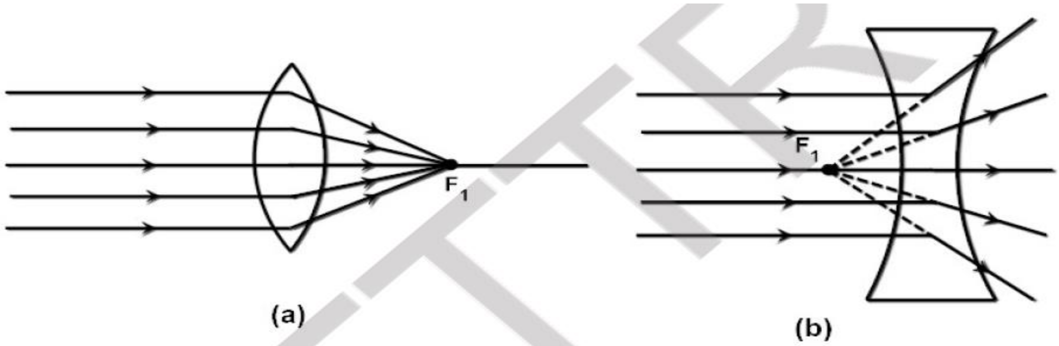


Fig. 2.10 Principal focus of (a) a convex lens and (b) a concave lens

Image formation by convex lens:

Image formation by spherical lenses can be understood by drawing ray diagrams. For constructing ray diagrams, we may draw at least two incident rays which are refracted by the convex lens according to the following rules:

1) Any incident ray traveling parallel to the principal axis of a convex lens will refract through the lens and travel through the principal focus on the opposite side of the lens.

2) The ray that travels through the principal focus on the way to the lens will refract and travel parallel to the principal axis.

3) An incident ray that passes through the optic center of the lens will pass through the lens without any deviation in its direction.

A convex lens can form two types of images namely real image and virtual image. If the refracted rays intersect on the other side of the lens, the image formed will be a real image. If the refracted rays appear to diverge from a point on the same side of the lens, the image formed is virtual. Real images can be captured on a screen whereas virtual images cannot be captured on a screen. Real images are inverted whereas virtual images are erect. The location, size, and nature of the image formed by a convex mirror mainly depend on the distance of the object from the optic center of the lens.

a) **Object at infinity:** When the object is at infinity or a very large distance, the rays from the object are always parallel to the principal axis of the convex lens. The parallel rays from the object, after refraction, converge to the principal focus on the other side of the lens and produce the image as shown in fig.2.11.The image formed is real, inverted and highly diminished.

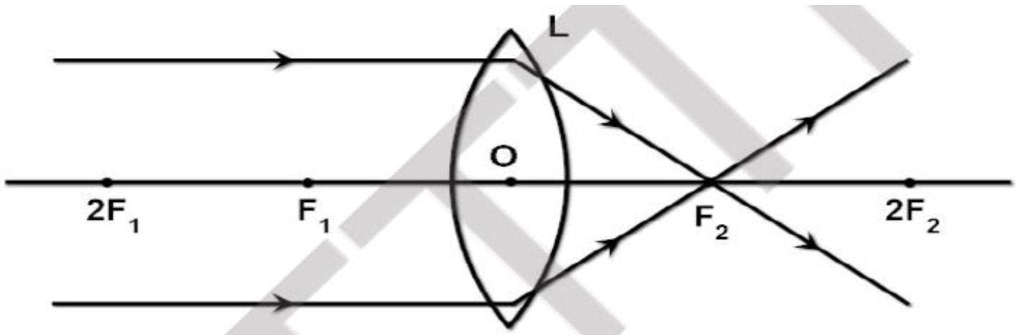


Fig. 2.11 Image formation by convexlens – Object at infinity

b) **Object beyond 2F**: When the object is just beyond 2F, the image is formed between F and 2F on the other side of the lens as shown in fig. 2.12. The image is real, inverted, and smaller than the object.

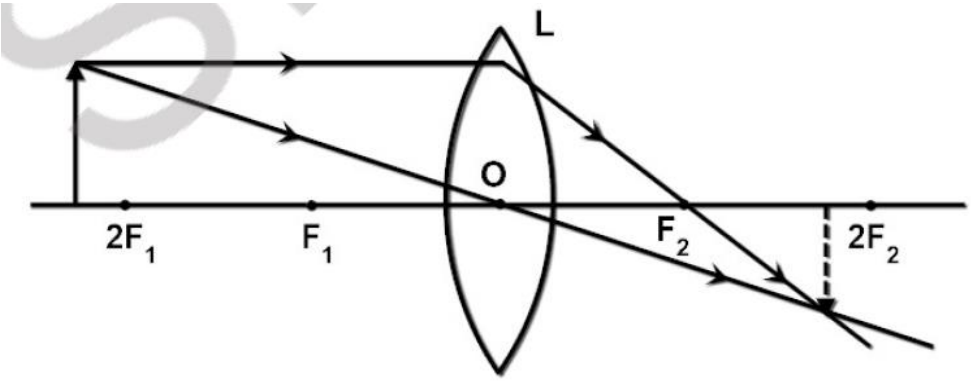
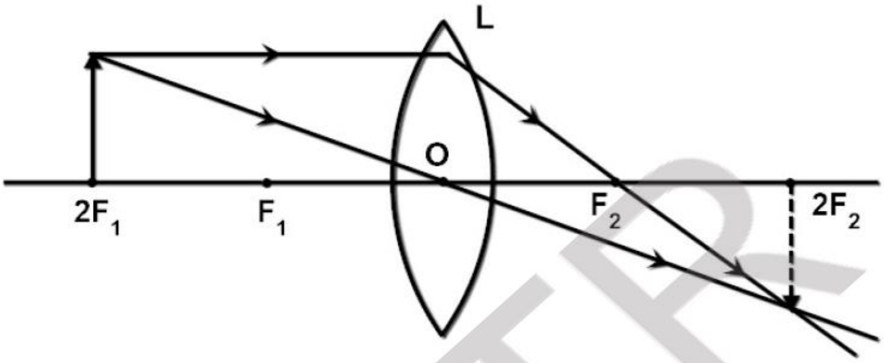


Fig. 2.12 Image formation by convexlens – Object beyond 2F

c) **Object at 2F**: When the object is at 2F, the image is formed exactly at 2F on the other side of the convex lens. The image formed is real, inverted, and exactly the same size as that of the object.



d) Object between 2F and F: When the object is between 2F and F, the image is formed beyond 2F on the other side of the convex lens. The image formed is real, inverted, and larger than the object.

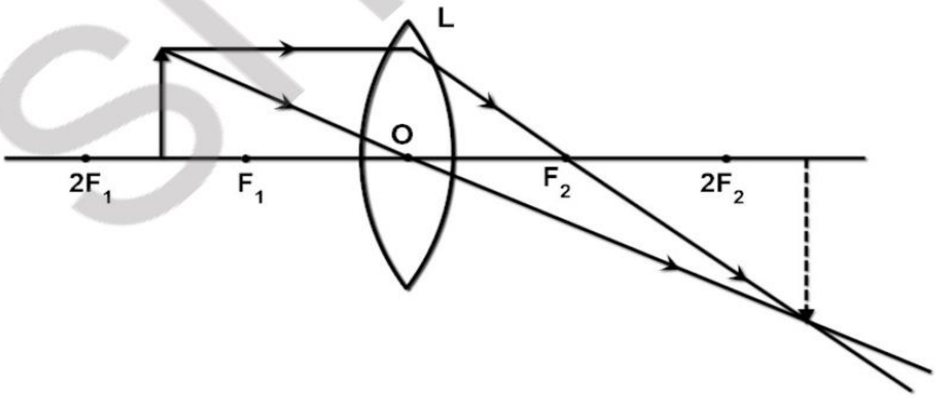


Fig. 2.14 Image formation by convexlens – Object between 2F and F

e) Object at F: When the object is at F, the refracted rays travel parallel to each other, and the image is formed at infinity.

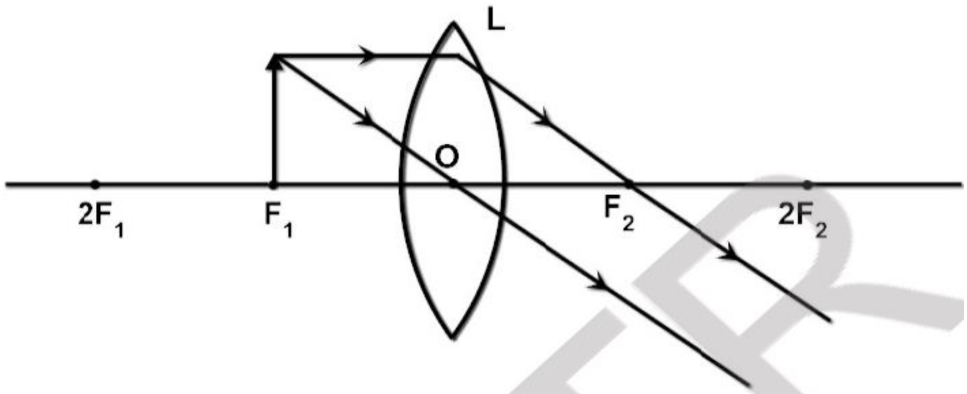


Fig. 2.15 Image formation by convexlens – Object at F

f) Object is between F and O: When the object is between F and O, the image is formed on the same side of the convex lens. The image is virtual, erect, and larger than the object.

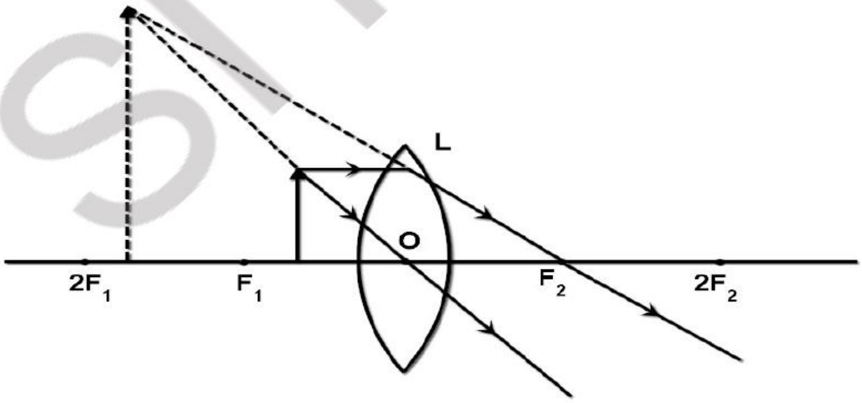


Fig. 2.16 Image formation by convexlens – Object between F and O

Table 2.2 Position, nature, and size of the image formed by a convex lens

Position of Object	Image formed by convex lens		
	Position	**Nature**	**Size**
At infinity	At F	Real and inverted	diminished
Beyond 2F	Between F and 2F	Real and inverted	diminished
At 2F	At 2F	Real and inverted	Same size
Between 2F and F	Beyond 2F	Real and inverted	Enlarged
At F	Infinity	-	-
Between F and O	Same side of the object	Virtual and erect	Enlarged

Image formation by a concave lens:

There are only two possibilities for the position of objects in front of the concave lens – object at infinity and object between the optic center and infinity. The position, nature, and size of the image formed by a concave lens are given in table 2.3.

Table 2.3 Position, nature, and size of the image formed by a convex lens

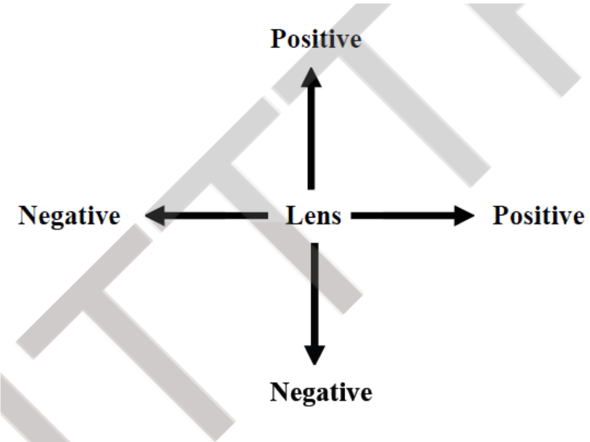
Position of Object	Image formed by a concave lens		
	Position	**Nature**	**Size**
At infinity	At F	Virtual and erect	diminished
Between O and infinity	Same side of the object	Virtual and erect	diminished

Lens formula:

The lens equation is a relation connecting the focal length of a lens with the distance of the object and image from the lens. The distance between the object and the optic center of the lens is called object distance ($\boldsymbol{u}$). The distance between the image formed and the optic center of the lens is called image distance ($\boldsymbol{v}$). If $\boldsymbol{f}$ is the focal length of the lens, then the lens formula is given by

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

For applying the equation, we need to find whether u, v, and f are positive or negative. The sign convention used for the lens is given below:



From the sign convention, it is clear that

a) The focal length of a convex lens is positive and that of a concave lens is negative.

b) The object distance is always negative since the object is in front of the lens.

c) If a real image is formed by a lens (always on the right side of the lens), the image distance is positive.

d) If a virtual image is formed by a lens (always on the left side of the lens), the image distance is negative.

Power of lens:

The ability of a lens to bend the light falling on it is called the power of a lens. The power of a lens is defined as the reciprocal of the focal length of the lens. If $\boldsymbol{f}$ is the focal length of the lens, then its power (P) is given by

$$P = \frac{1}{f}$$

The unit of power is m^{-1} or dioptre (D).The power of a convex lens is positive and that of a concave lens is negative.

Magnification of a lens:

Magnification (m) of a lens is defined as the ratio of the height of the image to the height of the object. If h_o is the height of the object and h_i is the height of the image, then linear magnification is given by

$$\boldsymbol{m = \frac{h_i}{h_0}}$$

From sign convention, object height is always positive since it is above the principal axis. If the image is erect (above principal axis), image height is positive. If the image is inverted below the principal axis), the image height is negative.

Magnification can also be defined as the ratio of image distance to object distance. If $\boldsymbol{u}$ is the object distance and $\boldsymbol{v}$ is the image distance, then magnification is given by

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

This relation is true for both convex and concave lenses and real as well as virtual images. Magnification is negative for real images and positive for virtual images.

Combination of lenses:

When a number of lenses are kept in contact, it will act as a single lens known as an effective lens or equivalent lens. Lenses are usually combined to

i) Increase magnification

ii) Make image erect

iii) Reduce defects

Consider a number of lenses of focal length f_1 , f_2 , f_3 etc. are kept in contact. The effective focal length of the combination is given by

$$\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2} + \frac{1}{f_3} + \cdots$$

The effective power of lens combination is given by

$$P = P_1 + P_2 + P_3 + \cdots$$

where P_1, P_2, P_3 etc. are the powers of individual lenses. If m_1, m_2, m_3 etc. are the magnifications produced by the lenses, then the net magnification produced by the combination is given by

$$m = m_1 \times m_2 \times m_3 \times .....$$

Lens defects:

Spherical aberrations and chromatic aberrations are the two most common defects of the lens.

a) Spherical aberration: When a parallel beam of monochromatic light, parallel to the principal axis, is incident on a convex lens, the marginal rays will converge at one point and the paraxial rays converge at another point on the principal axis. So, the focus will not be sharp. This defect is known as spherical aberration. Due to spherical aberration, the image of an object formed by a lens will be blurred and distorted. Spherical aberration can be minimized by using stops, crossed lenses, and plano-convex lenses.

b) Chromatic aberration: When a parallel beam of white light, parallel to the principal axis, is incident on a convex lens, dispersion takes place and it is split up into its constituent colours. The violet rays are deviated most and are focused very close to the lens at V. The red rays are deviated least and are focused away from the lens at R as shown in fig. 2.17. The other colours will focus between V and R. The inability of a lens to focus all the colours to a single point is called chromatic aberration. Chromatic aberration can be eliminated by combining a convex lens and concave lens of suitable focal length and material. Such a combination is called an achromatic doublet or achromat.

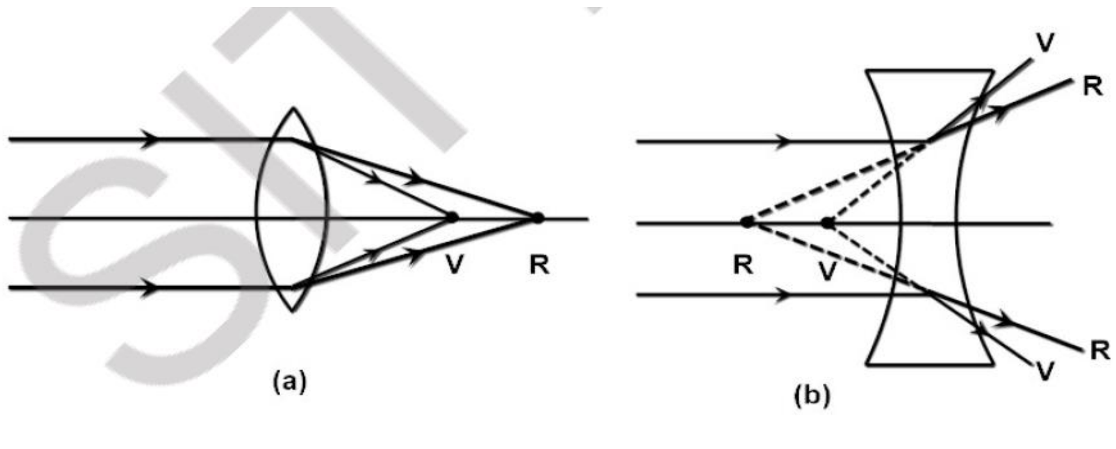


Fig. 2.17Chromatic aberration of (a) Convex lens (b) Concave lens

Optical Instruments:

Optical instruments are mainly classified into two categories:

a) Visual optical instruments

b) Spectral optical instruments

Microscopes and telescopes are examples of visual optical instruments. Prisms and gratings are examples of spectral optical instruments.

Simple microscope

A simple microscope or magnifier is an optical instrument to see the magnified image of an object. A simple microscope consists of a convex lens of a short focal length. The principle behind the simple microscope is that when a tiny object is placed between the principal focus and optic center of a convex lens, a virtual, erect, and magnified image of the object is formed on the same side of the lens as shown in fig.2.18. The lens is held near the object and the eye is positioned close to the lens on the other side. The idea is to get a virtual, erect, and magnified image of the object at a distance so that it can be viewed comfortably. The least distance of distinct vision(D) is the minimum distance of the object from the eye, which can be seen distinctly without strain. For a normal human eye, this distance is 25 cm. The linear magnification m, for the image formed at the least distance of distinct vision D, for a simple microscope can be obtained as follows:

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

From the lens formula,

$$\boldsymbol{\frac{1}{v} - \frac{1}{u} = \frac{1}{f}}$$

$$\boldsymbol{\frac{1}{u} = \frac{1}{v} - \frac{1}{f}}$$

$$\therefore \quad \boldsymbol{m = v\left(\frac{1}{v} - \frac{1}{f}\right)}$$

$$\therefore \quad \boldsymbol{m = 1 - \frac{v}{f}}$$

Now according to sign convention, $\boldsymbol{v}$ is negative and its magnitude is equal to $\boldsymbol{D}$.

$$\therefore \quad m = 1 - \frac{D}{f}$$

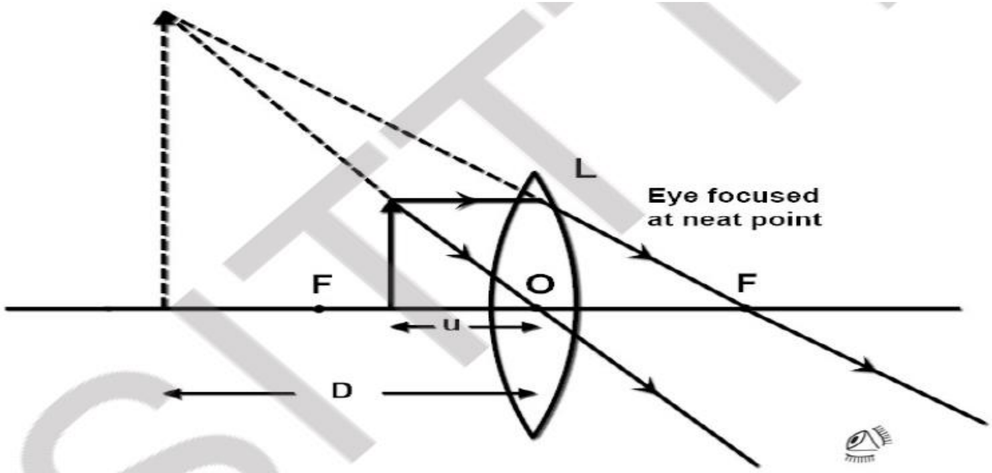


Fig. 2.18Principle behind the working of a simple microscope

Astronomical Telescope:

An astronomical telescope is an optical instrument used to see a magnified image of distant objects like planets, satellites, stars, galaxies, etc. The telescope provides angular magnification of distant objects. It consists of an objective and an eyepiece. The objective has a large focal length and a much larger aperture. Light from a distant object enters the objective and a real image is formed in the tube at the focal point of the objective lens. If this image is at the focal point of the eyepiece, a final magnified inverted image is formed at infinity.

Magnification of the telescope m is given by,

$$m = \frac{\beta}{\alpha}$$

Or
$$m = \frac{f_0}{f_e}\left(1 + \frac{f_e}{D}\right)$$

where β is the angle subtended at the eye by the image, α is the angle subtended at the eye by the object, f_o and f_e are the focal length of the objective and eyepiece and D is the image distance.

The purpose of most optical instruments, like telescopes, is not only to give a magnified image of the objects but also to reveal a greater amount of detail in them. The number of fine details revealed in an object by an optical instrument is known as its resolving power. The ability of an instrument to show two very closed objects as separate is called its resolving power. The resolving power of a telescope is defined as the reciprocal of the smallest angular separation $d\theta$ between two distant objects whose images are distinctly separated by the telescope.

$$Resolving\ power = \frac{1}{d\theta} = \frac{d}{1{\cdot}22\lambda}$$

where λ is the wavelength of the light used and d is the diameter (aperture) of the telescope.

Total internal reflection:

When light travels from a denser medium to a rarer medium, the refracted ray deviates away from the normal as shown in fig. 2.19 (a). For a particular angle of incidence, the refracted ray travels parallel to the surface of separation between the two media as shown in fig. 2.19 (b). The angle of incidence in the denser medium for which the angle of refraction is 90^o in the air is known as the critical angle of the denser medium. It is represented by 'c'. If the angle of incidence is greater than the critical angle the ray returns to the denser medium shown in fig. 2.19 (c). This is known as total internal reflection.

Total internal reflection is defined as the complete reflection of light back into a medium when light travels from a denser medium to a rarer medium and the angle of incidence in the denser medium is greater than the critical angle.

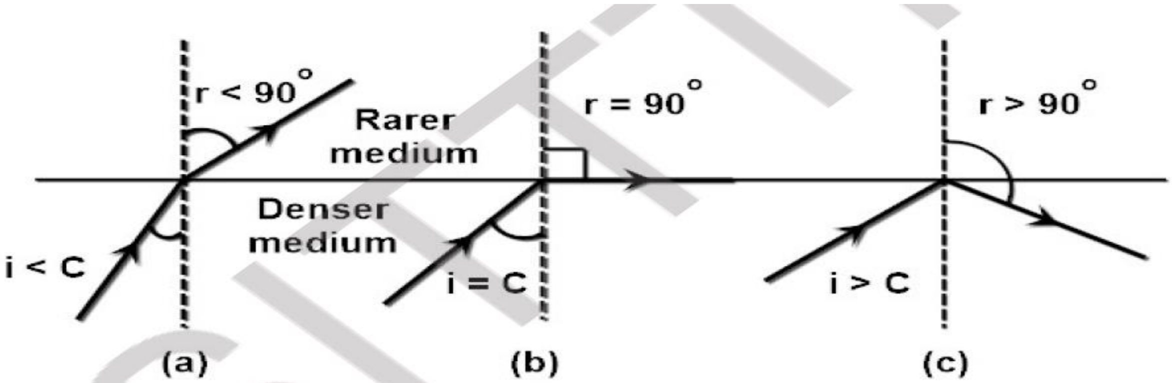


Fig. 2.19 Total internal reflection and critical angle

Total internal reflection obeys the laws of reflection. The angle of incidence is equal to the angle of reflection. The two conditions for total internal reflection are:

a) The light should travel from a denser medium to a rarer medium.

b) The angle of incidence in the denser medium should be greater than the critical angle.

If ‘n’ is the refractive index of the denser medium with respect to the rarer medium and the angle of incidence in the rarer medium is the critical angle ‘c’, then the angle of refraction in the rarer medium is 90°. Using Snell’s law,

$$n = \frac{\sin 90}{\sin c}$$

$$n = \frac{1}{\sin c}$$

Applications of total internal reflection:

a) Brilliance of diamond: Refractive index of diamond is high (n= 2.42) and the critical angle is small (c = 24.410). The light entering into the face undergoes total internal reflection many times inside the crystal and comes out through one or two faces. So these faces appear glittering. This is the reason why diamonds and certain precious stones exhibit brilliance.

b) Mirage: It is an optical illusion seen in deserts on hot days. Inverted images of distant objects like trees or the sky are obtained in hot sand or road. The same phenomenon is observed on a straight tarred road on a hot summer noon. The surface of the road appears wet as if it had rained. Mirage is due to total internal reflection. The layers of air in contact with desert or hot roads are less denser than the air above it. The rays of light from distant objects bend more and more when they pass through these layers and when the angle of incidence is greater than the critical angle it gets totally reflected back. When these rays enter into the observer’s eye, he can see the inverted image as though reflected from a pond as shown in fig. 2.20.

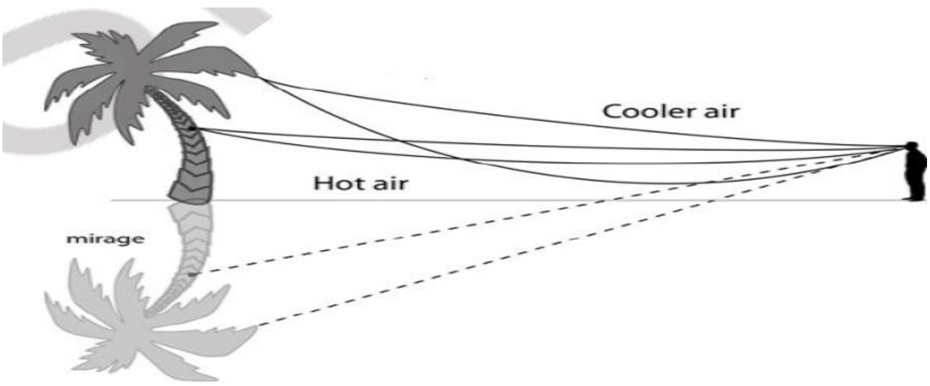


Fig. 2.20 Mirage of a tree in a desert

c) Total reflection prisms: Total reflection prisms are right-angled isosceles prisms made of crown glass of refractive index 1.5. They are based on the principles of total internal reflection. A prism having an angle of 90o between its two refracting surfaces and the other two angles each equal to 45°, is called a total reflecting prism. The critical angle of the crown is the glass is 41.8°. Therefore when the ray is incident at an angle greater than 41.8° within the glass, the ray undergoes total internal reflection. Total reflection prism can be used to produce the following actions:

i) To turn a ray of light through 90° as shown in fig.2.21 (a)

ii) To turn a ray of light through 180° as shown in fig.2.21 (b)

iii) To erect an inverted image without producing deviation in its path as shown in fig.2.21 (c).

The principles of deviation of a light ray through 180° are used in the construction of binoculars and bicycle reflectors.

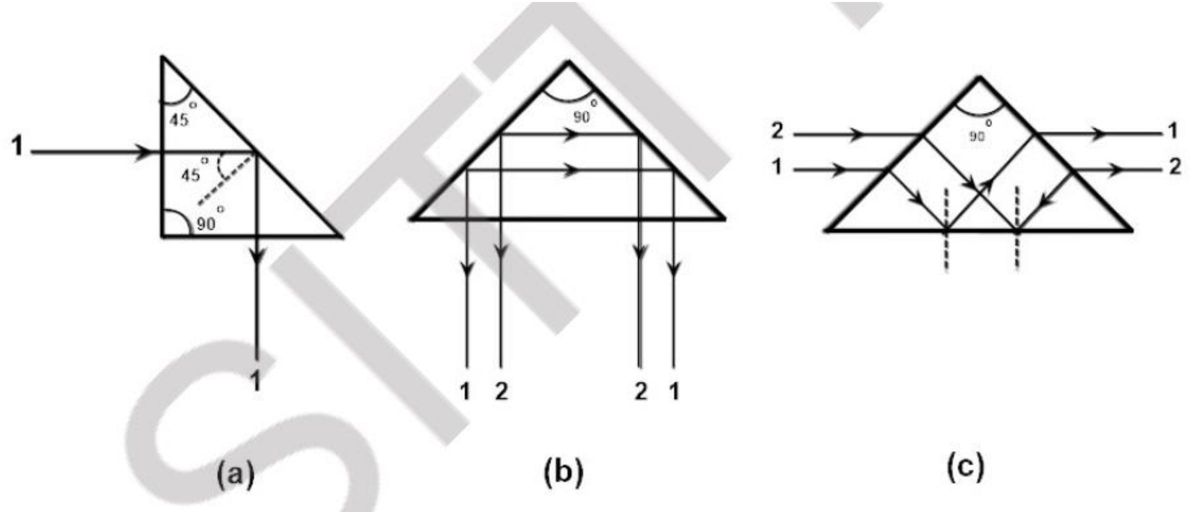


Fig. 2.21 Deviations of rays of light passing through a total reflection prism

Optical fiber:

Optical fiber is a device which works on the principle of total internal reflection and transmits light signals from one place to another without much loss of energy. Optical fiber is very a thin fiber made of glass, quartz, or plastic of very high refractive index. The diameter of a fiber is nearly one micrometer (10^{-6} m). An optical fiber consists of basically three parts – core, cladding, and coating or buffer. Core is the innermost part of the optical fiber and it provides a pathway for light signals to travel. Cladding is the layer just outside the core and it keeps the light signals inside the core. Both core and cladding are made of high purity optical media like glass or plastic. The core has a high refractive index and density compared to that of the cladding. The outer layer of the optical fiber is called coating or buffer which protects the fiber from external stresses. The coating is made of plastic and it has a high refractive index than the core and cladding which helps to refract unwanted light from the cladding.

Total internal reflection is the operating principle of optical fibers. Light is allowed to incident on at the core-cladding interface of the fiber at an angle greater than the critical angle, the light is totally reflected back into the core. Light travels along the core of the fiber undergo repeated total internal reflection and finally emerges out as shown in fig. 2.22.

Fig. 2.22 Transmission of light through an optical fiber

There are two types of optical fibers namely step-index fiber and graded-index fiber. In a step-index fiber, the refractive index of the core is uniform throughout and undergoes a sharp decrease at the core-cladding interface. In a step-index fiber, the refractive index of the core varies gradually from the core-cladding interface such that it is maximum at the center of the core. The path of the light signal in a step-index fiber is zig -zag and that in a graded-index fiber is helical. A bundle of optical fibers is called a light pipe. The applications of optical fibers are:

a) Optical fibers are used to transmit light from one place to another.

b) Optical fiber cables are used to transmit communication signals (telephone signals, internet data).

c) Optical fibers are used for decoration purposes (decoration lamps made of plastic fibers).

d) Optical fibers are used in the medical field to examine the interior parts of the human body like the stomach, intestine, etc. (Endoscopy).

e) Optical fibers can be used in toxic and hazardous environments instead of electrical cables.

Use of optical fibers in the medical field:

Optical fiber medical instruments may contain bundles of optical fibers. An optical fiber instrument used to see the internal parts of the human body is called an endoscope. The endoscopes contain two fiber optic sections inside a long tube; one of the sections provides the focusing light and the other transmits light to the doctor providing him a detailed image of the area under view. Endoscopes are used to examine hearts, the colon, lungs, shoulders, and knees. The endoscope facilitates physicians to see the internal parts of the body without performing surgery. Based on application, the endoscopes are classified into gastroscope, bronchoscope, orthoscope, etc.

Use of optical fibers in telecommunication:

Fiber-optic communication has revolutionized the telecommunications industry. Optical fiber is used by telecommunications companies to transmit telephone signals, internet data, and cable television signals. Due to lower attenuation and interference, optical fiber has advantages over the copper wire in long-distance, high-bandwidth applications. There are several compelling reasons that lead to the widespread adoption of fiber optic cabling for telecommunication applications:

i) Much lower levels of signal attenuation.

ii) Fiber optic cabling provides a much higher bandwidth allowing more data to be delivered.

iii) Fiber optic cables are much lighter than the coaxial cables that might otherwise be used.

iv) Fiber optics do not suffer from stray interference pickup that occurs with coaxial cabling.

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