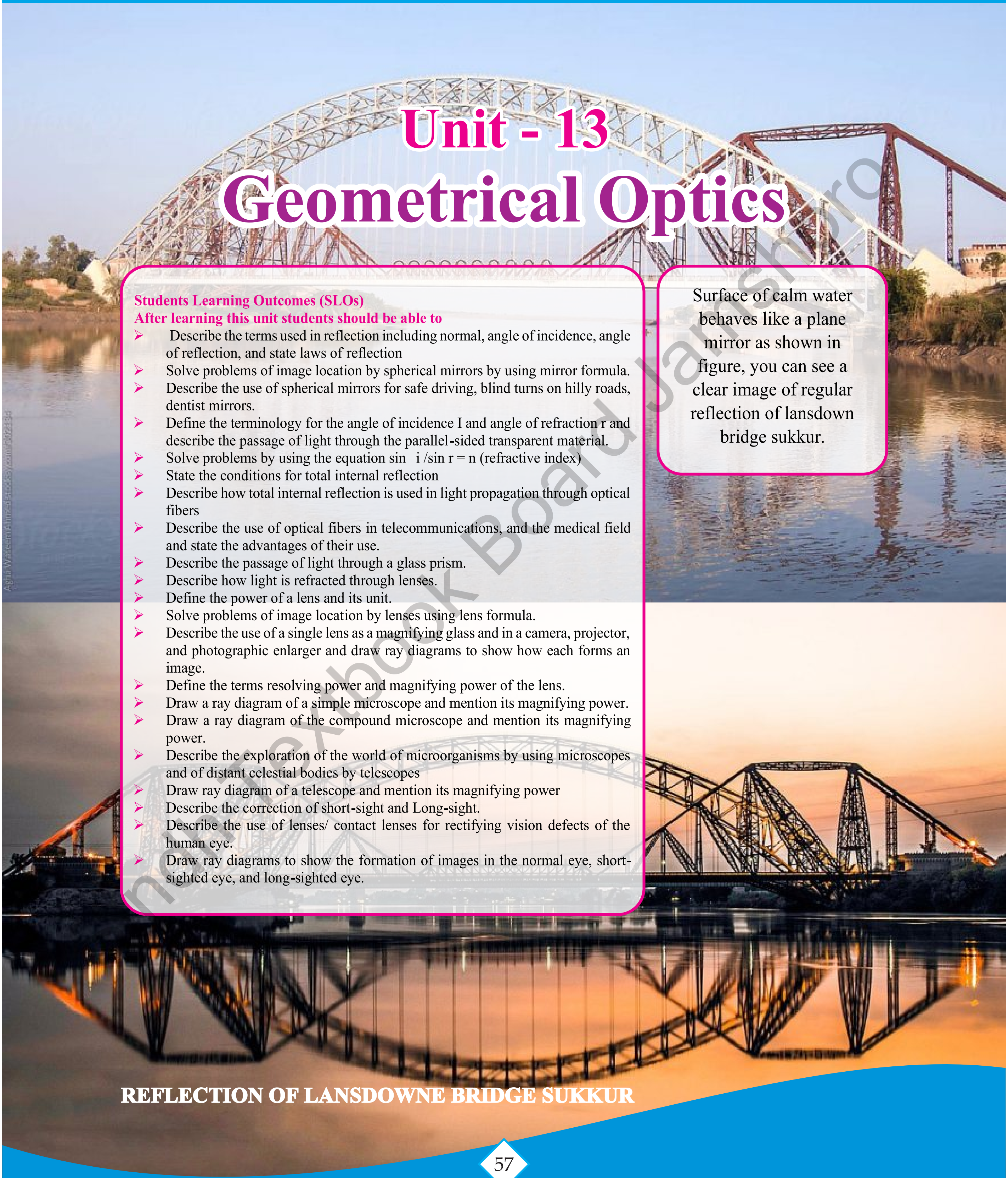
# Unit - 13

# Geometrical Optics



**Students Learning Outcomes (SLOs)**

**After learning this unit students should be able to**

- Describe the terms used in reflection including normal, angle of incidence, angle of reflection, and state laws of reflection
- Solve problems of image location by spherical mirrors by using mirror formula.
- Describe the use of spherical mirrors for safe driving, blind turns on hilly roads, dentist mirrors.
- Define the terminology for the angle of incidence I and angle of refraction r and describe the passage of light through the parallel-sided transparent material.
- Solve problems by using the equation $\sin i / \sin r = n$ (refractive index)
- State the conditions for total internal reflection
- Describe how total internal reflection is used in light propagation through optical fibers
- Describe the use of optical fibers in telecommunications, and the medical field and state the advantages of their use.
- Describe the passage of light through a glass prism.
- Describe how light is refracted through lenses.
- Define the power of a lens and its unit.
- Solve problems of image location by lenses using lens formula.
- Describe the use of a single lens as a magnifying glass and in a camera, projector, and photographic enlarger and draw ray diagrams to show how each forms an image.
- Define the terms resolving power and magnifying power of the lens.
- Draw a ray diagram of a simple microscope and mention its magnifying power.
- Draw a ray diagram of the compound microscope and mention its magnifying power.
- Describe the exploration of the world of microorganisms by using microscopes and of distant celestial bodies by telescopes
- Draw ray diagram of a telescope and mention its magnifying power
- Describe the correction of short-sight and Long-sight.
- Describe the use of lenses/ contact lenses for rectifying vision defects of the human eye.
- Draw ray diagrams to show the formation of images in the normal eye, short-sighted eye, and long-sighted eye.

Surface of calm water behaves like a plane mirror as shown in figure, you can see a clear image of regular reflection of lansdown bridge sukkur.

REFLECTION OF LANSDOWNE BRIDGE SUKKUR

**Do You Know!**

Ibn al- Haytham (965-1039) realized that he was seeing images of objects outside that were lit by the sun. He concluded that light rays travel in straight path and that accomplished when these rays pass into our eyes

**Do You Know!**

Ibn al- Haytham's most important work is kitab al Manazir (a book about optics). His long work in optics made possible the world of media and communications we live in today.

What makes things visible? During the day, the sunlight make able us to see objects. An object reflects light that falls on it. Our eyes detect reflected light, enabling us to see things. We can also see through a transparent medium as light is transmitted. Several beautiful phenomena are associated with light, such as the twinkling of stars, the beautiful colors of a rainbow, and the bending of light by a medium. The study of the properties of light helps us to explore them.

We shall study the phenomena using the rectilinear propagation of light and their application in real-life situations in this unit.

## 13.1. Reflection of light

To begin with, light is reflected whenever a beam of light strikes a smooth, polished surface and then returns. In other words, when a ray of light hits a surface, the surface reflects the light. In addition, the ray of light that strikes the surface is referred to as an Incident ray, but the ray of light that is reflected back is referred to as a Reflected ray. The term "normal" refers to the line that is created when a perpendicular is made between two rays on a reflecting surface.

Incident Ray = It is the ray that falls on the surface

Reflected Ray = The ray which is reflected from the surface

Normal = Perpendicular on the polished surface

P = Point of reflection

i = Angle of Incidence

r = Angle of Reflection

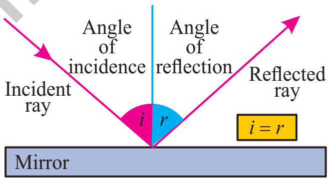



**Fig: 13.1**
**Experimental setup**

### Laws of Reflection

Having a basic comprehension of the concept of reflection, you must also be aware of its two essential laws. It is possible to determine the reflection of an incident ray on a variety of surfaces, such as a plane mirror, water, and metal surfaces, by applying these principles. Here are the laws of reflection:

- The angle of incidence is equal to the angle of reflection (i.e. $\angle i = \angle r$) is also known as the **first law of reflection.**
- The incident ray, reflected ray and the normal to the reflecting surface all lie in the same plane is also known as the **second law of reflection**

These laws of reflection apply to all types of reflections, including reflections from spherical surfaces. These are also applicable to regular and irregular types of reflections.

**SELF ASSESSMENT QUESTIONS:**

**Q1:** Why narrow beam of white light is used in the experiment?

**Q2:** List everyday examples of reflection of light.

Q3: Why the angle of incidence is always equal to the angle of refection?

## 13.2 Image location by spherical mirror equation

### Image Formation by Spherical Mirrors

Do you know how the images are formed by spherical mirrors? How can we locate the image formed by a concave mirror? Are the images real or virtual? Are they diminished, have the same size, or enlarged?

### Image formation by Concave Mirror

The ray diagrams illustrate the formation of images by a concave mirror for various positions of the object; Figure 13.2.

You can see in the ray diagrams that the nature, position, and size of the image formed depends on the position of the object at points P, F, and C. The images formed are real for some positions of an object and virtual images for a particular other position. An image formed is either reduced, has the same size, or is magnified. It depends on the position of the object. A summary of these observations is given for your reference in Table 13.1.

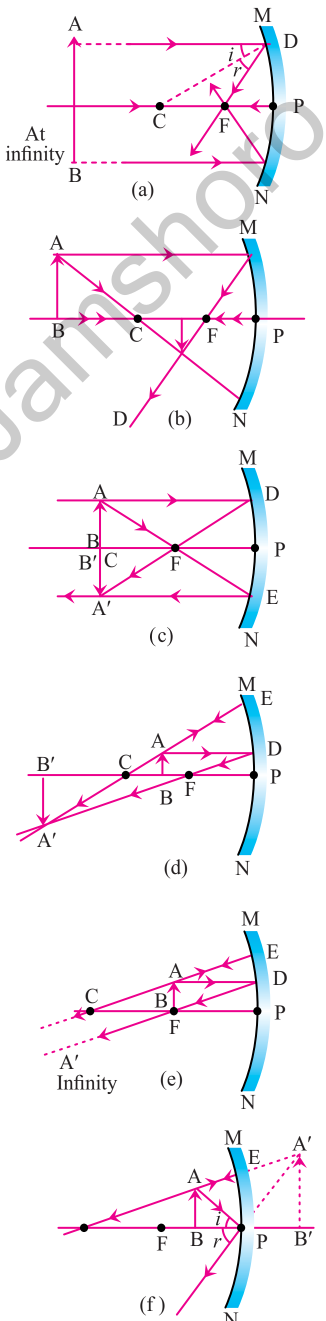



**Fig: 13.2.**
**Ray diagrams for the image formation by a concave mirror**

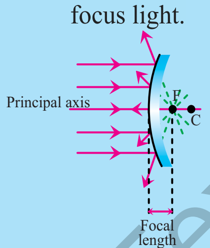
**Do You Know!**

If two plane mirrors are placed parallel, then infinite number of images are formed

**Do You Know!**

A **spherical mirror** is a mirror with a curved reflecting surface. Most curved mirrors have surfaces that are shaped like parts of a sphere.

A **convex mirror** is a spherical mirror in which the reflective surface bulges towards the light source. Convex mirrors reflect light outwards and are therefore not used to focus light.




A **concave mirror** has a reflecting surface that is recessed inward away from the light source. Concave mirrors reflect light inward to one focal point. They are used to focus light.

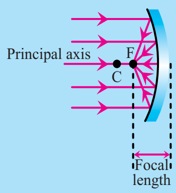



**Table 13.1.**
**Summary of images formed by ray diagrams for different positions of the object**

| Position of the object | Position of the image | Size of the image | Nature of the image |
|---|---|---|---|
| At infinity | At the focus F | Highly diminished point-sized | Real and inverted |
| Beyond C | Between F and C | Diminished | Real and inverted |
| At C | At C | Same size | Real and inverted |
| Between C and F | Beyond C | Enlarged | Real and inverted |
| At F | At infinity | Highly enlarged | Real and inverted |
| Between P and F | Behind the mirror | Enlarged | Virtual and erect |

**C**, the center of curvature, **F**, the focal point, **P**, optical center, ***p***, object distance, ***f***, focal length, ***q***, image distance

## Spherical Mirror Equation

Let us think of an object placed *p* cm in front of a spherical mirror of focal length *f* cm. The image is formed *q* cm from the mirror, then *p*, *f*, and *q* are related by the equation,

$$\frac{1}{f} = \frac{1}{p} + \frac{1}{q}$$

This is known as the mirror equation. This equation applies to both concave and convex mirrors as shown in figure 13.3.

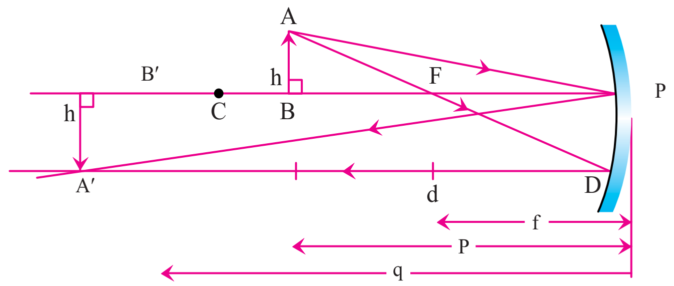



**Fig: 13.3. Ray diagram of image formed by concave mirror**

When applying the mirror equation, the following points must be observed:

- That all distances *p*, *f*, and *q* are measured from the optical center P as an origin.

- All real distances are taken positively, while all virtual distances are taken negatively.
- A concave mirror has a positive focal length, while a convex mirror has a negative focal length.

**Worked Example 1**

A concave mirror forms a real image at 25.0 cm from the mirror surface along the principal axis. If the corresponding object is at a 10.0 cm distance, what is the focal length of the mirror?

**Solution**

**Step 1:** Write down the known quantities and quantities to be found.

$q = 25.0$ cm

$p = 10.0$ cm

$f = ?$

**Step 2:** Write down the formula and rearrange if necessary.

$$\frac{1}{f} = \frac{1}{p} + \frac{1}{q}$$

**Step 3:** Put the values and calculate

$$\frac{1}{f} = \frac{1}{10} + \frac{1}{25}$$

$$\frac{1}{f} = \frac{5+2}{50}$$

$$\frac{1}{f} = \frac{7}{50}$$

$$f = \frac{50}{7}$$

$$f = 7.14 \text{ cm}$$

**Result:** The focal length of the mirror is 7.14 cm.

**Weblinks**

Encourage students to visit below link for image formation by concave mirror

https://www.youtube.com/watch?v=gPYlVBB8gyY&ab_channel=Learnnhvfun

## Use of spherical mirrors

Spherical mirrors have various applications in our everyday life such as sunglasses, rear-view mirrors, shaving mirrors. Let us discuss some of the applications given below:

### Use of convex mirrors

Convex mirrors are often used as rear-view mirrors or wing mirrors in vehicles, also called driver mirrors; Fig. 13.4. These mirrors are fitted on the sides of the vehicle so the driver can see traffic behind them for safe driving. Convex

Fig: 13.4.
A wider rear view image

Fig: 13.5.
The convex mirror used to see the vehicles on blind turns

mirrors are curved outwards that reflect the light outwards, allowing the drivers view of a much larger area of the field behind them. These mirrors always give an upright, diminished, and complete image of the vehicles.

Convex mirrors are also used for Traffic Safety purposes to see the blind turns on the roads; Fig. 13.5. Convex Mirrors are easy to install – they are mounted simply and easily with the brackets. Wide-angle vision allows drivers to see around blind corners and into hidden corners. These mirrors need to be placed at the blind corners and locations to avoid accidents and collisions of vehicles.

Concave mirrors also used by dentists, can see the tooth clearly and diagnose any infection or germ attack.

Fig: 13.6.
A dentist mirror

**SELF ASSESSMENT QUESTIONS**

**Q1:** Are the images formed by spherical mirrors always real?

**Q2:** Convex mirrors are used as a rear-view mirror in vehicles that produce diminished images. Why are these mirrors preferred over plane mirrors?

## 13.3 Refraction of light

You know that light seems to travel along a straight pathway in a transparent medium. What happens when light enters from one transparent medium to another? Does it always move along a straight-line path? Let us recall some of our daily experiences.

When a thick glass slab is placed over printed matter, the letters appear raised when viewed through the glass slab? Similarly, the coin placed at the bottom of a water tank appears to be raised; Fig. 13.7.

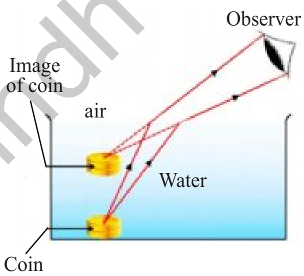
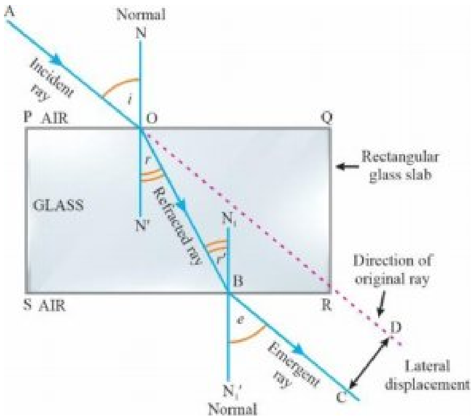



Fig: 13.7.
The coin appears to be raised in the water

Why does it happen? A pencil partly immersed in water in a beaker appears to be bent at the interface of air and water. A fish kept in water in a glass aquarium appears larger than its actual size. What is the physics behind such daily observations? We call these;

The bending effect of light as it passes from one transparent medium to another is **refraction of light**.

Consider the rectangular glass slab depicted in the following illustration.



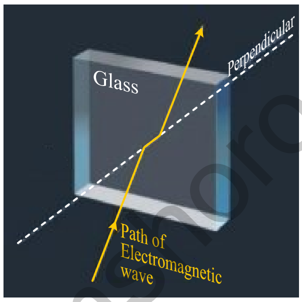




**Fig: 13.8**
**Refraction of light through a glass block**

A ray AO strikes the face PQ at an angle of incidence $\angle i$. As it enters the slab of glass, it takes a little bend to the right, travelling along OB at a refraction angle of $\angle r$. The refracted ray OB hits the face SR at an angle of incidence $\angle r'$. The emerging ray BC exhibits a refraction angle of $\angle e$, which causes it to deviate from the normal.
Therefore, the emerging ray BC is parallel to the incident ray AO; however, it has been laterally displaced with regard to the incident ray. When light emerges from a refracting material that has parallel sides, there is a shift in the pathway that the light takes.

**Table:13.2**
**The angle between angle of incidence and angle of refraction and ratio of sin $\angle I$ to sin $\angle r$**

| The angle of incidence $\angle i$ | The angle of refraction $\angle r$ | Sin$\angle i$ /sin $\angle r$ |
|---|---|---|
| 20 | 13 | 1.520 |
| 30 | 19 | 1.536 |
| 40 | 25 | 1.521 |
| 50 | 31 | 1.487 |
| 60 | 35 | 1.510 |
| 70 | 39 | 1.493 |

**Do You Know!**

Willebrord snell a mathematics professor, formulated the law of refraction in 1621. However, he did not publish his findings. It was only when Hugens, a dutch physicist, published snell's findings that it was called snell's law.

**Willebrord Snell (1580-1626)**

**Christiaan Huygens (1629-1695)**

## Conclusions

1. A ray of light perpendicular to the glass slab or along the normal is not refracted. However, its speed changes according to the medium.
2. A ray of light incident at an angle to the normal bends towards the normal when it enters into an optically denser medium (i.e., air to glass). Similarly, a ray of light bends away from the normal when it enters an optically less dense medium (i.e., glass to air).
3. The ratio of the sine angle of incidence to the sine angle of refraction gives us a constant called the refractive index of the medium.

From this activity;

The two laws of refraction are as follows:

1. The incident ray, the normal, and the refracted ray all lie in the same plane.
2. The refractive index can be defined as the ratio of the sine of the angle of incidence to the sine of the angle refraction when the ray of light enters from one medium to another.

Fig: 13.9. Image of fish seen due to total internal reflection

For two particular refracting mediums, the ratio of the sine angle of incidence to the sine of the angle refraction is constant

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

$$\frac{\sin\angle i}{\sin\angle r} = \text{refractive index}$$

$$\frac{\sin\angle i}{\sin\angle r} = \text{n}$$

$$\text{or} \quad \text{n} = \frac{\sin\angle i}{\sin\angle r}$$

This is also known as **Snell's law**.

Refraction of light is caused by a change in speed, so the wavelength of the ray and its direction are also changed at the interface of two different mediums. However, the frequency of light does not change as the color used remains unchanged. Thus,

$$\text{Refrective Index} = \frac{\text{speed of light in vacuum or air}}{\text{speed of light in the medium}}$$

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

**Worked Example 4**

The refractive index of the diamond is 2.42. What is the speed of light in a diamond?

**Solution:**

**Step 1:** Write down the known quantities and quantities to be found

n= 2.42

$c = 3 \times 10^8$ m/s

v=?

**Step 2:** Write down the formula and rearrange if necessary.

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

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

**Step 3:** Put the values and calculate

$v = 3 \times 10^8 / 2.42$

$= 1.24 \times 10^8$ m/s.

Hence, the speed of light in a diamond is $1.24 \times 10^8$ m/s.

**Table:13.3**
**Refractive index, speed of light and critical angle in some transparent material**

| Medium | Refractive Index | Speed of light ($\times 10^8$ ms$^{-1}$) | Critical angle |
|---|---|---|---|
| Diamond | 2.417 | 1.25 | $24.4^0$ |
| Glass (flint) | 1.66 | 1.81 | $37.0^0$ |
| Glass (Crown) | 1.517 | 2.01 | $41.2^0$ |
| Perspex | 1.495 | 2.00 | $42.0^0$ |
| Water | 1.333 | 2.25 | $48.8^0$ |
| Ice | 1.309 | 2.30 | $49.8^0$ |
| Air | 1.0003 | 2.99 | $88.6^0$ |
| Vacuum | 1.000 | 3.00 | $90.0^0$ |

**Do You Know!**

The greater the value of the refractive index of a medium, the greater the change in speed as well the greater bending of light when it passes from air into that medium.

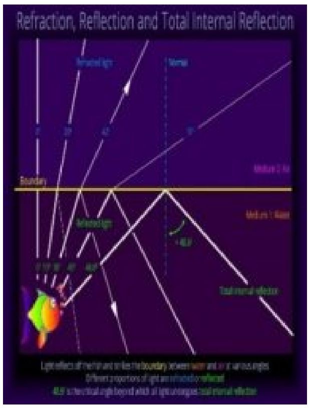
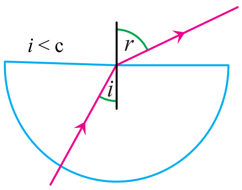
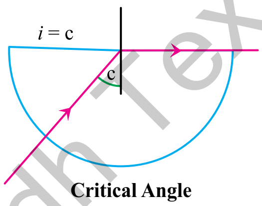


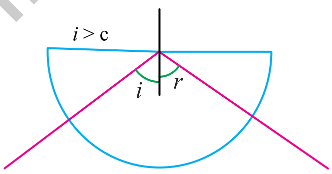

Fig: 13.10
What a swimmer can see inside the water?




Refraction
Fig: 13.11 (a)




Critical Angle
Fig: 13.11 (b)




Total internal reflection
Fig: 13.11 (c)

**SELF-ASSESSMENT QUESTIONS**

**Q1:** When a ray of light passes through a medium to another of different optical densities perpendicularly, it does not change its direction. Is it also refraction?

**Q2:** List the physical quantities that change when refraction occurs.

**Q3:** Which physical quantities do not change during refraction?

## 13.4 Total internal reflection

Figure 13.10 given shows an underwater reflection of a fish. This phenomenon is due to the **total internal reflection** of light. This phenomenon can occur when light passes from an optically denser medium to a rare medium. To understand this unique behavior of light, we have first to understand the **critical angle.**

When a ray of light passing through in a dense medium enters into a rare medium, it bends away from the normal; Fig.13.11 (a). If the angle of incidence '∠i' increases, the angle of refraction '∠r' also increases. For a particular value of the angle of incidence, the angle of refraction becomes $90^0$; Fig.13.11 (b).

The angle of incidence that causes the refracted ray in the rarer medium to bend through $90^0$ is called the critical angle

If the angle of incidence in the glass is increased beyond the critical angle, no light ray is refracted through the water to air interface. The entire light is reflected into the same denser medium; Fig.13.11 (c).

If a ray passes from a dense medium to a rare medium and its angle of incidence is greater than the critical angle, the incident ray is reflected into the dense medium. This phenomenon is called total internal reflection.

**Worked Example 5**

Calculate the value of critical angle for water refracted angle at $90^0$. The refractive index of water is 1.33.

**Solution:**

**Step 1:** Write down the known quantities and quantities to be found

$\angle r = 90^0$

$n = 1.33$

$\angle c = ?$

**Step 2:** Write down the formula and rearrange if necessary.

$n = \sin\angle i / \sin\angle r$

When light enters in rare from denser, Snell's law becomes

$n = \sin\angle r / \sin\angle i$

or $n = \sin\angle 90 / \sin\angle c$

$n = 1 / \sin\angle c$

$\sin\angle c = 1/n$

**Step 3:** Put the values and calculate

$\sin\angle c = 1/1.33$

$\sin\angle c = 0.752$

$\angle c = \sin^{-1}(0.752)$

or $\angle c = 48.8^0$

**Result:** Therefore, the critical angle of water calculated is $48.8^0$.

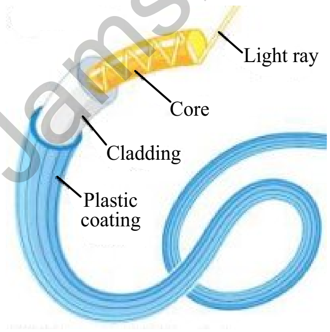



Fig: 13.12. Structure of the optical fiber

## Telecommunication through optical fibers

Optical fibers consist of hair-size threads made of flexible plastic or glass fibers that transmit light over long distances. An optical fiber comprises two parts, an inner part 'core' with a high refractive index, coated with another material 'cladding'; Fig. 13.12. When a light ray enters the fiber and hits the cladding, it is reflected internally in the core as the incidence angle is larger than the critical angle, even if the fiber is bent. Light rays entering the fiber are continuously reflected at the interface between two refractive materials and cover long distances without energy loss; Fig. 13.13.

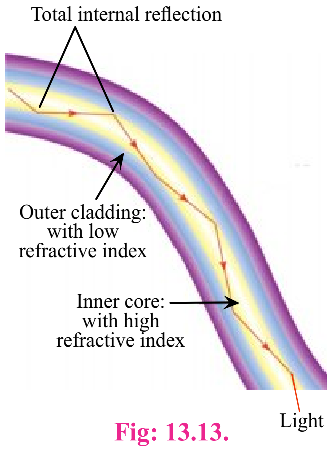



Fig: 13.13. Transmission of information through optical fiber

**SELF ASSESSMENT QUESTIONS**

**Q1:** State the conditions necessary for total internal reflection to occur.

**Q2:** Why a swimmer underwater cannot see the objects above the water surface?

**Q3:** What is meant by critical angle?

## 13.5 Refraction through a prism

Let us perform an activity to illustrate the passage of light through a prism.

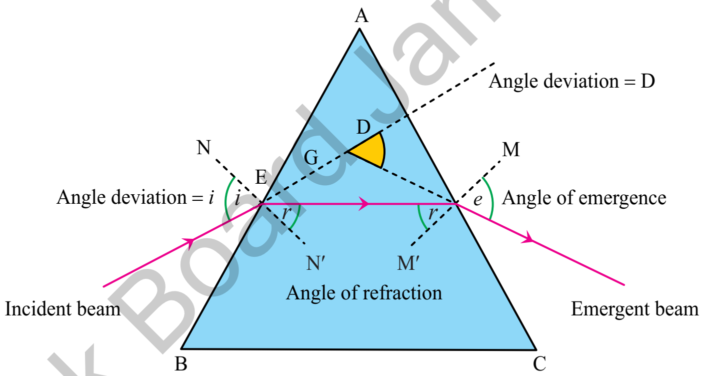



**Fig. 13.14.**
**Tracing the passage of light rays through a glass prism**

### Activity

1. Fix a paper sheet on a drawing board using drawing pins.
2. Place the triangular prism resting on its base. Using a pencil, outline the prism.
3. Draw 'NEN' normal to one facet of the prism AB. Suppose an angle between $30^0$ and $60^0$.
4. Fix two pins slightly apart on the line PE and label them as P and Q.
5. Look for the images of the pins at P and Q through the other facet of the prism AC.
6. Fix two pins at R and S to appear in a straight line as those of the P and Q when viewed from the AC facet of the prism.
7. Remove the pins and also the prism.
8. At point F, produce the points R and S meet by extending them.

**Do You Know!**

The lens is a piece of transparent material such as glass or plastic. It focuses or disperses the light rays using refraction in such a way as to form an image of the object. The curvature of the optical surfaces classifies the lenses. The convex lens converges the rays of light parallel to the principal axis on the focal point after passing through it. The concave lens diverges the rays of light if they approach parallel to the principal axis. After refraction light rays appear to originate from the focal point.

9. At point F, produce the points R and S meet by extending them.
10. PQE is the incident ray that is extended till it meets facet AC. SRF is the emergent ray extended backward to meet at point G.
11. Now measure the angle of incidence ∠i, angle of refraction ∠r, and the angle of emergence ∠e and ∠D.
12. Repeat the experiment for additional angles.

## Observations

1. At surface AB, the ray of light enters and bends towards the normal on refraction.
2. At surface AC, the ray of light bends away from the normal as it travels from one medium to the other medium.

## Conclusions

The incident ray bends towards the normal when enters the prism and bends away from the normal while leaving the prism.

**SELF ASSESSMENT QUESTIONS**

Q1; What is apperture?

Q2; What is difference between optical centre and pole?

## 13.6 Image location by lens equation

### How a Lens Refracts Light

Consider a monochromatic ray of light traveling parallel to the principal axis of the double convex lens. When a ray enters a lens, Lenses refract the light at each interface, i.e. air to glass and glass to air boundaries. The net effect of the refraction, the light ray, has changed its directions. Because of its special geometric shape, it converges the ray to the focal point; Fig. 13.15.

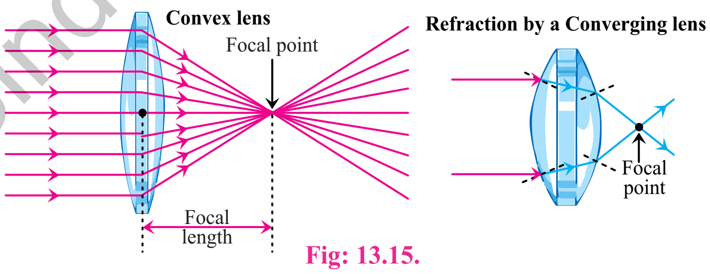



**Fig: 13.15.**
**Converging of the ray of monochromatic light parallel to the principal axis.**

**Do You Know!**

Concave lens: Incident rays traveling parallel to the principal axis refract through the lens and diverge in such a way will never intersect. A concave lens has a negative focal length and always produces diminished, vertically upright, and virtual images.

**Do You Know!**

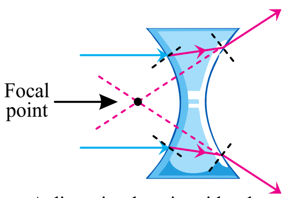
Monochromatic rays are those rays which have a single wavelength or of single tone colour and have the same frequency. Examples of monochromatic rays are light and sodium lamps etc.

**Do You Know!**

A convex lens behave like a concave lens when an object placed in the focal length

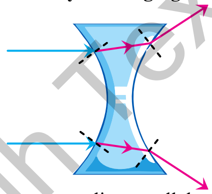
**Do You Know!**

All the rays originated from the point of an object when they pass through the convex lens to form an image in such a way that they always tend to converge on a single point.

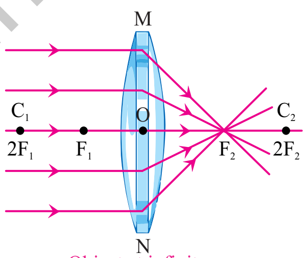



A diverging lens is said to have a negative focal length since rays which enter the lens traveling parallel to the principal axis diverge.

**Refraction by a diverging lens**



Incident rays traveling parallel to the principal axis will refract through the lens and diverge, never intersecting.




Object at infinity

Similarly, when the rays of light that are not parallel to the principal axis travel through the focal point approaching the lens, they will emerge out of the lens, traveling parallel to the principal axis; Fig. 13.16.

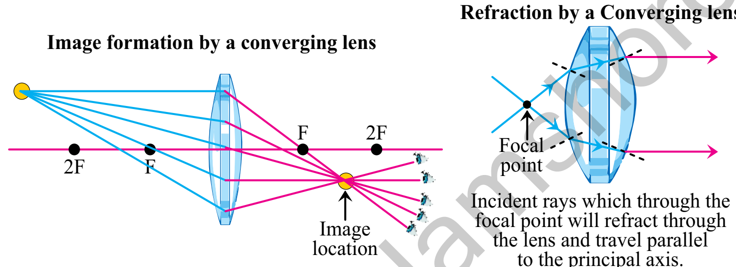



Fig: 13.16.
Converging or rays of light pass through the focal point

## The power of a lens

Lenses are used to converge or diverge the incident light rays. The ability of a lens to refract the rays of light depends on its focal length. For example, a convex lens with a shorter focal length bends the light rays through a higher convergence by focusing them closer to the optical center. Similarly, a very short focal length of the concave lens will cause the light rays to diverge at higher angles away from the focal point. The degree of convergence or divergence of light rays attained by a lens expresses its refractive power.

The power of a lens is defined as the reciprocal of its focal length, measured in meters inverse ($m^{-1}$).

The power is represented by the letter *P*. The power *P* of a lens of focal length *f* is given by

$$\text{Power} = \frac{1}{\text{focal length}}$$

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

The SI unit of power of a lens is 'diopter.' It is denoted by the letter D. The power of a lens whose focal length is $1D = 1m^{-1}$.

You always remember that the power of a convex lens is positive, and that of a concave lens is negative.

## Image Formation by lenses

You have studied the formation of images by spherical mirrors. How about the images formed by lenses?

The ray diagrams illustrate the formation of images by a convex lens for various object positions; Fig. 13.17.

You may observe in the ray diagrams that the nature, position, and size of the image formed by a convex lens depend on the position of the object about points 2F, F, and C. The image formed is real for some positions of the object and a virtual image for a certain other position. The image is either smaller, has the same size, or is magnified, depending on the position of the object. An overview of these observations is given for your reference in Table 13.4.

**Table 13.4.**
**An overview of images formed by ray diagrams for different positions of the object**

| Position of the object | Position of the image | Size of the image | Nature of the image |
|---|---|---|---|
| At infinity | At $F_2$ | Extremely small | Real and inverted |
| Behind $2F_1$ | Between $F_2$ and $2F_2$ | Small | Real and inverted |
| At $2F_1$ | At $2F_2$ | Same as that of the object | Real and inverted |
| Between $2F_1$ and $F_1$ | Beyond $2F_2$ | Enlarged | Real and inverted |
| At $F_1$ | At infinity | Highly enlarged | Real and inverted |
| Between $F_1$ and O | Same side of the lens | Enlarged | Virtual and erect |

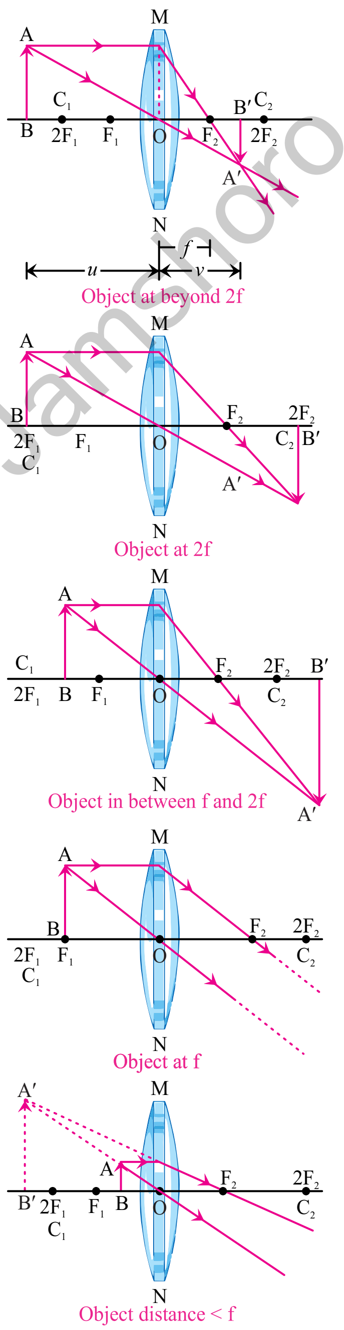



**Fig: 13.17.**
**Ray diagrams for the image formation by a convex lens**

## Lens Equation

Suppose an object is placed $p$ cm in front of a lens of focal length $f$ cm. Such that the image is formed $q$ cm from the lens, then $p$, $f$, and $q$ are related by the equation,

$$\frac{1}{f}=\frac{1}{p}+\frac{1}{q}$$

This equation is considered the lens equation. This equation is applicable for both concave and convex lenses.

When applying the lens equation, it is necessary to note the following points:

- All distances $p$, $f$, and $q$ are measured from the optical center P.
- All real distances are taken positively, while all virtual distances are taken negatively.

- A convex lens has a positive focal length, while a concave lens has a negative focal length.

**Worked Example 6**

A boy is standing 2.500 m in front of a camera. The camera uses a convex lens whose focal length is 0.050 m. Find the image distance (the distance between the lens and the film) and determine whether the image is real or virtual. Also, find the power of the lens.

**Solution:**

**Step 1:** Write down the known quantities and quantities to be found.

p = 2.500 m

f = 0.050 m.

i. q=?

ii. P=?

**Step 2:** Write down the formula and rearrange if necessary.

i. $\frac{1}{f} = \frac{1}{p} + \frac{1}{q}$

$\frac{1}{q} = \frac{1}{f} - \frac{1}{p}$

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

**Step 3:** Put the values and calculate

i. $\frac{1}{q} = \frac{1}{0.05} - \frac{1}{2.5}$

$\frac{1}{q} = \frac{50-1}{2.5} = \frac{49}{2.5}$

$q = \frac{2.5}{49} = 0.051$ m

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

$P = \frac{1}{0.05}$

P= 20 Diopter

**Result:** Here the image distance is positive, so the image formed is real and inverted on the film at the focal point of the lens. The power of the lens is 20 D.

## Uses of Convex lenses

Have you ever seen watchmakers using a small magnifying glass to see tiny parts? Might you have touched the surface of a magnifying glass? Is it a plane surface or curved? How

**Do You Know!**

A pinhole camera is a simple camera without a lens but with a tiny aperture. The pinhole camera was invented by Ibn al-Haytham

**Ibn al- Haytham**
**(965-1039)**

**Do You Know!**

A magnifying glass is also behaves like a simple microscope does it work? Now we discuss applications of lenses in some optical devices.

### The Magnifying Glass

A magnifying glass is a thin converging lens that can be used to make objects look bigger.

Figure 13.18 (a) below shows how the word (Magnifying Glass) is placed such that object distance is less than the focal length, i.e., $p<f$.

If the object is placed closer to a convex lens than the focal length, the rays never tend to meet at a point. Instead, they appear to come from the position behind the lens. The image produced is upright and magnified. It is a virtual image because no rays converge to form it, so it cannot be obtained on a screen; Fig. 13.18 (b). This type of use, a convex lens, is often called a simple microscope.


**Fig: 13.18 (a)**
**A magnifying glass enlarges the letters**

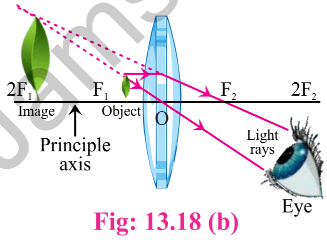



**Fig: 13.18 (b)**
**The ray diagram of a magnifying glass**

### The camera

A camera uses a convex lens to reproduce a small, inverted, and small image on photographic film that is placed on the back inside the diaphragm.

While the photograph is taken, the lens is moved in or out to focus the adjustments from the film. The shutter opens and shuts quickly to allow a small amount of light through the aperture into the camera. The photo-sensitive film is kept in darkness in the diaphragm until the shutter opens.

A distant object requires the lens to film distance equal to the focal length of the lens. A nearer object requires the lens to film distance slightly more than the focal length of the lens; Fig. 13.19.

Many cameras have automated focus setting adjustments. More inexpensive cameras usually have fixed adjustments

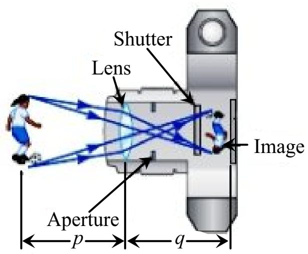



**Fig: 13.19.**
**The cross-sectional view of a simple camera**

### The Projector

A projector uses a convex lens as a projection lens and pair of condenser lenses to produce a large, inverted, and real image on a screen.

In the projector, an object or a film is positioned between f and 2f from the projection lens. A concave mirror is used to reflect the light from the lamp onto a pair of condenser lenses so that the light from the lamp is concentrated on the film or

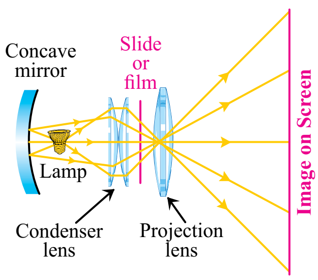



**Fig: 13.20. The schematic diagram of the slide projector**

slide, illuminating it evenly and directing it through the film (object) to the projection lens; Fig. 13.20. The image formed on the screen is inverted, real, and magnified.

As the image formed is inverted, must turn the film must upside down to maintain an upright picture on the screen? Move the lens from the screen to obtain a large image. The lens is moved forward or backward to get a sharp picture on the screen.

### The photographic enlarger

*The photographic enlarger* uses a convex lens to produce an inverted, real, and magnified image of the film on photograph paper.

An enlarger is a specialized transparency projector used to produce photographic prints from glass negatives or transparencies or microfilm. The photographic enlarger works on the same principle as a projector. In the case of the enlarger, object is placed at a distance greater than F but less than 2F. In this way, we get an inverted, real, and enlarged image, as shown in Figure 13.21.

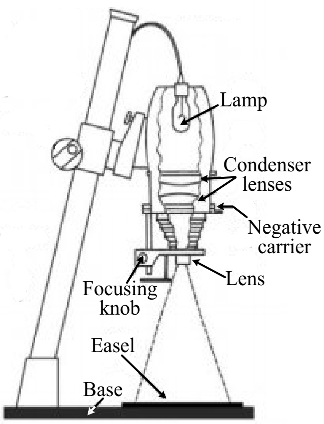



**Fig: 13.21. The schematic diagram of a photographic enlarger camera**

### SELF-ASSESSMENT QUESTIONS:

**Q1:** What is difference between real and virtual image?

**Q2:** The power of the lens is reciprocal of its focal length. What does it mean?

**Q3:** Why the film in the projector needs to be placed upside down?

**Q4:** The concave lens is also considered to be the diverging lens. Explain why?

**Q5:** A convex lens behaves like a concave lens in which condition?

**Q6:** Find the image distance for an object placed 20cm in front of a convex lens with focal length 17cm.

## 13.7 Resolving power and magnifying power

### Resolving power:

The resolving power is usually taken as the smallest distance at which two points can be seen as distinctly when viewed through the optical instrument. The greater the resolving power, the smaller the minimum distance between two points or lines that can still be distinguished. For example, we use a high resolving power microscope to see tiny organisms individually and a telescope to view distant stars separately in the sky.

It is defined as a measure of the ability of an optical instrument to form separable images of close objects or to separate close wavelengths of radiation.

**Magnifying Power**

Magnifying power is usually taken as the apparent increase in angular size of an object when viewed through a microscope, telescope, or binoculars, compared with the direct view of the same object with an unaided eye. The greater the magnifying power, the enlarged image of the object that can be visualized. For example, we use the microscope of magnification 100, and then we can see the image of that object 100 times bigger. A magnifying power or magnification of, say, 100 is often referred to as a power of 100 and written as ×100. It is a dimensionless number.

For an optical instrument;

*Magnifying power* is defined as the ratio of the image size to the object size.

Magnification = Size of image / Size of object

M = size of image / size of object

$M = h_i / h_o$

**SELF ASSESSMENT QUESTIONS:**

**Q1:** Define the term resolving power.

**Q2:** Define the term magnifying power?

## 13.8 Microscopy

Microscopy is the field that uses microscopes to view objects that cannot be seen with the unaided eye.

In optical instruments, the phenomenon of angular magnification is mainly used to see the magnified images of the objects. Now we discuss applications of angular magnification in some optical devices.

**Simple Microscope**

A simple microscope uses a convex lens to produce magnified images of small objects.

The object is placed nearer to the lens than the focal length to produce an upright, virtual, and magnified image. It is also called magnifying glass.

**Do You Know!**

The apparent size of an object perceived by the eye depends on the angle the object subtends from the eye. An image formed at a small distance is larger than an image formed by the same object positioned at a farther distance. Thus, objects that subtend large angles from the eye appear larger because they form larger images on the retina. For example, the tree appears smaller if you move away from it.

**Do You Know!**

The near point of the eye is the minimum distance to which one can see the objects distinctly without strain. It varies from person to person with age. For a normal human eye, it is 25 cm. The far point of the eye is the maximum distance to which one can see the objects. The far point of the normal human eye is infinity.

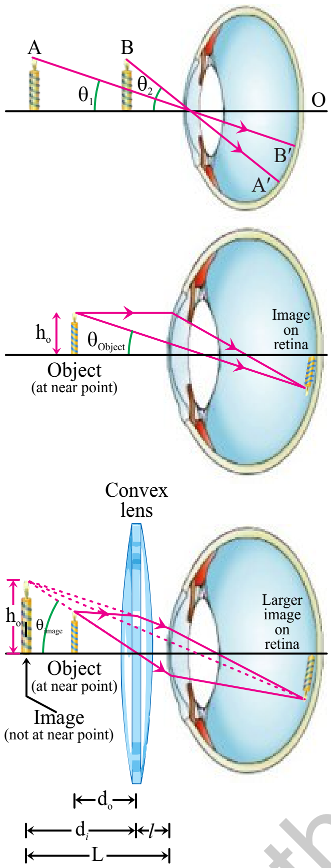



**Fig: 13.22(a) Image produced on the retina without convex lens (b) Image produced with a convex lens**

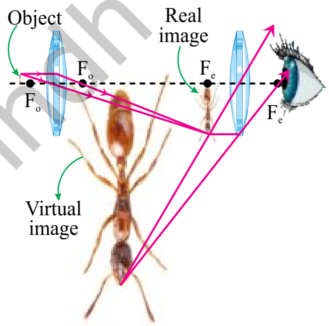



**Fig: 13.23. Ray diagram of a compound microscope**

## Magnification by simple microscope

Let $\theta_0$ be the angle subtended at the eye by a tiny object when placed at the near point of the eye. If the object is brought closer to the eye, the angle will increase and become $\theta_i$, but the eye can not see it. To see the object, we place a convex lens between the object and the eye within the focal length so that the lens makes a magnified virtual image of the object at the near point of the eye; Fig. 13.22. The magnifying power, in such a case, will be:

$$M = \frac{\theta_1}{\theta_2}$$

It can be shown that the relation gives the magnifying power

$$M = \frac{\theta_1}{\theta_2} = 1 + \frac{d}{f} = 1 + \frac{25(\text{cm})}{f}$$

Where d is the near point of accommodation, for a normal human eye, it is 25 cm. This relation indicates that a lens of a shorter focal length will have the greater magnifying power.

## Compound microscope

A **compound microscope** is an upright microscope that uses two sets of lenses (a compound lens system) to obtain higher magnification than a stereo microscope.

The objective lens has a shorter focal length, $f_o$, than the focal length of eyepiece, $f_e$. It is used to study the structure of small objects.

## Magnification by compound microscope

When rays of light from a point on a nearby object pass through an objective lens. The objective forms a small image $I_1$ on the inside focal point of the eyepiece. This image behaves as an object for the eyepiece, and the larger image $I_2$ is formed at the near point of the normal human eye; Fig. 13.23. This final magnified virtual image makes an angle $\theta i$ at the eyepiece.

The magnification of a compound microscope is given by

$$M = \frac{L}{f_o} = \left(1 + \frac{25(\text{cm})}{f}\right)$$

Where L is the length equal to the distance between the objective and eyepiece, $f_o$ and $f_e$ are the focal lengths of the objective and eyepiece, respectively.

## Uses of Microscopes

Scientists believe that a human with a normal eye and regular vision can see the tiniest objects as small as about 0.1 millimeters, like an ant or lice. To explore an even smaller world of microorganisms, we use microscopes with high magnifying power and resolution power. The invention of the microscope allowed scientists to see cells, bacteria, and other smallest structures that cannot be seen with the unaided eye. Microscopes gave them a direct view into the unseen world of extremely tiny objects.

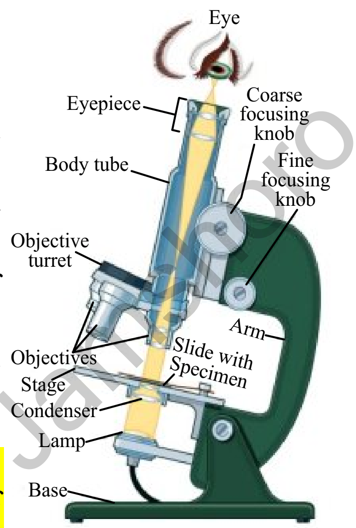



**Fig: 13.24. Mechanical parts of a compound microscope**

**SELF-ASSESSMENT QUESTION:**

**Q1:** Explain the near point of accommodation of an eye of a normal human.

**Q2:** Give the working principle of the optical microscopes?

**Q3:** How does magnification of a simple microscope relate to the focal length?

**Q4:** What is the difference between simple microscope and compound microscope?

## 13.9 Telescope

The telescope is also an optical instrument that uses two convex lenses, the objective and the eyepiece.

The objective lens has a larger focal length, $f_o$, than the eyepiece, which has a focal length, $f_e$. Telescopes are helpful because they can gather far more light than the human eye. It is used to form magnified images of distant objects.

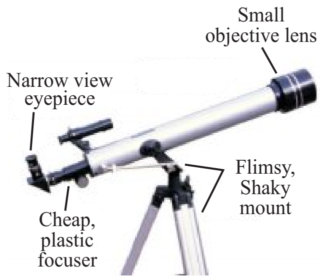



**Fig: 13.25. Mechanical parts of a refracting telescope**

## Magnification by telescope

When parallel rays from a point on a distant object pass through the objective lens, a real image $I_1$ is formed at the focal point f of the objective lens. This image behaves as an object for the eyepiece. The eyepiece forms a magnified virtual image $I_2$ a considerable distance from the objective lens; 13.26. This enlarged virtual image makes an angle $\theta i$ at the eyepiece.

The magnification of a telescope is given by the formula

$$M = \frac{f_o}{f_e}$$

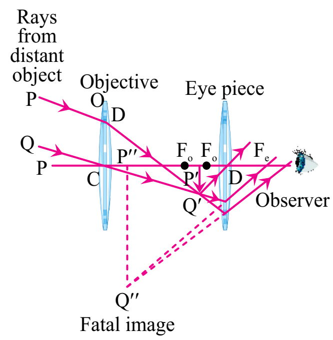



**Fig: 13.26. Ray diagram of a telescope**

**Do You Know!**

Length of Astronomical telescope given by $f_o + f_e$

## Uses of Telescopes

How far the human eye can see it depends on how many light particles a distant object emits. **Telescopes** are used to collect and focus the light towards the eyepiece. Telescopes have extended our sights to the universe. Earlier telescopes revealed that Earth was not the center of the universe. They also showed mountains and carters on the moon. Later telescopes have revealed geography and weather on the planets in our solar system and new planets and asteroids. Modern telescopes provide evidence of billions of galaxies, each containing billions of stars. Telescopes are now discovering planets around the stars and possible life over there. In the future, telescopes will answer us, are we living-being alone in the universe?

**SELF ASSESSMENT QUESTIONS**

**Q1:** Distinguish between a compound microscope and a telescope?

**Q2:** How are telescopes helpful to us to explore the universe?

## 13.10 The human eye and defect in vision

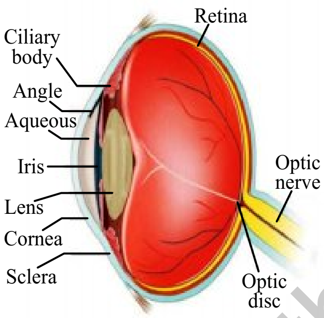



Fig: 13.27 Anatomy of a normal eye

The human eye is one of the light-sensitive organs. It enables us to see the beautiful world and the colors around us. The human eye uses a convex lens system to form a real, inverted, a small image of an object on a light-sensitive screen called the retina. The eye lens is comprised of a fibrous, jelly-like material; Fig. 13.27.

The curvature of the eye lens can be adjusted to some extent by the ciliary muscles that change its focal length. When the muscles relax, the lens becomes thin. Thus, its focal length increases. This refractive effect enables us to see distant objects. When you look at objects closer to the eye, the muscles contract. The eye lens then becomes thicker. Hence, the focal length of the eye lens decreases. This refractive effect enables us to see nearby objects clearly.

**Do You Know!**

The human eye has a convex lens and 580 megapixel range and a frequency of 16Hz.

## Defects of the eye and their correction by lenses

For many people, changes in the shape of the eye lens are not enough to produce a sharp focusing image on the retina. In such conditions, the person cannot see the objects distinctly and comfortably.

There are mainly two common refractive defects of vision. These are (i) short-sightedness and (ii) long-sightedness. The use of suitable spherical lenses can correct these defects. Let us discuss these defects and their correction.

## Short sight or Myopia

A person with short sight can see nearby objects clearly but cannot see distant objects distinctly.

A person with this defect has a far point nearer than infinity. Such a person can see clearly up to a distance of several meters. In a short-sight eye, the image of a distant object is formed in front of the retina and not at the retina itself. This defect can be noticed when the lens is not thin enough to look at distant objects. So the rays are bent inward too much and converge before they reach the retina.

By placing a concave lens or contact of appropriate power in front of the eye. A concave lens of suitable power; Fig. 13.28 will bring the image back onto the retina, and thus can correct the defect.

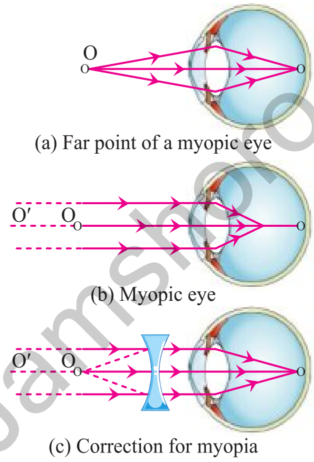



**Fig: 13.28. (a) The far point of an eye of a normal person (b) short-sight eye (c) correction of short-sight eye**

## Long-sight or Hyperopia

A person with long sight can see distant objects clearly but cannot see nearby objects distinctly.

A person with this defect has a nearer point farther away from the near-normal point (i.e., 25 cm). Such a person has to keep reading material beyond 25 cm from the eye for comfortable reading. In a long-sight eye, the image of a nearby object is formed behind the retina and not at the retina itself. This defect can be noticed when the lens is not thick enough to look at close objects. So the rays are not bent inward enough. The light rays from a close-by object are focused behind the retina.

By placing a convex lens or contact of suitable power in front of the eye. A convex lens of suitable power provides the additional focusing power required for forming the image on the retina; Fig. 13.29. Thus the defect can be corrected.

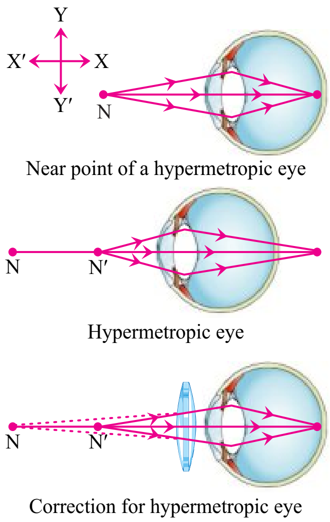



**Fig: 13.29. (a) Near-point of an eye of a normal person (b) long-sight eye (c) correction of long-sight eye**

**SELF-ASSESSMENT QUESTIONS**

**Q1:** Why near-sightedness (myopia) makes far-away objects look blurry?

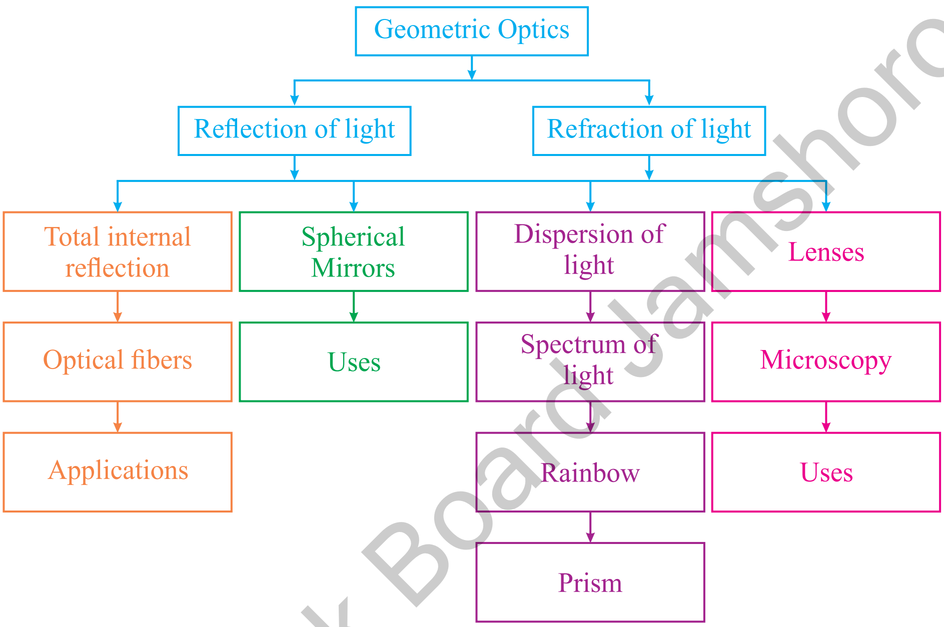
**Q2:** What is the most common treatment for refractive error of long-sight?

## SUMMARY

- A highly polished surface reflects the light.
- The incident ray reflected ray, and the normal to the reflecting surface all lie in the same plane. This phenomenon is called the first law of reflection.
- The angle of incidence is equal to the angle of reflection (i.e., $\angle i = \angle r$). This is the second law of reflection.
- Some uses of a convex mirror are sunglasses, rearview mirrors, and shaving mirrors.
- Some applications of concave mirrors are reflectors, converging of light, and solar cookers.
- The driver uses concave or rearview mirrors to view an upright, smaller, and full vehicle image.
- The dentist uses a concave mirror to see the tooth is larger and if there is any infection or germ attack.
- A ray of light incident at an angle to the normal bends towards the normal when it enters an optically denser medium.
- A ray of light bends away from the normal when it enters a rear medium.
- The angle of incidence that causes the refracted ray in the rarer medium to bend through $90^0$ is called the critical angle.
- If the angle of incidence in the denser material is beyond the critical angle, the entire light is reflected into the same denser medium.is called total internal reflection.
- Optical fibers are an important application that works on total internal reflection.
- Convex lenses are used to converge the light.
- Concave lenses are used to diverge the light.
- The power of a lens is the reciprocal of its focal length.
- The magnifying glass uses a convex lens to produce an upright and magnified image to see the tiny object.
- The camera uses a convex lens to reproduce a small, inverted, and small image on photographic film.
- The projector uses a convex lens as a projection lens and pair of condenser lenses to produce a large, inverted, and real image on a screen.
- The photographic enlarger uses a convex lens to produce an inverted, real and enlarged image of the film on a photo paper.

- The resolving power of an optical instrument is a measure of the ability to form separable images of close objects or to separate close wavelengths of radiation.
- The magnifying power of an optical instrument is the ratio between the apparent size of an object and its true size.
- The compound microscope is an optical instrument that uses two convex lenses, used to investigate the structure of the tiniest objects.
- The telescope is also an optical instrument that is used to form magnified images of distant objects.
- The human eye is a light-sensitive sense organ.
- The short-sight person can see nearby objects clearly but cannot see distant objects distinctly.
- The short-sight defect can be corrected by placing a concave lens or contact of appropriate power in front of the eye.
- The long-sight person can see distant objects clearly but cannot see nearby objects distinctly.
- The long-sight defect can be corrected by placing a convex lens or contact of appropriate power in front of the eye.

## CONCEPT MAP






## Section (A) Multiple Choice Questions (MCQs)

**Choose the correct answer from the following choices:**

1. In a concave mirror, the image size depends upon
   (a) Size of the object (b) Position of the object
   (c) Area covered by the object (d) The shape of the object
2. In the normal human eye, the image is formed
   (a) In from of the retina (b) Behind the retina
   (c) On the retina (d) In between lens and retina
3. When a light ray enters from a denser medium to a rare medium, it bends
   (a) Perpendicular to normal (b) Parallel to normal
   (c) Toward normal (d) Away from normal
4. In a compound microscope, as compared to an objective, the eyepiece lens has a focal length
   (a) Zero (b) negative
   (c) Small (d) Large
5. When the angle of refraction is 90° and the refractive index for water is 1.33, the critical angle is
   (a) 48.8° (b) 49.1°
   (c) 50.0° (d) 51.0°

6. To view dim stars, we use
   (a) Compound microscope (b) Simple microscope
   (c) Endoscope (d) Telescope
7. The human eye acts like a
   (a) Camera (b) Projector
   (c) Telescope (d) Microscope
8. A magnifying glass forms an enlarged
   (a) Real and upright image (b) Real and inverted
   (c) Virtual and upright image (d) Virtual and inverted image
9. The entire light is reflected into the same denser medium, which is called total
   (a) External reflection (b) Internal reflection
   (c) External refraction (d) Internal refraction
10. In the optic fiber, the core is made of glass or plastic of relatively
   (a) Zero refractive index (b) High refractive index
   (c) Low refractive index (d) No refractive index
11. A magnifying glass is also called
   (a) Endoscope (b) Compound microscope
   (c) Simple microscope (d) Telescope
12. The defect in which the image is formed beyond the retina is called,
   (a) Long-sightedness (b) Short-sightedness
   (c) Blind spotting (d) Image defect
13. The short-sightedness can be corrected by using.
   (a) Convex glasses (b) Convex mirror
   (c) Concave mirror (d) Convex glasses
14. Lenses form images through
   (a) Dispersion (b) Refraction
   (c) Diffraction (d) Reflection
15. To illuminate the inaccessible places in the tooth, dentists use
   (a) Concave mirror (b) Convex mirror
   (c) Convex lens (d) Concave lens

## Section (B) Structured Questions

1. **a.** What do you understand by the term reflection of light?
   **b.** Outline a diagram to illustrate reflection at a plane surface.
   **c.** Describe the following terms used in reflection:
   **i.** Normal **ii.** The angle of incidence **iii.** The angle of reflection.
   **d.** Also, express the laws of reflections.
2. Name the type of mirror used in the following situations.
   **a.** Side /rearview mirror of a vehicle.

b. To locate the blind spots on roads of the hilly side.
c. Dentist mirror.

Support your answer with reason.

3. a. Define the refraction of light.
b. Outline the passage of light through a parallel-sided glass slab.
c. Define the following terms used in refraction:
i. The angle of incidence ii. The angle of refraction.

Also, express the laws of refraction.

4. a. What do you understand by the refractive index of a material?
b. Cite experimentation on how you can determine the refractive index of a parallel-sided glass slab?
c. Which physical quantity remains unaffected when refraction of light occurs?

5. a. What is the glass prism?
b. Describe the passage of monochromatic light rays through a glass prism.
c. Suppose a ray of light approaches the surface of the prism. What happens when it enters the glass at the angle of?
i. $0^0$ with the normal
ii. $30^0$ with the normal. Answer in terms of its change in the quantities of frequency, speed, wavelength, and direction.

6. a. What is the lens?
b. What happens if a light ray parallel to the principal axis enters a convex lens?
c. The convex lens is considered a converging lens. Explain why?
d. Describe the power of a lens and its units.

7. a. Define critical angle.
b. What do you understand by the term total internal reflection?
c. State the conditions required for a total internal reflection.
d. Give some practical examples of a total internal reflection in everyday life.

8. Determine the critical angle of light in a diamond? The refractive index of the diamond is 2.41.

9. a. What are optical fibers?
b. Describe how total internal reflection is used in an endoscope?

10. a. Draw the ray diagram of a magnifying glass.
b. How can you use a thin converging lens as a magnifying glass?
c. Give the magnification of magnifying glass.

11. With the help of a ray diagram, give the magnifying powers of the following optical instruments:
i. simple microscope or magnifying glass
ii. compound microscope
iii. refracting telescope

12. a. What is meant by the terms?
   i. short-sight, and  ii. long-sight
   b. How can these defects be corrected?
   i. short-sight, and  ii. long-sight
   c. Why is a normal eye not able to see the objects put closer than 25 cm?

## Section (C) Numericals

1. A thumb pin is positioned at a distance of 15 cm from a convex mirror of a focal length of 20 cm. Determine the position and nature of the image. **(8.57cm)**
2. An image of a specimen appears to be 11.5 cm behind a concave mirror with a focal length of 13.5 cm. Find the specimen's distance from the mirror. **(6.21cm)**
3. A convex mirror used for rear-view on an automobile has a radius of curvature of 4.00 m. If a bus is located at 5.00 m from this mirror, find the image's position, nature, and size. **(1.428m)**
4. An object is placed 15 cm away from a converging lens of a focal length of 10 cm. Determine the position, size, and nature of the image formed. **(2cm)**
5. A concave lens of focal length 20 cm forms an image 15 cm from the lens. Determine the power of a lens. Also, how far is the object positioned from the lens? **(0.05cm)**
6. The angle of incidence for a ray of light from air to water interface is 40◦. If the ray travels through the water with a refractive index of 1.33, calculate the angle of refraction. **($28.8^o$)**

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