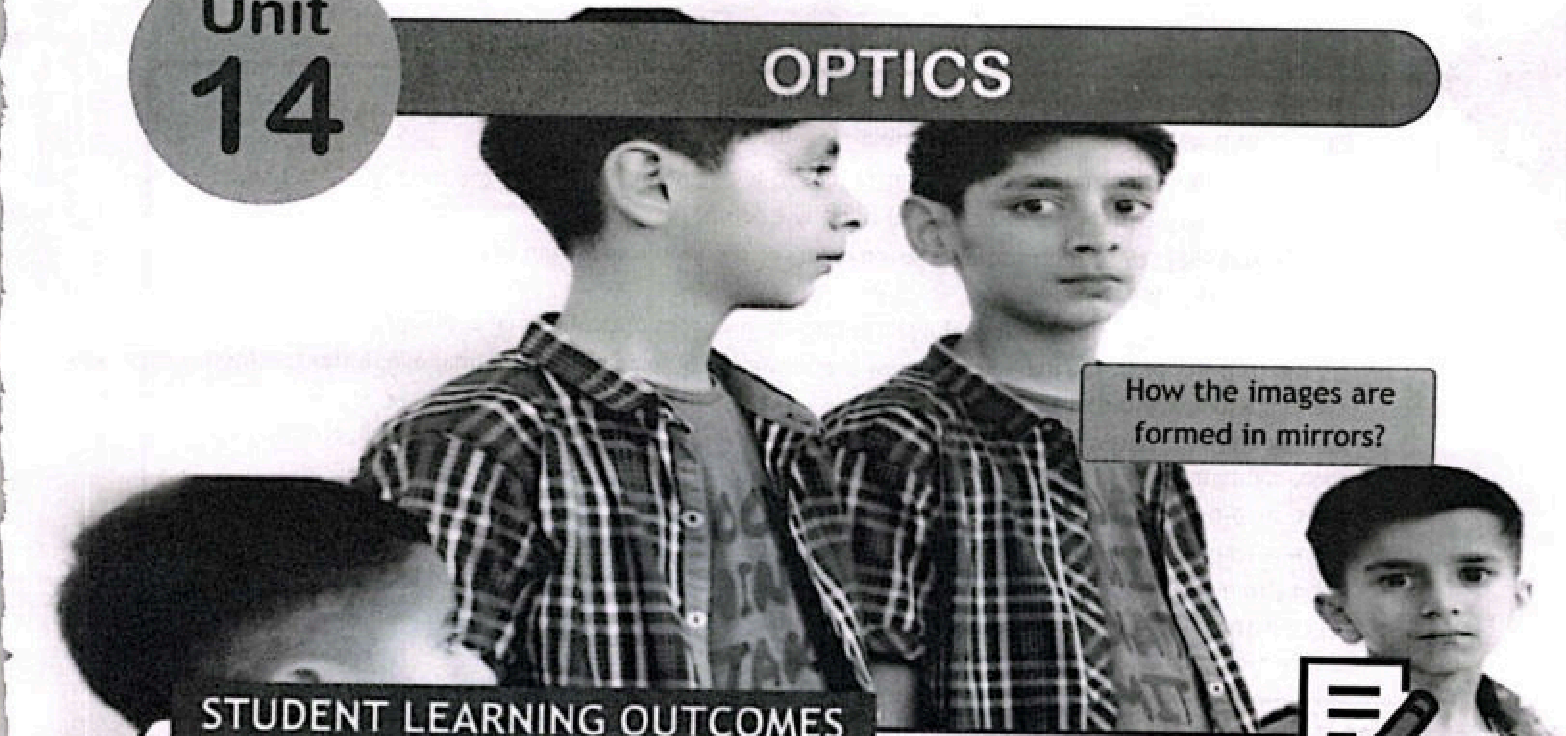
Unit 14 OPTICS



STUDENT LEARNING OUTCOMES

The students will:

- ✓ [SLO: P-10-D-32] Define and use the terms normal, angle of incidence and angle of reflection.
- ✓ [SLO: P-10-D-33] Describe an experiment to find the position and characteristics of an optical image formed by a plane mirror.
- ✓ [SLO: P-10-D-34] Use the law of reflection to solve simple optical problems.
- ✓ [SLO: P-10-D-35] Define the terms normal, angle of incidence and angle of refraction.
- ✓ [SLO: P-10-D-36] Apply the qualitative principle that a wave refracts towards the normal when it slows down while entering a medium, and that it refracts away from the normal if it speeds up when it enters a new medium.
- ✓ [SLO: P-10-D-37] Define and use the refractive index from a vacuum to a medium for light as c/v.
- ✓ [SLO: P-10-D-38] Define refractive index n as $n = \sin(i)/\sin(r)$. Apply Snell's law, $n_1 \sin(i) = n_2 \sin(r)$ to solve simple problems.
- ✓ [SLO: P-10-D-39] Describe an experiment to show refraction of light by transparent blocks of different shapes.
- ✓ [SLO: P-10-D-40] Define the terms critical angle and total internal reflection.
- ✓ [SLO: P-10-D-41] Derive the equation $n = 1/\sin(c)$.
- ✓ [SLO: P-10-D-42] Apply the equation $n = 1/\sin(c)$ to solve simple problems.
- ✓ [SLO: P-10-D-43] Describe experiments to show internal reflection and total internal reflection.
- ✓ [SLO: P-10-D-44] Evaluate and illustrate the use of optical fibers.
- ✓ [SLO: P-10-D-45] Analyze the action of thin converging and thin diverging lenses on a parallel beam of light.
- ✓ [SLO: P-10-D-46] Define and use the terms focal length, principal axis and principal focus (focal point).
- ✓ [SLO: P-10-D-47] Draw ray diagrams to illustrate the formation of real and virtual images of an object by a converging lens.

- ✓ [SLO: P-10-D-48] Differentiate between real and virtual images.
- ✓ [SLO: P-10-D-49] Define and calculate linear magnification.
- ✓ [SLO: P-10-D-50] Describe the use of a single lens as a magnifying glass.
- ✓ [SLO: P-10-D-51] Explain the dispersion of light by a prism.
- ✓ [SLO: P-10-D-52] State the traditional seven colors of the visible spectrum in order of frequency and in order of wavelength.
- ✓ [SLO: P-10-D-53] Describe the use of a single lens as in various optical device applications.
- ✓ SLO: P-10-D-54] Draw ray diagrams to show the formation of images in the normal eye, a short-sighted eye and a long-sighted eye.
- ✓ [SLO: P-10-D-55] Describe the use of converging and diverging lenses to correct long-sightedness and short-sightedness.
- ✓ [SLO: P-10-D-56] Illustrate with examples how the biological eye processes color in various organisms.
- ✓ [SLO: P-10-D-57] State that extreme gravity from interstellar objects like blackholes can cause light to bend (from the perspective of the observer) in a way that is analogous to a simple lens.
- ✓ [SLO: P-10-D-58] State that 'acoustic lenses' are made of materials and shapes that work to focus or diverge sound.

Optics is the science of light and its interaction with matter. It explores the behavior of light waves, the properties of lenses and mirrors and the intricacies of human vision. But beyond its practical applications in fields like photography, microscopy and astronomy, optics holds a deeper significance. How do we see the world around us? What role does light play in shaping our understanding of reality? These and alike questions have puzzled the ancient scientists which derived the quest for knowledge in the realm of optics.

Our lives are filled with light, through vision the most valued of our senses. light has innumerable uses beyond vision like it can carry telephone signals through glass fibers or cook a meal in a solar oven. Life itself could not exist without light energy.

14.1 REFLECTION OF LIGHT

Light from this page is formed into an image by the lens of your eye much as the lens of camera that made this photograph. Light can travel in three ways: directly from the source to the observer (like sunlight reaching Earth through space), through different materials like air or glass, or after being reflected by objects like mirrors. In all cases, light travels in a straight line or as a ray. The word ray comes from mathematics and it means a straight line, we would use the travelling of light in ray diagram in this unit.

Reflection of light is a fascinating phenomenon that occurs when light rays bounce off a surface. Whenever you look into mirror you are seeing a reflection even when you look at this page, actually you are seeing the light reflected from this page. Large telescopes use reflection to form an image of stars and other astronomical objects. To study the reflection of light from a surface we use some terms like perpendicular to the surface which is a line "normal" to the reflecting surface. One ray which strikes the surface is called the "incident ray" which makes an angle called "angle of incidence" with the reflecting surface. Similarly after striking the surface the ray of light reflected this is called "reflected ray" at some angle known as "angle of reflection" as shown in figure 14.1 (a).

'When a ray of light approaches a smooth polished surface and bounces back is called reflection'.

14.1.1 LAWS OF REFLECTION

There are two laws which govern the reflection of light as:

1. The incident ray, the reflected ray, and the normal all lie in the same plane.

2. The angle of incidence 'θ_i' and angle of reflection 'θ_r' are equal. This can be represented mathematically as:

$$\theta_i = \theta_r \quad (14.1)$$

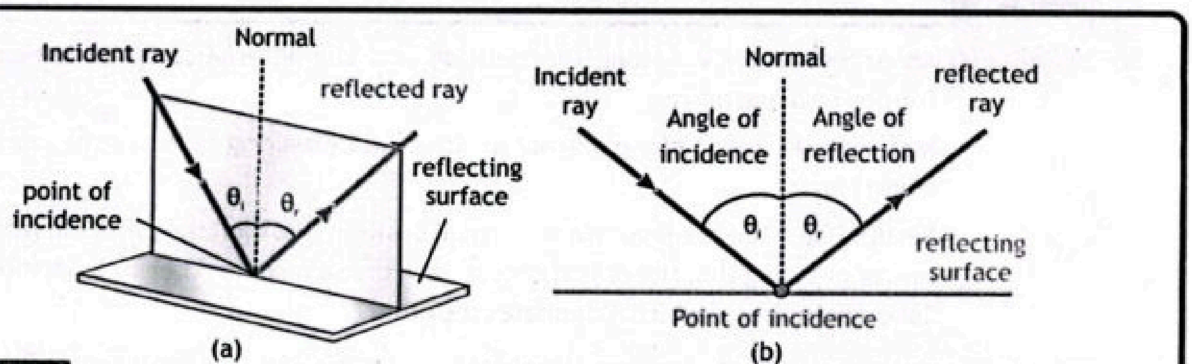


FIGURE 14.1 Laws of reflection

A. Regular or specular reflection: this occurs on smooth surfaces like mirrors, where the reflection is clear and sharp. The angles of reflection are consistent across the surface leading to a distinct image being formed. This phenomenon is shown in figure 14.2 (a).

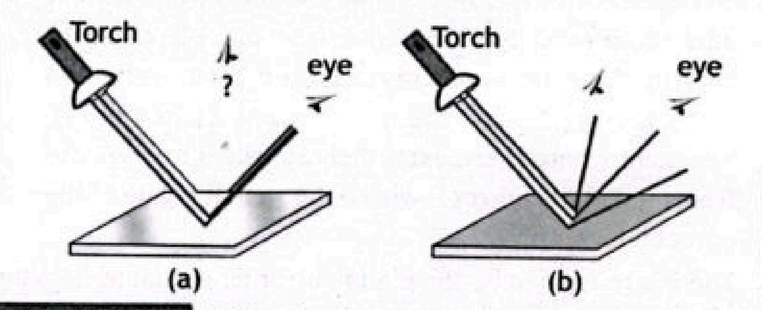


FIGURE 14.2 Reflection from smooth and rough surfaces

POINT TO PONDER

How does multiple reflections occur?

When light bounces between two mirrors facing each other, it creates multiple reflections. For instance, in a barber shop, you can see a series of your images due to the reflections between the front and back mirrors as shown.

B. Diffused reflection: This happens on rough surfaces where the reflected rays scatter in many directions. This type of reflection allows us to see most non-shiny objects like this page of your book that is why you can see this page from all sides not from only at a single point the diffused reflection of light and image from many sides is shown in figure 14.2 (b).

CAN YOU TELL?

A light ray strikes a reflective plane surface at an angle of 47° with the surface. Find the angle of incident, angle of reflection and angle between the incident and reflected rays.

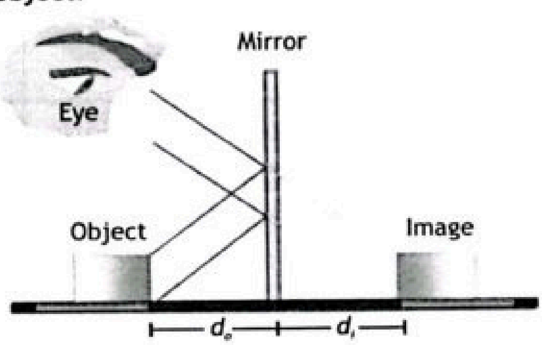
MINI LAB

An experiment for finding the position and characteristics of an optical image formed by plane mirror.

Material needed: A plane mirror, an object, a measuring tape, a light source and a white paper.

Setup: Place the plane mirror in vertical position. Position the object in front of the mirror ensuring that the object should have the same or less height as that of mirror. Take a light source which illuminates the object.

Procedure: Observe the reflected rays from the object that strike the mirror surface. Note that two rays emerged from the object strike the mirror and reflect into observer's eye. Use the law of reflection to construct the reflected rays. Extend these reflected rays backward behind the mirror (using dashed lines). The point where these extended rays seem to originate from behind the mirror is where the virtual image of the object is located.



The image formed by the plane mirror is, virtual as it cannot be projected onto a screen. It is erect means image has same orientation as that of the object. The size of the image is the same as the size of the object. The distance of the image is the same as the distance of the object from the mirror i.e. $d_i = d_o$ (where d_i and d_i are the distances of object and image from the mirror respectively.)

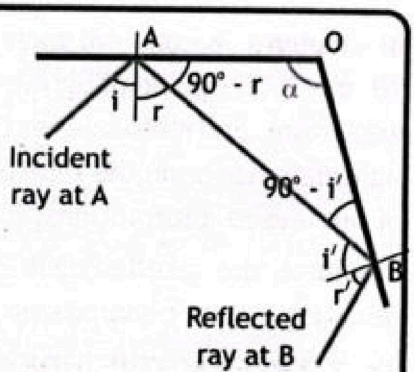
UNIT OPENER?

We see ourselves in a mirror it appears that our image is actually behind the mirror. We see the light coming from a direction determined by the law of reflection. The angles are such that our image is exactly the same distance behind the mirror as we stand away from the mirror. If the mirror is on the wall of room the images in it are all behind the mirror which can make the room seem bigger.

To understand it consider an object which is placed in front of a mirror at distance 'd_o'. Light rays coming from the object after reflecting from the mirror enter into the eye of observer. To the observer these light rays appear to be coming from behind the mirror from a distance 'd_i'. Hence the image will be seen by you behind the mirror due to reflection of light.

Example 14.1

Find the angle 'α' made by the system of the two mirrors as shown, provided that the incident ray '*A*' and the reflected ray '*B*' are parallel.



GIVEN:
Incident ray '*A*' is parallel to reflected ray '*B*'

REQUIRED:
Angle 'α' = ?

SOLUTION:
To find the value of angle we use laws of reflection as for the incident ray at 'A' and the reflected ray at 'B' to be parallel. and the angles $(i + r)$ and $(i' + r')$ have to be supplementary: $i + r + i' + r' = 180^\circ$

By laws of reflection: $i = r$ and $i' = r'$

Using these values we get: $i + i + i' + i' = 180^o$ and $i + i' = 90^o$

In the triangle 'AOB' we have: $\alpha + (90^o - r) + (90^o - i') = 180^o$ or $\alpha = r + i' = i + i'$

Therefore $\boxed{\alpha = 90^o}$ — **ANSWER**

So, for incident ray '*A*' and the reflected ray '*B*' to be parallel 'α' must be 90°.

14.2 REFRACTION OF LIGHT

It is easy to notice odd things when you look on half submerged things into the water. For example if you dip a straight pencil into the glass water such that the full length of pencil does not sink into the water you would observe that the pencil is not straight but it is bended or broken which is known as broken pencil illusion as shown in figure 14.3. This is because the light coming from the water to us changes direction when it leaves the water and enters into the air. In this case the light has to travel two different paths to get to our eyes. **'The changing of a light ray's direction when it passes through variations in matter is called diffraction'.** Refraction is responsible for a tremendous range of optical phenomenon from the action of lenses to voice transmission through optical fibers.

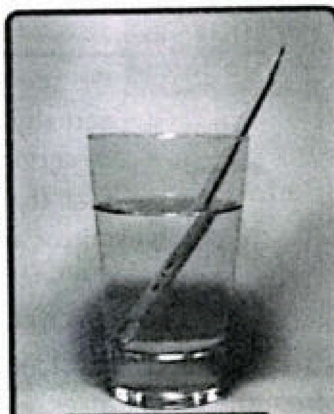


FIGURE 14.3
Broken pencil illusion due to diffraction of light.

14.2.1 SPEED OF LIGHT IN MATERIAL MEDIA

Why does light changes direction when passing from one material to another? It is because the speed of light does vary in a precise manner with the material it traversed i.e. going from one material to another. So before we study the law of refraction it is useful to discuss the speed of light and how it varies in different media. Although the speed of light in vacuum 'c' is constant such that it is accepted as universal constant with a fixed value *'$c = 3 \times 10^8\ m/s$'*. The speed of light through matter is less than that of in vacuum, because light interacts with atoms and molecules of the medium which hinders the speed of light that is why the speed of light depends upon the type of material. The speed of light is slower in denser mediums because of increased interactions, causing light to bend towards the normal. Conversely, in rarer mediums, the speed of light is faster due to fewer interactions, resulting in light bending away from the normal.

Table 14.1 REFRACTIVE INDICES

Medium	Refractive index (n)
Air	1.000293
Carbon dioxide	1.00045
Oxygen	1.000271
Benzene	1.501
Glycerin	1.473
Water	1.333
Diamond	2.419
Polystyrene	1.49
Glass (crown)	1.52
Glass (flint)	1.66
Ice	1.309
Zircon	1.923

14.2.2 REFRACTIVE INDEX

As we have discussed that the speed of light in any material media is always less than the speed of light in vacuum hence we can take the speed of light in vacuum as reference. The quantity which describes the speed of light in any medium as compared to the speed of light in vacuum as called as refractive index and can be defined as:

'The measure of bending of a light ray when passing from one medium to another is called refractive index such that one medium is vacuum'. It can also be defined as the ratio of the velocity of a light ray in an empty space to the velocity of light in a substance. If 'c' is the velocity of light in vacuum and the 'v' is the velocity of light in some medium then the refracted index 'n' of that medium can be given as:

$$n = \frac{c}{v} \qquad \boxed{14.2}$$

As the speed of light in vacuum is the highest hence the above ratio i.e. refractive index of any medium cannot be equal to or less than unity. It has unit value only for vacuum itself. Refractive index being the ratio of similar quantities hence has no unit and a dimensionless quantity which describes how fast the light travels in a medium. In gases the value of refractive index is taken as unit if great precision is not needed as the atoms and molecules of gases are widely separated hence light interacts with them rarely. Refractive indices of some commonly used transparent materials are given in table 14.1.

Example 14.2

What is the speed of light in diamond, a material with a refractive index of 2.49, often found in jewelry?

GIVEN:
Refractive index 'n' = 2.419
Speed of light 'c' = 3×10^8 m/s

REQUIRED:
Speed of light in medium 'v' = ?

SOLUTION:
To find the speed of light in diamond we use formula: $n = \frac{c}{v}$ Rearranging $v = \frac{c}{n}$

putting values $v = \frac{3 \times 10^8 m\ s^{-1}}{2.419}$ Therefore $\boxed{v = 1.24 \times 10^8 m\ s^{-1}}$ **ANSWER**

The speed of light reduces to 1.2×10^8 m/s

14.2.3 LAWS OF REFRACTION (SNELL'S LAW)

To study the laws of refraction first we have to know about the terms associated with the refraction phenomenon like normal, incident ray and refracted ray as shown in figure 14.4. The perpendicular line to the boundary of the two media is known as "normal", the light ray coming from the first medium is known as "incident ray" and the angle it makes with the normal is called "angle of incidence" while the ray entering into the other medium is called "refracted ray" and the angle it makes with the normal is called "angle of refraction".

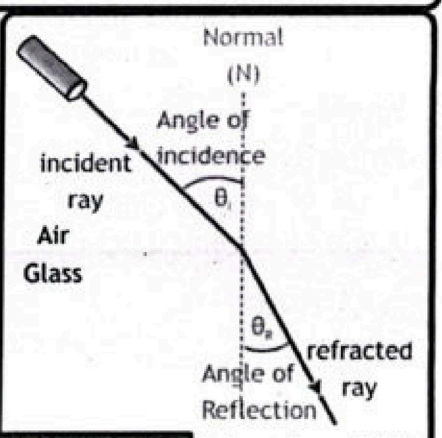


FIGURE 14.4 Refraction of light

The amount that a light ray changes its direction depends both on the incident angle and the amount that the speed changes. For a ray at a given incident angle a large change in speed causes a large change in direction and thus a large change in angle of refraction. Similarly, for the same speed of incident ray of light the large angle of incident causes a large change in refracted angle (up to a limit only). The laws of refraction are also known as Snell's law, after the name of a Dutch scientist (1591-1626) but were first given by a Muslim scientist Ibn-e-Sahl in 984 in his book "On burning *mirrors and lenses*". These laws can be given in two steps i.e.

1. The first law states that the incident ray of light, the normal and the refracted ray of light all lie in the same plane.
2. The second law is about the relationship between the angles and the indices of refraction of the two media. It can be mathematically given as:

$$n_1 \sin\theta_i = n_2 \sin\theta_r \quad \text{— } \boxed{14.3}$$

Here 'n_1' and 'n_2' are the refractive indices of the two media and 'θ_i' is the angle of incident and 'θ_r' is the angle of refraction. The same relation can also be written as:

$$\frac{n_1}{n_2} = \frac{\sin\theta_r}{\sin\theta_i}$$

If one of the two media is vacuum, and light enters from vacuum to some medium then '$n_1 = 1$' and relation reduces to:

$$\frac{1}{n_2} = \frac{\sin\theta_r}{\sin\theta_i} \quad \text{or simply} \quad \frac{1}{n} = \frac{\sin\theta_r}{\sin\theta_i} \quad \text{— } \boxed{14.4}$$

When light enters into vacuum from some medium then '$n_2 = 1$' and relation becomes:

$$n_1 = \frac{\sin\theta_r}{\sin\theta_i} \quad \text{or simply} \quad n = \frac{\sin\theta_r}{\sin\theta_i} \quad \text{— } \boxed{14.5}$$

Example 14.3

Find the refractive index for the medium if light enters into it from air at an angle 37° and refracted into it at angle 21°.

GIVEN:
Refractive index of air 'n_1' = 1
Angle of incident light 'θ_i' = 37°
Angle of refracted light 'θ_r' = 21°

REQUIRED:
Refractive index of medium 'n_2' = ?

SOLUTION:
The Snell's law can be written as: $\frac{n_2}{n_1} = \frac{\sin\theta_i}{\sin\theta_r}$ putting values $\frac{n_2}{1} = \frac{\sin 37^\circ}{\sin 21^\circ}$

Therefore $\boxed{n_2 = 1.68}$ — **ANSWER**

This is the refractive index of a type of glass which is used for the core of optical fibers.

14.2.4 EXPERIMENT TO STUDY REFRACTION

To study the refraction due to transparent blocks of different shapes we can device an experiment even in our classroom or lab in the school.

A. Aim of the Experiment: To study the refraction of light using a rectangular block, semi-

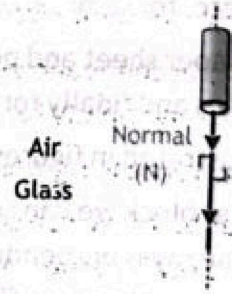
SCIENCE TIDBITS

If the light enters from one medium to another medium perpendicular to the surface which divides the media then the angle of incident becomes zero. As in this case the light is incident parallel to the normal then Snell's law will give the angle of refraction also to be zero as:

$$n_1 \sin\theta_i = n_2 \sin\theta_r \quad \text{as} \quad \sin 0 = 0$$

$$\text{as} \quad 0 = n_2 \sin\theta_r \quad \text{and} \quad \theta_r = \sin^{-1} 0$$

$$\text{Finally,} \quad \theta_r = 0$$



This shows that whenever light enters from one medium to another at right angle, whatever their refractive indices may be the angle of refraction will be zero i.e. the light does not bend in such situations.

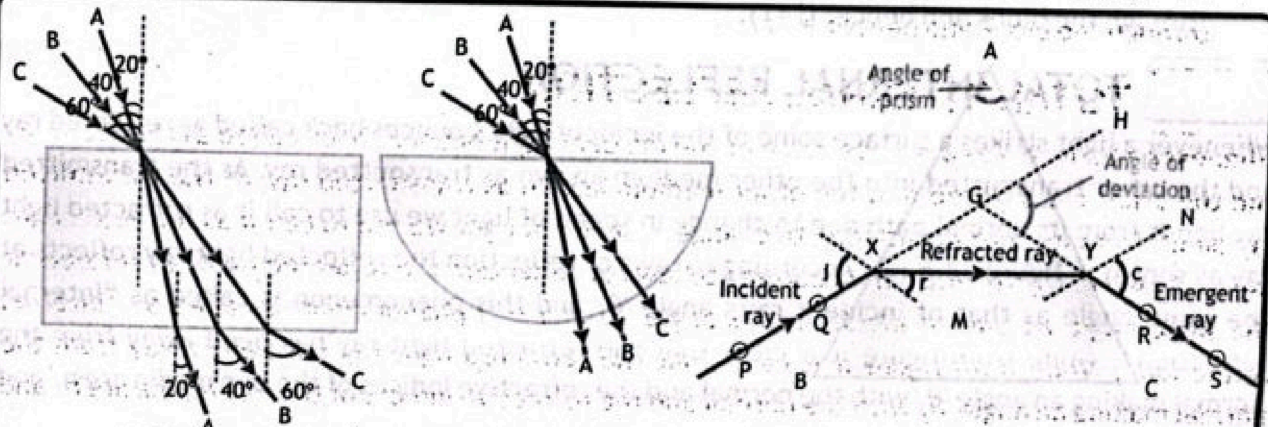
circular block and triangular prism made of glass.

B. Equipment required: Laser light, protractor, sheet of paper ; pencil, ruler and perspex blocks (rectangular, semicircular and prism).

C. Method for studying refraction: Place the glass rectangular block on the paper draw lines around it. Now draw the perpendicular lines which are called as normal. Illuminate one plane side of the block making some angle with the normal already drawn on the paper.

Mark the following and carefully make observations:

- A point on the paper near the light source.
- A point where the light ray enters into the block.
- The point where the light ray exits the block.
- Another point along the path of exit light ray at a distance of say 4 to 5 cm.



(a) Rectangular block (b) Semi-circular block (c) Prism

FIGURE 14.5 Experiment for refraction of light

- Remove the light source and the block and join the points marked on the paper sheet with straight lines.
- Replace the block again and repeat the above experiment for some different angles like for 20°, 40° and 60° etc. for semi-circular block too.

Now take another paper sheet and perform the same experiment for the semi-circular block with three different angles and finally for a glass prism.

All the three are illustrated in figures 14.5 (a), (b) and (c).

For the semi-circular block we can see that the light rays are not refracting because at each point the radial path of the ray is perpendicular to the tangent hence the light rays are leaving the block along the normal line and hence suffer no refraction.

D. Results: Consider the light paths for different shaped blocks.

- The final diagram for each shape will include multiple light ray paths for the different angles of incidents (i) at which the light strikes the blocks.
- This will help to demonstrate how the angle of refraction (r) changes with the angle of incident.
- Label these paths for first two blocks as 'A', 'B' and 'C' to make the paths clear.
- Incident and refracted angles are always measured from the normal.
- In all the cases you would observe that:
  - the light entering the block bends towards the normal line hence: $(i > r)$.
  - For light rays exiting the Perspex blocks all the light rays refract away from the normal line hence: $(i < r)$.
  - For light rays entering along the normal the light ray does not refract i.e. it passes straight through the block and hence: $(i = r)$.

14.3 TOTAL INTERNAL REFLECTION

Whenever a light strikes a surface some of the incident light bounces back called as reflected ray and the other transmitted into the other medium known as transmitted ray. As the transmitted ray bends from its normal path due to change in speed of light we use to call it as refracted light ray as shown in figure 14.6 (a). According to laws of reflection the reflected light ray reflects at the same angle as that of incident ray's angle 'θ_1' and this phenomenon is called as "internal reflection", while from figure it is clear that the refracted light ray has bend away from the normal making an angle 'θ_2' with the normal and the refractive indices of the two media are 'n_1' and 'n_2'.

When light travels from a less dense medium to a denser one, it bends toward the normal line. As the angle of incidence increases, the angle of refraction decreases, causing the refracted light to approach the normal line. In contrast, when light moves from a denser medium, such as glass or water, to a less dense medium like air, it bends away from the normal. Increasing the angle of incidence results in a larger angle of refraction, moving it further from the normal line.

If we further increase the angle of incident the refracted light ray by moving away from the normal makes an angle of 90° with the normal as shown in figure 14.6 (b). At this angle the refracted light without entering into the second medium rather it moves along the boundary between the two media. At this stage the incident angle is called the critical angle, which can be defined as: **"The angle of incidence for which the angle of refraction is 90 degrees is called as the critical angle."**

The critical angle is represented by 'θ_c'. When the angle of incidence of the light ray becomes greater than the critical angle the refracted light ray also reflects back into the same medium from the boundary of two media. At this stage there is no more refraction of light and is known as the total internal reflection of light as shown in figure 14.6 (c), total internal reflection can be defined as: **"Total internal reflection is the phenomenon of reflection of light ray back to the same medium when passing from denser medium to rarer medium in such a way that angle of incidence is greater than its critical angle."**

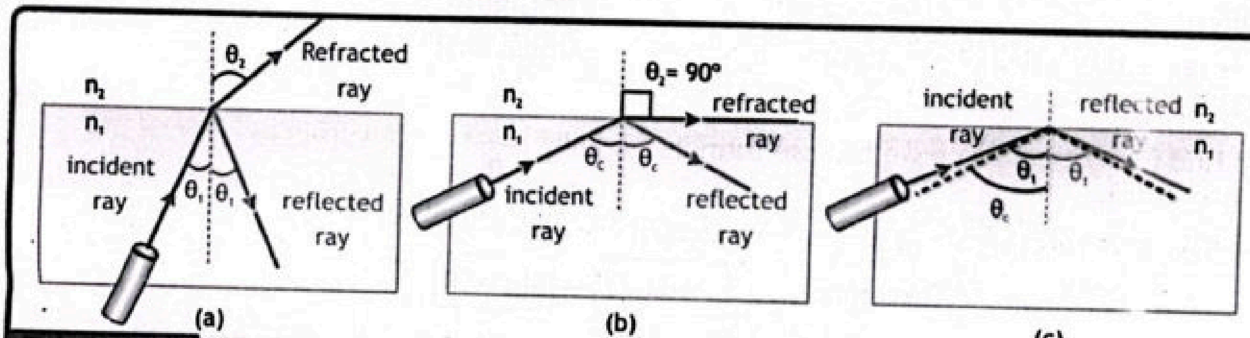


FIGURE 14.6 Total internal reflection

14.3.1 DERIVATION

To derive a relation for the total internal reflection we use Snell's law from equation 14.3:

$$n_1 \sin\theta_i = n_2 \sin\theta_r$$

As for total internal reflection the refracted angle becomes 90° as shown in figure 14.11, hence the above equation gets the form:

$$n_1 \sin\theta_1 = n_2 \qquad \text{as} \qquad \sin 90^\circ = 1$$

The sine of critical angle for the given combination of materials is: $\sin\theta_c = \frac{n_2}{n_1}$ —— $\boxed{1}$

The critical angle can be found as: $\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$ —— $\boxed{14.6}$

As we know that the trigonometric ratio of sine can have values maximum up to 1, for this it is necessary that the refractive index of first medium (from which light ray is incident) should be greater than the refractive index of the second medium (in which light ray is entering) i.e. total internal reflection can only be happened if light ray travels from denser medium into the lighter medium. If second medium is air we can take the refractive index of air unity as '$n_2 = 1$' then '$n_1 = n$' and equation (1) becomes:

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

And in general refractive index of the other material can be given as: $n = \frac{1}{\sin\theta_c}$ —— $\boxed{14.7}$

The above relation holds good only if light is entering from any denser medium having refractive index 'n' into the air.

Example 14.4

Find the critical angle of polystyrene ($n = 1.49$) pipe surrounded by air.

GIVEN:
The refractive index of polystyrene 'n' = 1.49

REQUIRED:
critical angle 'θ_c' = ?

SOLUTION:
To find the critical angle we can use formula: $\sin\theta_c = \frac{1}{n}$

putting values $\sin\theta_c = \frac{1}{1.49}$ or $\theta_c = \sin^{-1}(0.671)$

Therefore $\boxed{\theta_c = 42.2^\circ}$ —— ANSWER

This mean that the light ray moving in the polystyrene if strikes the boundary with an angle greater than 42.2° will totally be reflected internally.

14.3.2 EXPERIMENT TO STUDY TOTAL INTERNAL REFLECTION:

To study the total internal reflection due to transparent block of semi-circular shape we can device an experiment even in our classroom or lab in the school.

A. Aim of the Experiment: To study the total internal reflection of light using a semi-circular block of glass.

B. Equipment required: Laser light, protractor, sheet of paper, pencil, ruler and perspex block.

C. Method for studying reflection: Place the semi-circular glass block on the paper draw lines

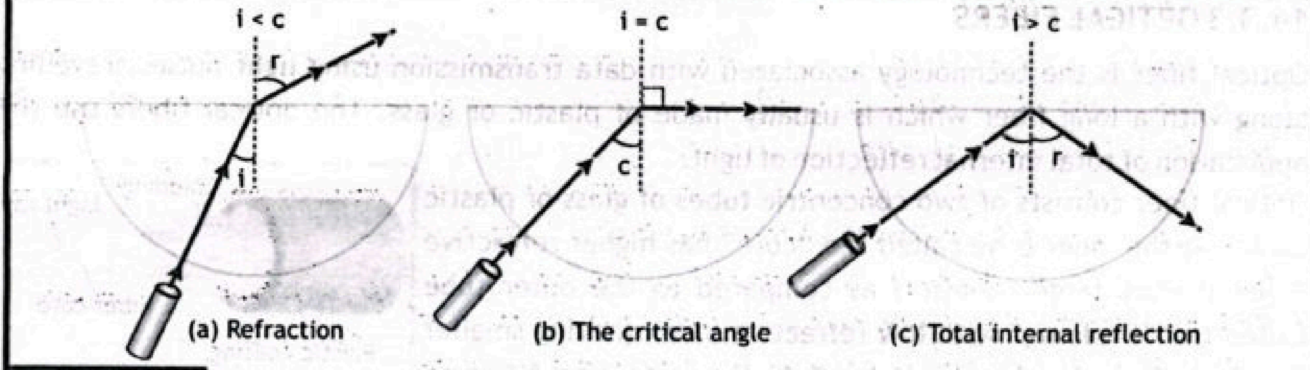


FIGURE 14.7 Experiment for total internal reflection

around it. Now draw the perpendicular line which is called as normal. Illuminate one plane side of the semi-circular block making some angle with the normal already drawn on the paper. Make the following carefully.

- A point on the paper near the light source
- A point where the light ray enters into the block
- The point where the light ray exits the block
- Another point along the path of exit light ray at a distance of say 4 to 5 cm
- Move the light source slowly such that the angle of incidence keeps on increasing.

While moving the light source the angle of incident increases which in turn increases the angle of refraction until the refracted line makes an angle of 90° with the normal this incident angle is called as 'critical angle'. Now mark two points for incoming ray at this stage.

Now increase the incidence angle further the refracted light now enters back into the same semi-circular block in spite of going into the other medium this phenomenon is known as total internal reflection as shown in figure 14.7.

D. Results: Consider the light paths for different angles and draw lines. These lines give the following results about the phenomenon of refraction and reflection as:

- In the case when the incidence angle was less than the critical angle we noticed the phenomenon of refraction and light entered into the lighter medium from the semi-circular glass block: $i < c$.
- For the case when the incidence angle was equal to that of the critical angle we noticed the refracted light made an angle of 90° with the normal and traveled on the boundary between the two media: $i = c$.
- For the case when the incidence angle was greater than the critical angle we noticed the phenomenon of total internal reflection and light bounced back to the same block in spite of going into the lighter medium from the semi-circular glass block: $i > c$.

14.3.3 OPTICAL FIBERS

Optical fiber is the technology associated with data transmission using light pulses travelling along with a long fiber which is usually made of plastic or glass. The optical fibers use the application of total internal reflection of light.

Optical fiber consists of two concentric tubes of glass or plastic such that the inner tube called the "core" has higher refractive index (having larger density) as compared to the outer tube called the "cladding" with low refractive index (having smaller density). The whole setup is covered for protection by some material called "jacket". The light enters into the core at an angle greater than the critical angle of the core material, moves within the core by successive total internal reflections. An optical fiber cable is shown in figure 14.8. Optical fibers have applications in many fields of life but the most commonly used application of optical fibers is their role in modern telecommunications. Optical fibers offer several advantages over traditional copper based network infrastructure some of them can be given as:

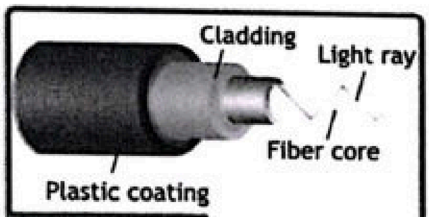


FIGURE 14.8 Optical fiber

A. High bandwidth: Optical fibers provide significantly higher band width compared to copper wires, where band width is the data transfer capacity of a network in bits per second. In modern times we need a lot of data from our internet at very high speed hence larger bandwidth of optical fibers serves the best to our requirement

B. Faster Speed: They can transmit data at faster speeds due to the use of light pulses instead of electrical signals. They transfer the data from one place to another at the speed of light

C. Resistance to electrical interference: As we use light in optical fibers hence the electrical interference has no effect on the data as it was a major problem in copper-network transmissions

D. Long Distance: It can transmit data over much longer distances without significant signal loss like under-sea cables and inter-continental connections.

E. Low Power: They consume less power than copper cables and their durability and longevity reduces maintenance costs.

Optical fibers are used in various sectors, including healthcare, defense, manufacturing, broadcasting, lighting, and communications. In telecommunications, they are essential for data transmission, offering greater speed and accuracy than copper wires. Optical fiber cables are lighter, more flexible, and can carry more data. Data is converted into a light signal using transducers like LEDs or laser diodes and introduced into the fiber's core at an angle greater than the critical angle as shown in figure 14.9.

This light signal travels through the optical fibers for long distances until it reaches the destination. At the receiving end the light signal is converted into electrical signal with the help of transducers like photo-diode, PIN diode or avalanche diode. These diodes convert light signal into electrical signal near the user end and electrical signal is finally converted into text, voice or video data as required.

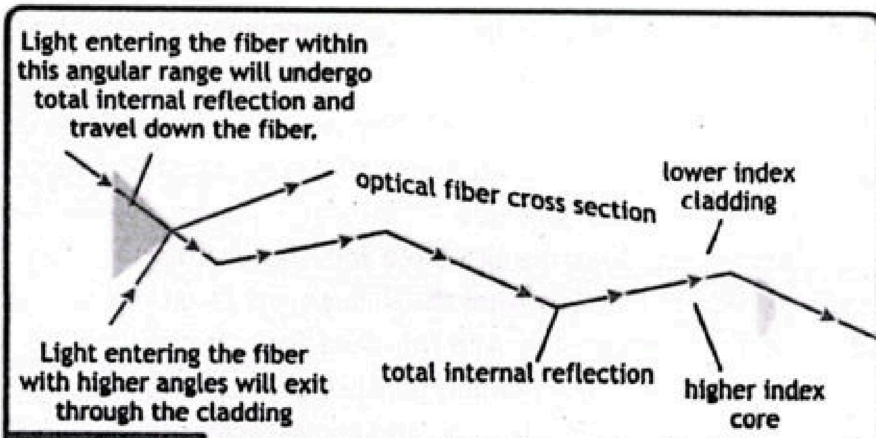


FIGURE 14.9 Light signal transmission through optical fibers

14.4 THIN LENSES

Optics is a fascinating branch of physics that explores the behavior and properties of light. One of the most intriguing aspects of optics is the study of lenses which can be defined as: **'The transparent objects that refract light in specific ways to form images are called the lenses.'**

Understanding the action of lenses is fundamental to various applications in science, technology and everyday life from eye-glasses, cameras, microscopes and telescopes etc. lenses are optical devices made from transparent materials typically glass or plastic with at least one curved surface. They work on the principle of refraction which is the bending of light as it passes from one medium to another.

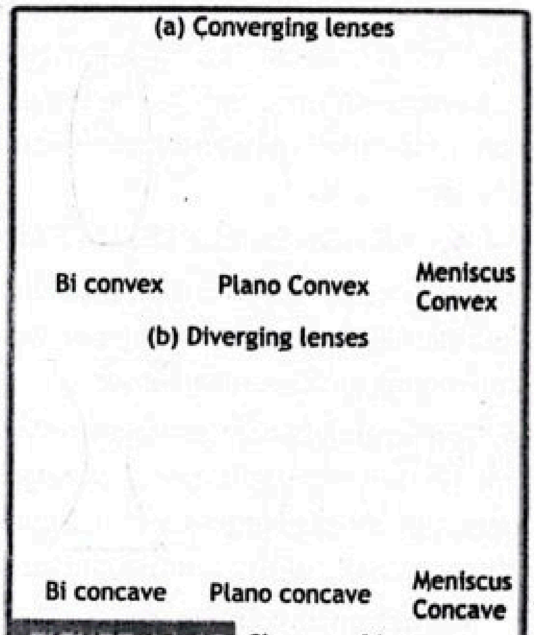


FIGURE 14.10 Shapes of lenses

Lenses are broadly classified into two main types i.e. converging (also called a convex lens) and diverging (also called a concave lens) lenses with variety of different shapes as shown in figure 14.10. There are some common terms associated with the lenses which are required to study the image formation from the lenses which can be given as:

A. Focal Length: The focal length *'f'* of a lens is the distance from the lens to its focal point (focal point may be real or virtual). For a converging lens the focal length is positive. It represents the distance from the lens to the point where parallel rays converge after passing through the lens while for a diverging lens the focal length is negative. It represents the distance from the lens to the point where parallel rays appear to diverge from (the virtual focal point).

B. Principal Axis: The principle axis is an imaginary straight line passing through the center of the lens. Light rays that pass through the center of the lens along the principle axis are not deviated.

C. Principle Focus (Focal Point): The principle focus is also called the focal point which is the point on the principle axis where parallel rays of light converge for a converging lens and appear to diverge from a diverging lens.

For a converging lens the principle focus is on the opposite side of the lens from the incoming parallel rays and for diverging lens the principle focus is on the same side as the incoming parallel rays but it appears to be behind the lens, all the above terms of a lens are shown in figure 14.11.

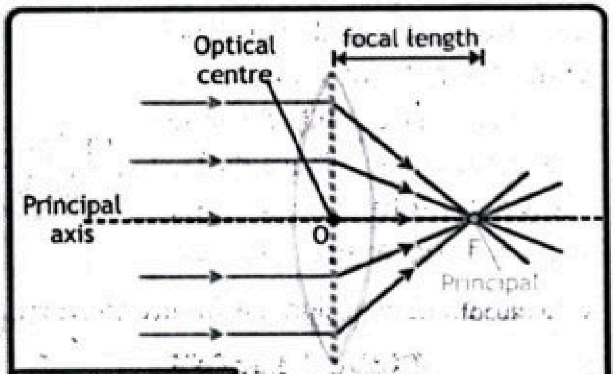


FIGURE 14.11 Lenses terms

D. Optical Centre: The centre of a lens is the point from which the principle axis passes through is called the "optical center" it is represented by *'O'*.

E. Centre of Curvature: As the lenses are the parts of spherical materials then the centre of the sphere is called the center of curvature of the lens. This is usually twice apart from the lens as that of focal point.

14.4.1 ACTION OF LENSES ON PARALLEL RAYS:

When we strike parallel light rays to a lens these light rays after refraction from the lens show a fascinating pattern. Upon the behavior of a lens to the parallel light rays lenses are classified as converging and diverging lenses.

A. Converging Lens: Convergence lens is thicker at its center and thinner at the edges. When a parallel beam of light passes through a thin converging lens (convex lens) the lens refracts the light rays and converges them to a point known as focal point on the other side of the lens. The key characteristics of this process can be given as:

- **Refraction and Convergence:** The parallel rays are bent towards the principal axis of the lens due to refraction. The curvature and the refractive index of the lens material cause this bending. After passing through the lens all the parallel rays converge at a single point on the principle axis that is the focal point of the lens.
- **Formation of Image:** The formation of image from the lens depends upon the location of the lens. The image from the converging is normally real and inverted but in some cases it may be virtual image. The behavior of converging lens towards the parallel light rays is shown in figure 14.12 (a).

B. Diverging Lens: Divergence lens is thinner at its center and thicker at the edges. When a parallel beam of light passes through a thin diverging lens (concave lens) the lens refracts the

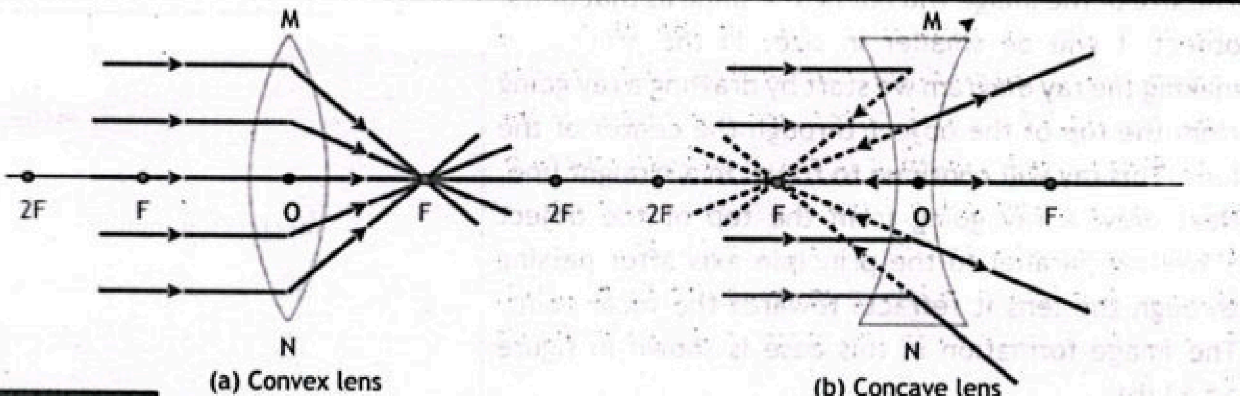


FIGURE 14.12 Action of lens on parallel rays

light rays and diverges them as if they are coming from a point known as the focal point on the same side of the lens from which the light is coming the characteristics of this process are:

- **Refraction and Divergence:** The parallel rays are bent away from the principle axis of the lens due to refraction. This divergence gives the impression that the rays are emanating from a focal point behind the lens.
- **Virtual Focal Point:** The focal point for a concave lens is virtual because the light rays do not actually converge there instead they appear to be diverging from this point when extended backward.
- **Formation of Image:** If an object is placed at infinity the image formed by the diverging lens will be at its virtual focal point and the image will be virtual, upright and diminished. The divergence of parallel light rays from a divergence lens is shown in figure 14.12 (b).

14.4.2 RAY DIAGRAMS BY THE LENSES

Lenses can be used to form images of the objects placed in front of them the location and nature of the image can be found by drawing a ray diagram. In this process we take a minimum of two light rays emerging from the object and pass them through the lens from two different points join to give us an image. The distance of the object from the lens determined the nature of the image formed.

A. Object Placed at Infinity: When an object is placed at infinity the real image is formed at the focus. The size of the image is highly diminished and it seems as an image of point size. In the process of making the ray diagram we take all the rays coming from the body as parallel because the body is at infinity hence the rays after travelling such a long distance can be considered as parallel rays and converge all the rays at focal point. The ray diagram for an object at infinity is shown in figure 14.13 (a).

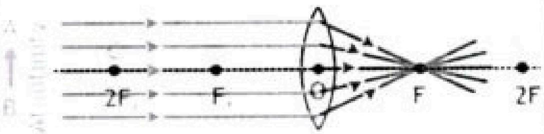
B. Object Placed Beyond 2F: When an object is placed beyond the center of curvature 'C' (beyond 2F) the real and inverted image is formed between the center of curvature and the focus.

The size of the image will not be the same as that of the object it will be smaller in size. In the process of making the ray diagram we start by drawing a ray going from the top of the object through the center of the lens. This ray will continue to travel in a straight line. Next draw a ray going from the top of the object travelling parallel to the principle axis after passing through the lens it refracts towards the focal point. The image formation in this case is shown in figure 14.13 (b).

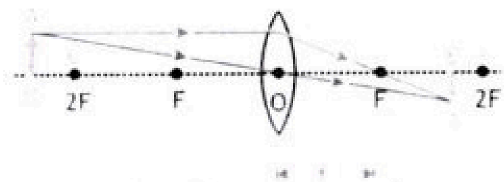
C. Object Placed at 2F: When an object is located at the center of curvature (2F), a real image is produced at the same point. The image will be the same size as the object, and it will be inverted and real. To illustrate this, start by drawing a ray from the top of the object that passes through the center of the lens, continuing in a straight line. Then, draw another ray from the top of the object that travels parallel to the principal axis; after it passes through the lens, it will refract towards the focal point. This image formation is depicted in figure 14.3 (c).

D. Object Placed between F and 2F: When an object is positioned between the center of curvature (2F) and the focal point (F), a real image is produced beyond the center of curvature. This image will be larger, inverted, and real. A ray from the top of the object that passes through the center of the lens will continue in a straight line. Additionally, a ray from the top of the object that travels parallel to the principal axis will refract towards the focal point after passing through the lens. The intersection of these two rays will determine the location of the image. This process is illustrated in figure 14.13 (d).

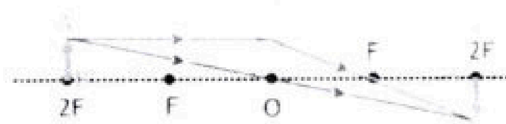
E. Object Placed at F: When an object is placed at the focal point (F) the real image is formed at infinity. The size of the image will be much larger than the object in size. The image formed will be larger, inverted and real.



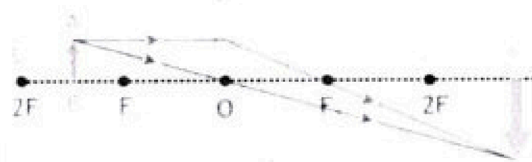
(a) object at infinity



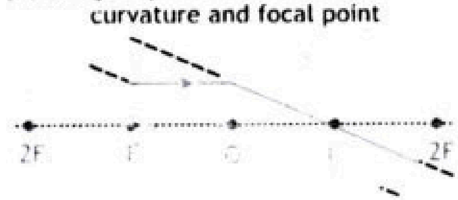
(b) object placed beyond center of curvature



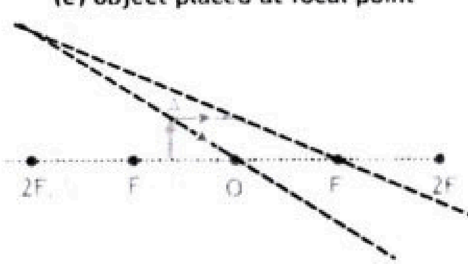
(c) object placed at center of curvature



(d) object placed between center of curvature and focal point



(e) object placed at focal point



(f) object placed inside focal point

FIGURE 14.13 Image formation in convex lens

In the process a ray going from the top of the object through the center of the lens will continue to travel in a straight line. Next draw a ray going from the top of the object travelling parallel to the principle axis after passing through the lens it refracts towards the focal point. The lines appear to move in parallel fashion but the image will be formed but at infinity. The image formation in this case is shown in figure 14.13 (e).

F. Object Placed inside F: When an object is positioned at the focal point (F), a virtual image is created beyond the center of curvature and on the same side of the lens as the object. This image will appear larger larger, upright, and virtual. A ray originating from the top of the object and passing through the center of the lens will continue in a straight line. Next, draw a ray from the top of the object that travels parallel to the principal axis; after passing through the lens, it will bend towards the focal point. As these two rays diverge, they will not meet, so we extend dotted lines backward until they intersect. The intersection point of these dotted lines indicates the location of the image. This process is illustrated in figure 14.13 (f).

14.4.3 LINEAR MAGNIFICATION

Linear magnification is a fundamental concept in optics particularly when dealing with lenses and mirrors. It can be defined as: '**The ratio of height (or length) of image to the height (or length) of an object is called the linear magnification.**'

It describes how much an image appears larger or smaller compared to the actual object. It is also known as lateral magnification or transverse magnification. Mathematically it can be given as:

$$M = \frac{I}{O} \quad \text{—} \boxed{1}$$

Here 'M' is the linear magnification, 'I' is the height of the image and 'O' is the height of the object. Measure the length of the object you are examining which can be done using a ruler or any other measuring tool then determine the length of the image produces by the lens this is the size of the image as it appears in the lens or on a screen. Some of the characteristics of linear magnification are given in the table 14.2.

Table 14.2 LINEAR MAGNIFICATION

Condition	Explanation
$\|M\| > 1$	The image size is less than that of object size
$\|M\| < 1$	The image size is greater than that of object size
$\|M\| > 0$	The image has the same vertical orientation as the object called an upright image
$\|M\| < 0$	The image has the opposite vertical orientation as the object called an inverted image

In some cases the size of images or objects are so small that they cannot be measured easily for such condition we can find linear magnification with the help of distances of image and object from the lens. It is very interesting fact that the ratio of distance of image from the lens to the distance of object from the lens is same as that of the ratio of sizes of image to the object. We can also define linear magnification as: **'The ratio of the distance of image from the lens to the distance of object from the lens is called the linear magnification.'** Mathematically,

$$M = \frac{q}{p} \quad \text{—} \boxed{2}$$

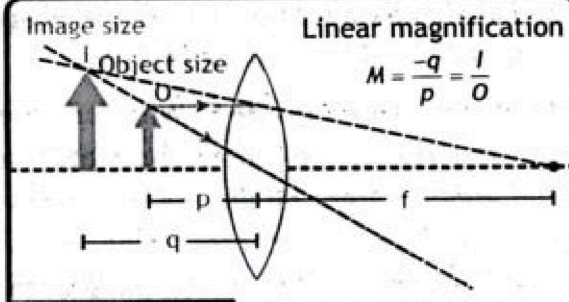


FIGURE 14.14 Linear magnification

Here 'M' is the linear magnification, 'q' is the distance of the image from the lens and 'p' is the distance of the object from the lens. Measure the distance of the object you are examining which can be done using a ruler or any other measuring tool then determine the distance of the image produces by the lens.

From equation 1 and 2 we can write as: $M = \frac{I}{O} = \frac{q}{p}$ — $\boxed{14.8}$

For real image we use the distance of image '+q' as positive and for virtual image we use the distance of image '-q' as negative. The light ray diagram for calculating the linear magnification is shown in figure 14.14.

Example 14.5

Find the distance and height of the image if the object of height 2cm is placed at 6cm from a converging lens with magnification as 3. Also find the nature of image if the focal point of the lens is 5cm from the lens.

GIVEN:
Heigh of object 'O' = 2 cm
Distance of object 'p' = 6 cm
Magnification 'M' = 3

REQUIRED:
Height of image 'I' = ?
Distance of image 'q' = ?
Nature of image

SOLUTION:

The relation for magnification is: $M = \frac{I}{O}$ or $I = MO$ Using values $I = (3)\ (2\ cm)$

Therefore $\boxed{I = 6\ cm}$ — ANSWER

To find the distance of image we can again use magnification relation as: $\frac{I}{O} = \frac{q}{p}$

or $q = p \times \frac{I}{O}$ Using values $q = (6\ cm) \times \frac{(6\ cm)}{(2\ cm)}$

Therefore $\boxed{q = 18\ cm}$ — ANSWER

As the object is placed outside of the focal point hence the image formed in this case will be real, inverted, enlarged and opposite side of the lens as that of object.

14.4.4 DIFFERENCE BETWEEN REAL AND VIRTUAL IMAGES

Lenses can make two types of images one is called a real image and the other is called as virtual image. The differences between real and virtual images are given in table 14.3.

Table 14.3 DIFFERENCE BETWEEN REAL AND VIRTUAL IMAGES

Real Image(s)	Virtual image(s)
can be caught on the screen	cannot be caught on the screen
is always inverted	is always erect
formed when the rays of light after reflection or refraction actually meet at some point	formed when the rays of light after reflection or refraction appear meet at some point
formed by the actual intersection of light rays	formed by the imaginary intersection of light rays
can be formed in a screen	can only be seen in mirrors
formed by only convex lens	concave lens, convex lens and plane mirrors also
formed on the other side of lens then the side of the object	formed on the same side of lens as the side of the object
Example is the image on our TV screen	Example is our reflection in mirror

14.5 APPLICATIONS OF LENSES

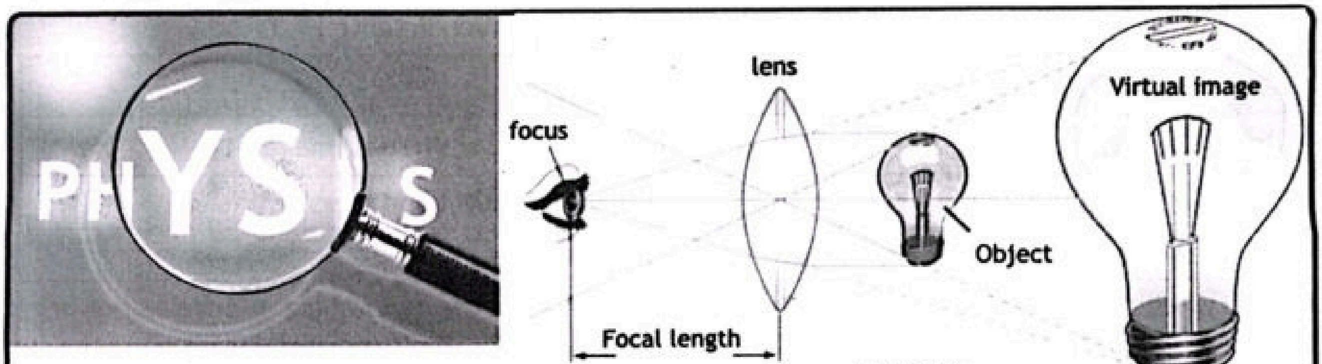
Lenses are fundamental optical elements that play an important role in a wide range of scientific, engineering, medical and everyday life applications from the simple magnifying glass to complex systems. They are used in consumer optics like eyeglasses, camera and binoculars, microscope optics like scientific and medical research and diagnostics, telescope optics like using telescopes to explore the cosmos, photographic optics like capturing images. Some of the commonly used applications of lenses are given here:

14.5.1 MAGNIFYING GLASS

A single lens is used as magnifying glass which is a simple optical device designed to magnify objects. The lens used in the magnifying glass is convex lens. As we know that when an object is placed near the lens such that the object's distance from the lens is less than the distance of focal point of the lens, it produces an enlarged, erect and virtual image of the object. The eye perceives this image as being larger than the actual object. A magnifying glass is shown in figure 14.15 (a). To use a magnifying glass, we have to take care of the following steps:

- **Position:** The position of object is crucial in the use of magnifying glass. Hold the magnifying glass close to the object you want to magnify.
- **Distance:** Move the lens closer to or further from the object until the image comes into clear focus.

- **Viewing:** Look through the lens to see the magnified image the optical viewing distance is usually a few centimeters away from the object.



(a) Picture (b) Working

FIGURE 14.15 Magnifying glass

14.5.2 DISPERSION OF LIGHT BY PRISM

A prism is an optical element which is usually made of glass with triangular and rectangular sides. It has the ability of bending the light passing through it due to refraction. As we know that the visible light has a range of wavelengths and refraction of light depends upon the wavelength hence different wavelengths diffract at different extent which disperse the light.

Dispersion of light can be defined as: **'The splitting of white light into seven constituent colors when passed through the prism is called the dispersion of light'.**

The white light that travels through the prism is separated due to the processes of refraction and dispersion. As white light enters the prism, it slows down and bends toward the normal line. Each color of light has a unique wavelength, and as the light moves through the prism, each wavelength is refracted by varying degrees. This results in the shorter wavelengths, such as violet and blue, bending more than the longer wavelengths like red and orange. Consequently, the light that exits the prism is split into seven distinct colors, ranging from red to violet. This collection of colors is known as the visible light spectrum as illustrated in figure 14.16 (a).

Beyond the visible spectrum, there are wavelengths of light that the human eye cannot perceive, such as infrared and ultraviolet. These wavelengths can also be dispersed by the prism, but since they are invisible, alternative detection methods are necessary. One such method involves thermometers equipped with sensors that can detect a broad range of wavelengths. These thermometers can sense infrared radiation emitted by objects, which correlates with their temperature. When the dispersed light from the prism reaches these thermometers, they can detect both infrared and visible light. By measuring the intensity of the infrared radiation, the thermometer can determine the temperature of the emitting body. These thermometers can also

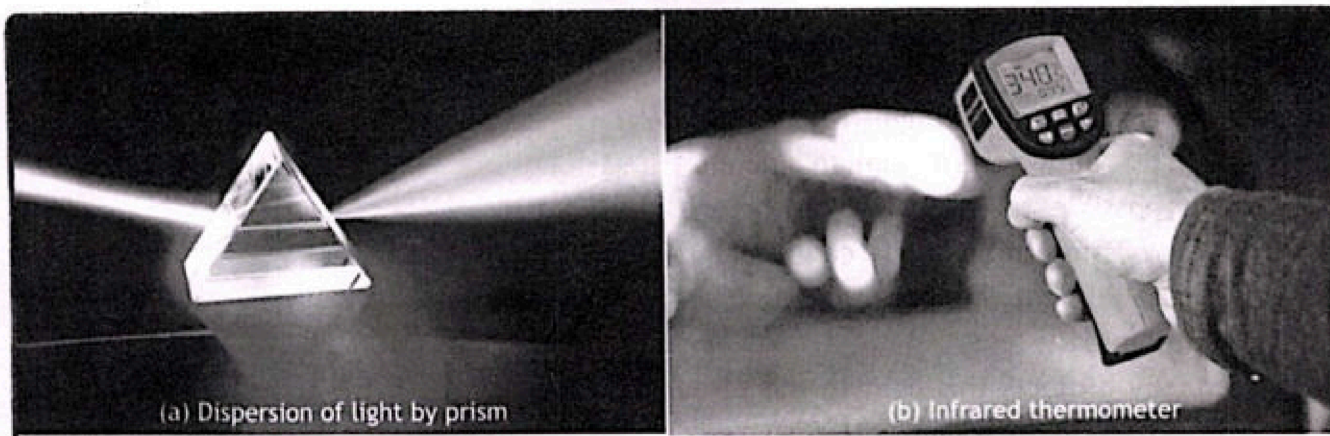


FIGURE 14.16 Light dispersion

measure human body temperature without direct contact. An example of such an infrared thermometer is shown in figure 14.16 (b).

14.5.3 SOME OPTICAL DEVICES WITH SINGLE LENS

Lenses have wide range application in everyday life. Even a single lens can be used to make many valuable devices like a magnifying glass, camera, projector and a photographic enlarger etc. We can show how these devices form images with the help of ray diagrams.

A. Camera: Most people today have a mobile phone with a built-in camera, so we are all familiar with cameras. Figure 14.17 illustrates the process of how a photographic camera creates an image. In simple explanation a camera has a lens and an image film placed in line to the lens. Every time the button is pressed, light from an object positioned *'p'* units away from the camera lens enters the lens. The light then goes through a shutter that opens briefly to allow the light from the object to reach the photographic film or CCD. Here, the information in the form of light about the object is received, creating a real and inverted image of the object at a distance *'q'* from the lens.

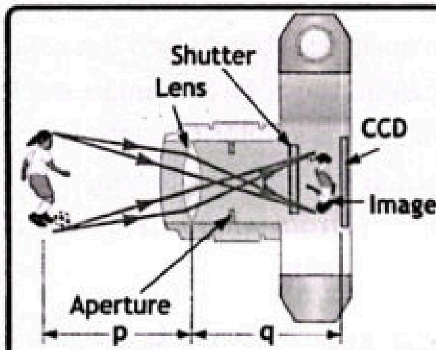


FIGURE 14.17
Image formation in camera

B. Projector: We commonly use slide projectors in our classrooms, seminar rooms and halls which show an enlarged image on the main screen or wall. The slide projector is also a single lens device. The working of the projector is shown by the ray diagram as shown in figure 14.18. In the projector there is a bulb which produces light behind it we use a concave mirror which reflects back the light coming from the bulb to increase the intensity of light so that a sharp and detailed image can be formed by the projector.

The next part of the projector is the condensing lens the aim of the condenser lens in a projector is to align the light rays into a straight path this allows the maximum amount of the light possible to reach the projector screen. After passing through the condensing lenses the parallel light rays pass through the slide and enter into the lens.

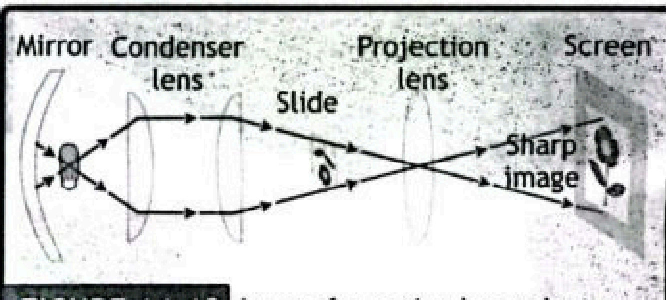


FIGURE 14.18 Image formation by projector

The lens finally projects this light to the screen by magnifying it many times so that a small object's image may be seen in a very large size.

C. Photographic Enlarger: The enlarger in photography is a device that gives an image of object larger than the original size. It consists of a projection assembly which includes an illumination system like a bulb, a lens for projecting the image onto the photographic paper and a mechanism for focusing the image on the paper.

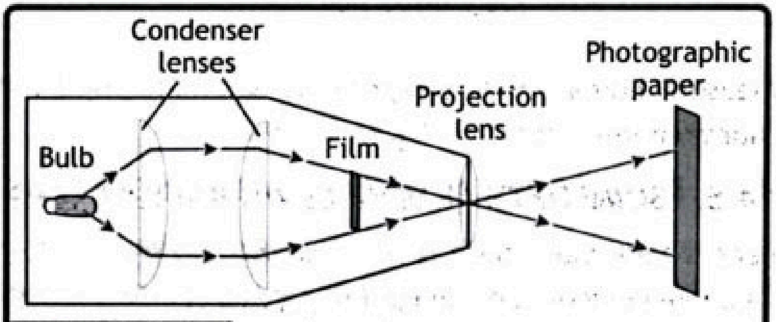


FIGURE 14.19 Photographic enlarger

An optical system called the condenser is used in it which is a system of lenses that focus the beam of light towards the enlarging lens through the film. The optical system of the photographic enlarger is similar to that of the system used in projector and is shown in figure 14.19. Here the light of bulb passing through the condenser lenses which focus the light on film and hence falls on the lens from where the lens makes an enlarge image on photographic paper. The final image is made clear by using intense light to give more details and enlarged as compared to the object.

14.6 VISIBLE SPECTRUM

Among the large ranges of electromagnetic radiations, only a small portion is visible to the human eye. This portion is referred to as the visible spectrum, which is categorized into seven distinct color ranges How we see colors? Why the sky is seen blue? Why the traffic signal to stop the vehicles is seen as red? The answer to all these questions depends on how we see objects. A Muslim scientist Al-Hazen (Ibn al Haithem) gave the concept of vision. When light strikes an object, it experiences two main phenomena: some of the light is absorbed by the object (or passes through it), while the remaining light reflects off the object and enters our eyes, allowing us to see. If an object absorbs all wavelengths of light and reflects none, we perceive it as black. If it absorbs all wavelengths except for red, we see it as red. Similarly, if it absorbs all wavelengths except blue, it appears blue to us. When only one color's wavelength hits an object and reflects back, we perceive the object's color as that of the incident light, as illustrated in figure 14.20. The visible spectrum consists of seven primary colors: red, orange, yellow, green, blue, indigo, and violet, each with its own range of wavelengths and frequencies. In order of frequency and wavelength the seven colors can be given as:

A. Red: Light of red color has the largest range of wavelengths i.e. ranging from 620-750 nm which are among the largest wavelengths in visible spectrum. Conversely this range has the lowest frequencies ranging from 400-480 Thz.

B. Orange: Light of orange color has larger wavelengths than the red color and smaller than rest of the colors. The wavelength range for orange color is 590-620 nm with frequencies from 480-510 Thz.

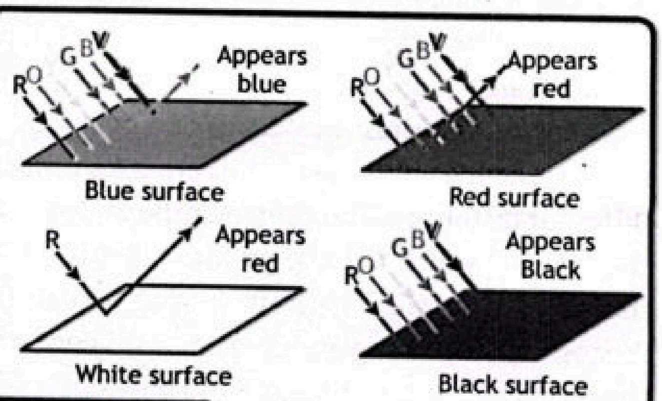


FIGURE 14.20 How colors appear to us

C. Yellow: Light of yellow color has larger wavelengths than the red and orange colors and smaller than rest of the colors. The wavelength range for yellow color is 565-590 nm with frequencies from 510-530 Thz.

D. Green: Light of green color has intermediate wavelength range within visible spectrum. The wavelength range for green color is 500-565 nm with frequencies from 530-600 Thz.

E. Blue: Light of blue color has larger wavelengths than the indigo and violet colors and smaller than rest of the colors. The wavelength range for blue color is 485-500 nm with frequencies from 600-620 THz.

F. Indigo: Light of indigo color has larger wavelengths than the violet color and smaller than rest of the colors. The wavelength range for indigo color is 450-485 nm with frequencies from 620-670 THz.

G. Violet: Light of violet color has the smallest wavelengths in the entire range of the visible spectrum and highest frequencies among all the colors in visible light. The wavelength range for violet color is 400-450 nm with frequencies from 670-790 THz.

14.7 HUMAN EYE AND COLOR PERCEPTION

The human eye is one of the natural optical instrument which is the most interesting and important of all the optical instruments. It performs a vast number of functions. A Muslim scientist Ibn al Haithem was the first scientist who explained the image formation by our eyes, he was known as the father of optics. He recognized that light reflected from objects entered the eye through the lens and was passed to the optic nerves. The basic structure of human eye is shown in figure 14.21. The cornea and lens form a system that acts like a single thin lens. For clear vision a real image must be projected on the retina which lies a fixed distance from the lens. The flexible lens of the eye allows it to adjust the radius of curvature of the lens to produce an image on the retina for objects at different distances. The centre of the image falls on the "fovea" which has the greatest density of light receptors and the sharpest in the visual field. Processing of visual optic nerve impulses begins from the retina and end into the brain. These optic nerves convey the signals by the eye to the brain. The cornea acts like a thin lens with approximate focal length of 2.3 cm and the lens of eye has an approximate focal length about 6.4 cm. the image formed by the eye is much like the image made by the convex lens i.e. a real and inverted image. Although images formed in the eye are inverted the brain inverts them once more to make them seem erect. The nearest point an object can be placed so that eye can form a clear image of that object is called the "near point" of the eye and it is 25 cm from the eye.

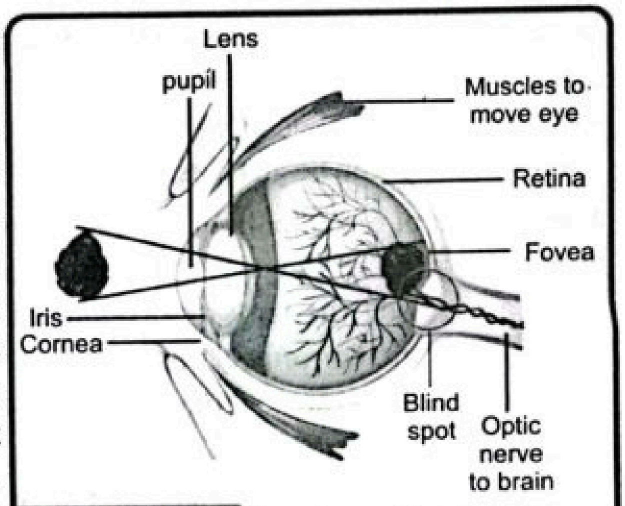
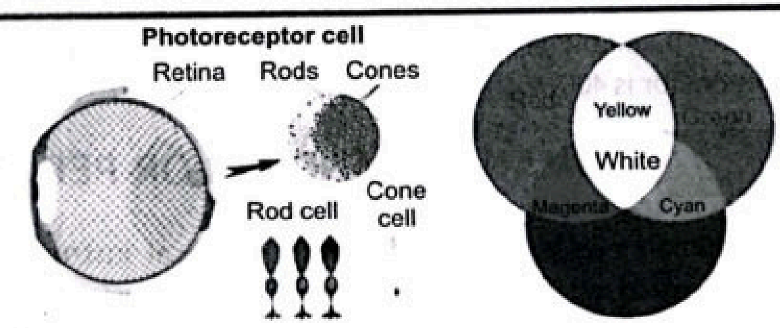


FIGURE 14.21 Structure of human eye

14.7.1 COLOR PERCEPTION

In the figure 14.35 we see that the back of the eye is lined with a thin layer called retina this is where the photoreceptors are located. The retina also contains the nerves that tell the brain what the photoreceptors are seeing. Photoreceptors are the special cells in the eye's retina that are responsible for converting light into signals that are sent to the brain. Photoreceptors give us our color vision and night vision. There are two types of photoreceptor cells i.e. rods and cones as shown in figure 14.22 (a).

Rods work at very low levels of light hence we use them for night vision because a very less amount of light can activate a rod. Rods cannot help in color vision that is why at night we see everything in almost grey scale. A human eye has over 100 million rod cells. On the other hand, cones require a lot more light and they are used to see color. The



(a) Rod and cone cells in the eye (b) Overlap of rods

FIGURE 14.22 Human eye and color perception human eye has 6 million cones many of these are packed into the fovea which helps with the sharpness or details of images. We have three types of cones red, blue and green and each cone is most sensitive to a specific color of light still they can detect other colors also. This is possible due to the overlap of cones and how the brain integrates the signals sent from the cones as shown in the figure 14.22 (b). As every cone upon reception of light stimulate specific color the brain determines the color perception for example if red cone and green cone equally stimulated the brain gives the yellow color. The brain processes the electrical signal from the cones in the retina and combines them to produce the color perception. The three color vision system enables human to perceive a rich spectrum of colors by mixing the combination of red, blue and green. In fact, rods are responsible for night vision and motions around us while the cones are responsible for the colorful view of this world for us. Due to having cones of three different colors human have trichromatic vision. Some animals have dichromatic vision as they have only two types of cone cells for example dogs and cats have dichromatic vision and they can primarily see shades of blue and yellow color. Dichromatic vision is advantageous for those animals which use to operate in dim light like the hunters. Many birds have tetra-chromatic vision i.e. they have four different types of cone cells in their eyes. In addition to red, blue and green they have one extra cone which can detect ultraviolet light this enables the birds to see colors and patterns which are invisible to humans.

14.7.2 FORMATION OF IMAGE ON NORMAL EYE

The image for a normal eye is made on retina i.e. all the rays coming from the object focused on retina which makes the clear image of the object on eye. The ray diagram for the formation of image by eye on retina is shown in figure 14.23. The light rays from the object after converging from the lens of eye focused on retina. Consider the path of two light rays coming from the top of the object named '1' and '2' again coincide on retina similarly the rays coming from the bottom of the object also coincide at retina to make a clear image on retina.

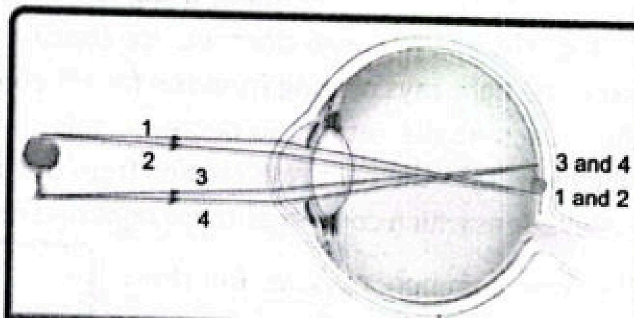


FIGURE 14.23 Image formation by eye

14.7.3 SHORT-SIGHTEDNESS

The short-sightedness or myopia is the condition in which a person can see near objects clearly but distant objects appear blurry. This condition usually occurs in early ages or in adults which is due to the reason that the eye over converges the nearly parallel rays coming from the distant object due to which they cross in front of the retina and hence the image is formed before

SCIENCE TIDBITS

Mantis Shrimp: live in warm, shallow waters in the oceans, they possess an extraordinary vision system that sets it apart from most other animals. They have 12 to 16 color channels which make them to distinguish a much broader spectrum of colors.

They can see ultraviolet light which help them underwater lifestyle and for catching their prey. They can also detect polarized light (the light which has the oscillations in only one direction). As under-water the light becomes polarized after travelling some distance and mentis shrimp perceive this polarized light which is helpful for them for hunting and communication the eyes of a mantis shrimp are shown in figure.

reaching to retina as shown in figure 14.24 (a). As it is seen from the figure that the rays reaching retina are not focused but they are dispersed and hence the image formed on the retina will by blurry.

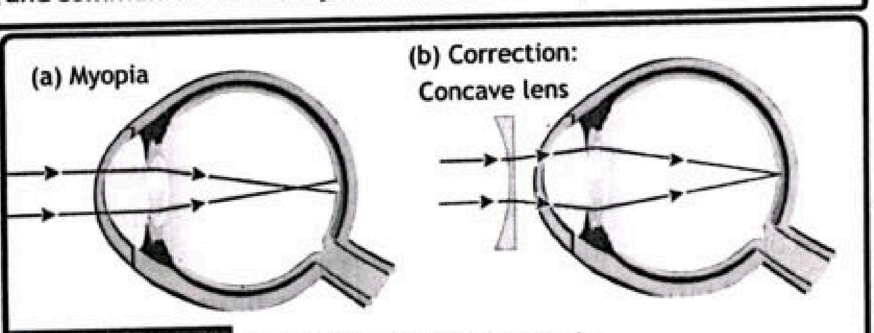


FIGURE 14.24 Short-sightedness or myopia

Correction: The short-sightedness can be corrected by using lenses as in eye-glasses or in the form of contact lenses. In both of the above corrections we use concave lens. As the eye in myopia condition, converges more the light rays coming from the far off objects which results in the cross of light rays before they reach at the retina. To decrease this convergence of the eye lens we use a concave lens which diverges the light rays coming from the object then more spread light rays are received by the eye-lens which converges these light rays exactly on the retina as shown in figure 14.24 (b).

The two common reasons for short-sightedness are the thinning of the eye-lens or the size of the eye to be too long. If the eye-lens becomes thin it converges more and focus the image before retina similarly if the length of eye increases the eye-lens focus at normal distance but due to long eye retina is moved backward and image does not form on retina as shown in figure 14.25.

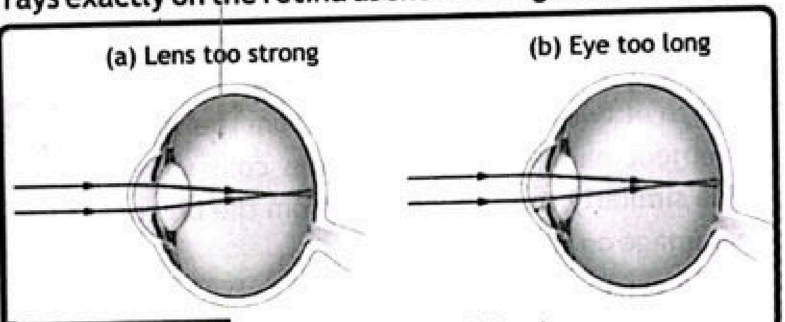


FIGURE 14.25 Reasons of Short-sightedness

14.7.3 LONG-SIGHTEDNESS

In the normal eye when the object is placed at near point of the eye the light rays coming from the object after converging from the eye-lens meet at retina and make a clear, real and inverted image which can be seen as distinct image of an object as shown in figure 14.26 (a) The long-sightedness or hyperopia is the condition in which a person can see distant objects clearly but near objects appear blurry to him. Hyperopia is also called as hypermetropia.

This condition usually occurs in elderly ages, which is due to the reason that the eye converges less the nearly parallel rays coming from the nearer objects due to which they cross after passing the retina and hence the image is formed behind reaching to retina as shown in figure 14.26 (b) as the object is not placed at near point (N) in spite of it the object is placed nearer than the near point of the eye at (N′). As it is seen from the figure that the rays reaching retina are not focused but they are dispersed and hence the image formed on the retina will by blurry.

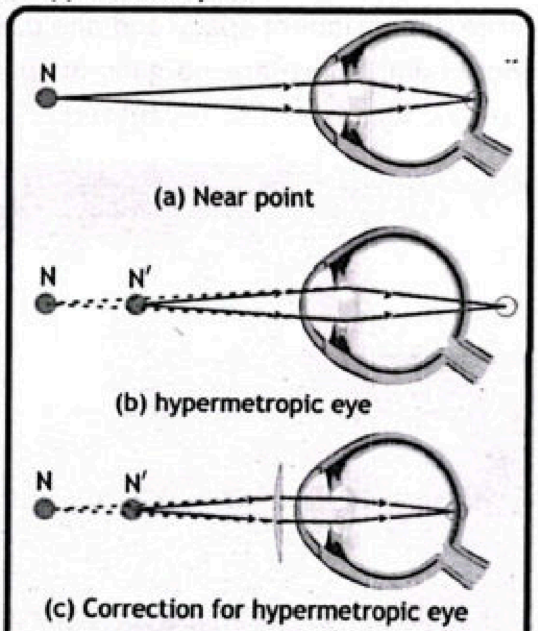


FIGURE 14.26 Long-sightedness

Correction: The long-sightedness can be corrected by using lenses as in eye-glasses or in the form of contact lenses. In both of the above corrections we use convex lens. As the eye in hypermetropia condition, converges less the light rays coming from the nearer objects which results in the cross of light rays after they passed by the retina. To increase this convergence of the eye lens we use a convex lens which additionally converges the light rays coming from the object then less spread light rays are received by the eye-lens which converges these light rays exactly on the retina as shown in figure 14.26 (c).

The two common reasons for long-sightedness are the thickening of the eye-lens or the size of the eye to be too short. If the eye-lens becomes thick it converges less and focus the image after retina similarly if the length of eye decreases the eye-lens focus at normal distance but due to short eye retina is moved forward and image does not form on retina as shown in figure 14.27.

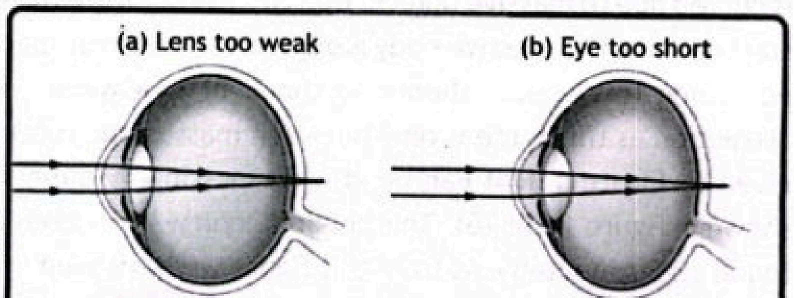


FIGURE 14.27 Reasons of long-sightedness

14.8 GRAVITATIONAL LENSING

As we know the classical view of gravity i.e. every point mass in this universe attracts any other point mass towards it with a force known as the force of gravitation. This force depends upon the magnitude of masses and distance between the point masses. Einstein gave the modern view of gravitation which is somehow different to the classical view of gravitation. He gave the idea of curvature of space-time around the massive bodies in his famous general theory of relativity. In this theory space time also called space-time continuum is a mathematical model that fuses the three dimensions of space and one dimension of time into a single four dimensional space-time continuum. There are no gaps in space or time as Einstein showed that time and space are inseparably mixed. Each event requires three space dimensions and one time dimension.

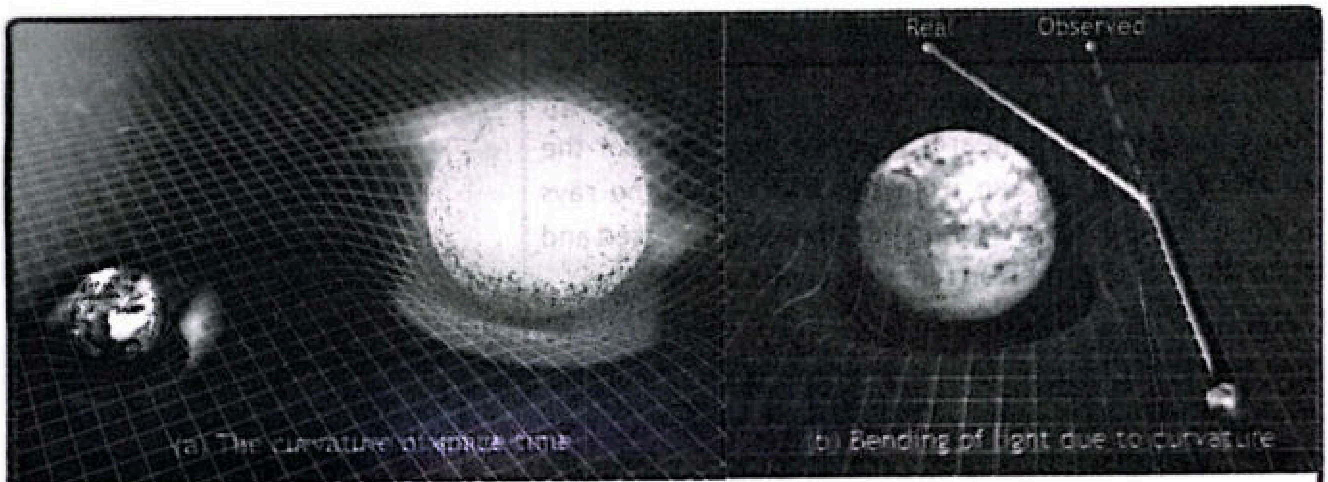


FIGURE 14.28 Generation of gravitational lensing

To understand it you can take an example of space time as a fabric of elastic material when you placed a heavy object upon it you observe that the massive body makes a curve in the fabric having center of curve at the location of body. Similarly, he took space and time as a fabric and it is curved due to massive bodies. Due to this curvature the lighter bodies when come close to them start orbiting the massive body along the curvature of space and time as shown in figure 14.28 (a). According to classical theory as the light is a wave and wave cannot feel the gravitational attraction as this force is only between masses but according to the modern view of gravitation given by Einstein light can bend while passing by a massive body due to curvature of space as shown in figure 14.28 (b). This phenomenon was not given attention at that times but later it was found experimentally. As from this figure we have seen that light bent towards a mass producing an effect much like a converging lens hence it is called as "gravitational lensing" which can be defined as: **'The phenomenon in which a massive celestial body causes a sufficient curvature of space-time for the path of light around it to be visibly bent as if by a lens is called gravitational lensing.'**

The body causing the light to curve is called a gravitational lens. For this phenomenon to be observed the body should be massive enough like a galaxy, a black hole or a cluster of galaxies etc. On galactic scale the light from a distant galaxy could be lensed into several images while passing

POINT TO PONDER

Gravitational lensing serves as a powerful tool for finding the distribution of dark matter (it is invisible glue that keeps stars, dust and gasses together in galaxies and make up majority of galaxy's mass) and dark energy in the universe as dark matter exerts gravitational influence without emitting light. Future advancements in observational techniques such as next generation telescopes and surveys promise to revolutionize our understanding of the universe unveiling new discoveries and insights into the nature.

close by another galaxy on its way to reach the Earth. Einstein predicted this effect but he considered it unlikely that we would ever observe it. But in 1979 gravitational lensing was observed and it becomes an observable phenomenon when the double Quasar (Quasars are the highly luminous cores of distant galaxies) was discovered became the first example of lensed object, as it was behind another galaxy i.e. that galaxy lies exactly between the Earth and the double Quasar. This quasar was named as "double" due to a special effect of the phenomenon of gravitational lensing i.e. gravitational lensing can lead to the formation of multiple images of the same distant source. This can be explained by the figure 14.29 (a).

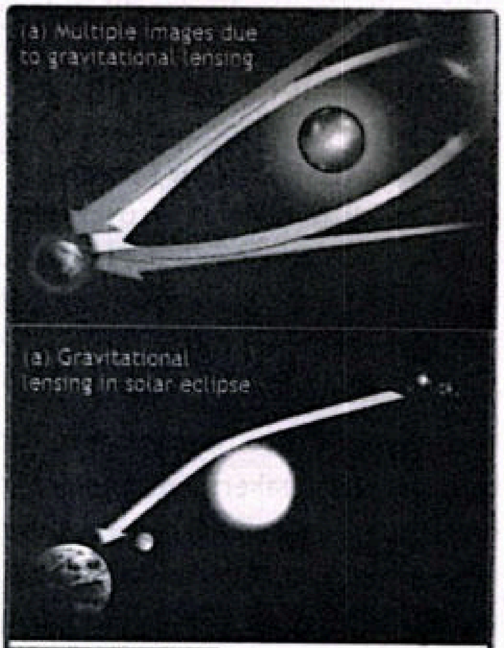


FIGURE 14.29 Gravitational lensing

As from the above figure it is seen that the light coming from the source is bending from both sides of the intervening galaxy and making two images of the source. Similarly in some cases when the source lies exactly behind a galactic object due to bending of light all around the intervening object makes a ring of light around it and is called "Einstein rings". The first time the bending of light due to a heavy object was found in 1919 during the observation of total solar eclipse and found that the light was bent by the amount predicted by the general relativity as shown in figure 14.29 (b).

14.9 ACOUSTIC LENSING

Sound is a form of energy which can be transmitted from one place to another. It is the form of pressure wave created by the vibration of bodies. The science of sound is known as acoustics and can be defined as: **'The branch of physics that deals with examining and studying the sound is called acoustics.'**

It deals with the production, transmission and effects of sound. The main application of acoustics is to make the music or speech sound as good as possible. When a sound wave is used as an information carrier or energy orientation method its energy gradually reduces during propagation. Therefore, we must use different techniques to focus sound waves to efficiently utilize sound energy.

Acoustic lenses can focus the energy of sound waves in a relatively small space which is a region with high energy density as shown in figure 14.30. In this figure an electrical signal is converted into sound which is released from a speaker (which acts like an object plane) then we use acoustic lens which focuses these sound waves on a single point at the end which acts like the image plane. Acoustic lenses manipulate sound waves in a manner similar to how optical lenses handle light and can be defined as: **'A lens that brings sound waves to a focus by having walls of collodion film and being filled with a heavy gas, which retards and refract sound waves, is called acoustic lens.'**

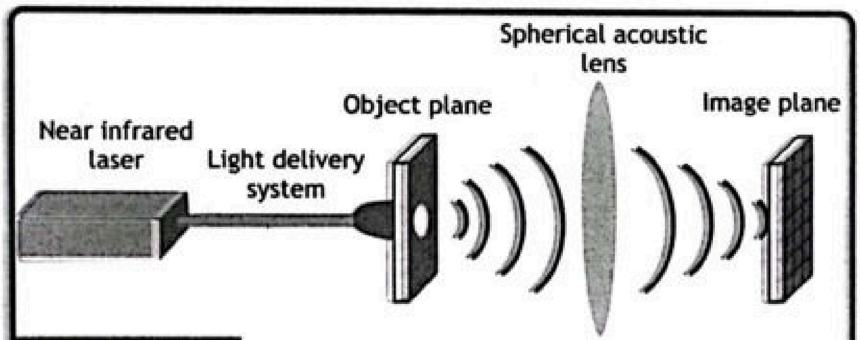


FIGURE 14.30 Focusing sound with acoustic lenses

The aim of the acoustic lens is to focus sound in much the same way that an optical lens focuses light. In loudspeakers a mechanical device used to improve the dispersion of high frequencies so that dispersion is much more uniform across the audible spectrum. A high frequency loudspeaker mechanical acoustic lens spreads a single point sound source into a parallel wave front.

14.9.1 TYPES OF ACOUSTIC LENSES:

There are two commonly used types of acoustic lenses i.e. the slant-plate lenses and perforated-plate lenses.

A. Slant-Plate Lens: The design of the most commonly seen acoustic lens is the slant-plate lens which utilizes a series of plates with carefully calculated hyperbolic shapes which results in a horizontal response patterns. A slant-plate lens is shown in figure 14.31 (a). They make to select portion of expanding pressure wave to travel farther than other portions of the wave this tend to shape the pressure wave by controlling the dispersion.

B. Perforated-Plate lens: Perforated-plate lenses consist of a collection of perforated barriers at the horn

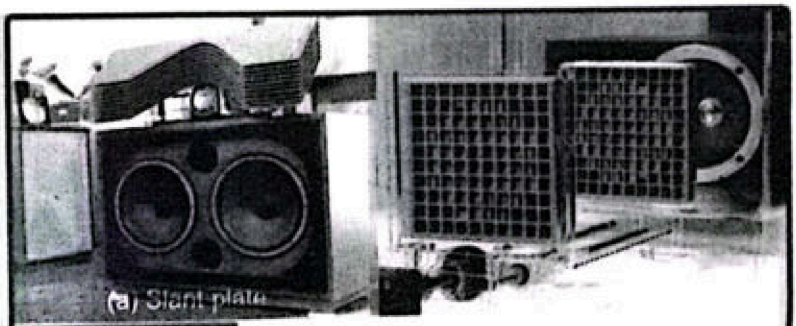


FIGURE 14.31 Types of acoustic lenses

mouth. These perforated screens are actually ring shaped with varying sizes of center cutouts. These perforated plate lenses can diverge as well as converge the sound just like diverging and converging lenses do with the light signals. Perforated plate lens is shown in figure 14.31 (b).

14.9.2 MATERIAL AND SHAPES OF ACOUSTIC LENSES:

Acoustic lenses can be made from various materials like plastic, epoxy, rubber and liquids due to reasons given below:

A. Plastic: Plastic materials are commonly used for making acoustic lenses because it can easily be fabricated and have good acoustic properties.

B. Epoxy: Epoxy is also commonly used material for making acoustic lenses it offer good sound permeability and can be molded into specific shapes.

C. Rubber: Rubber is used in acoustic lenses for their flexibility and the ability to deform the lenses.

D. Liquid: Some acoustic lenses use liquid filled chambers to converge or diverge sound waves.

Similarly acoustic lenses come in different shapes each shape serves specific purpose. They can be shaped in spherical, ellipsoidal, parabolic and gradual geometric curves as explained here:

E. Spherical Acoustic Lenses: These acoustic lenses have curved surface like a sphere, they focus or diverge the sound waves according to their curvature.

F. Ellipsoidal Acoustic Lenses: These are similar to spheres but a little elongated in one direction (somehow like an egg) they can focus sound waves in a specific direction.

G. Parabolic Acoustic Lenses: These acoustic lenses have a parabolic shape and are excellent at focusing sound waves to a single point.

H. Gradual Geometric Acoustic Lenses: Lenses with gradual geometric curves achieve gradient refractive index distribution allowing precise acoustic focusing.

Acoustic lenses are important for applications like under water imaging, sonar systems and medical ultrasound etc. They are also used in non-destructive testing of materials which are opaque to light but sound waves can penetrate the material and find the voids and cracks without destructing the material. Now researchers are exploring 3-D printed meta-materials with balcony like structures to create impact resistant acoustic lenses.

SUMMARY

- **Optics** is the science of light and its interaction with matter.
- **Reflection of light** is when a ray of light approaches a smooth polished surface and bounces back is called reflection.
- **First law of reflection** states that the incident ray, the reflected ray and the normal all lie in same plane.

- **Second law of reflection** states that the angle of incident ray is equal to the angle of the reflected ray.
- **Refraction of light** is the phenomenon in which the light ray's direction changes when it enters from one medium to another.
- **Speed of light in vacuum** is constant but in other transparent media the speed of light decreases, its speed depends upon the density of the medium.
- **Refractive index** is the measure of bending of a light ray when passing from one medium to another.
- **Perspex Block** is a tough transparent plastic block which is used instead of glass blocks.
- **Total internal reflection** is the phenomenon in which a light ray travelling in denser medium bounces back to the same medium after striking the boundary of a rarer medium.
- **Critical Angle** is the angle of incident light ray for which in spite of transmission into other medium the light ray moves along the boundary between the two media.
- **Optical Fibers** are the doubly refractive indices concentric tubes of glass or plastic which are used for transmission of light using the phenomenon of total internal reflection.
- **Lenses** are transparent objects that refract light in a specific way to form images.
- **Convex Lens** is a type of lens which is thick from the center and thin from the outer edges it converges the parallel light rays to a single point.
- **Concave Lens** is a type of lens which is thin from the center and thick from the outer edges it diverges the parallel light rays.
- **Focal length** is the distance from the lens to its focal point for a converging lens the focal length is positive while for a diverging lens the focal length is negative.
- **Magnifying glass** is a single lens device which is used to see bigger images of the objects.
- **Dispersion from a prism** is the phenomenon in which white light splits into its seven constituent colors due to different extent of refraction.
- **Near Point** is the minimum distance at which if the object is placed we have clear image on our retina.
- **Gravitational Lensing** is the phenomenon in which light bends while passing by a heavy galactic object due to its strong gravity.
- **Acoustic Lensing** is the technique in which some materials are used to focus or diverge sound waves.

EXERCISE

MULTIPLE CHOICE QUESTIONS

QI. Choose the best possible option in the following questions.

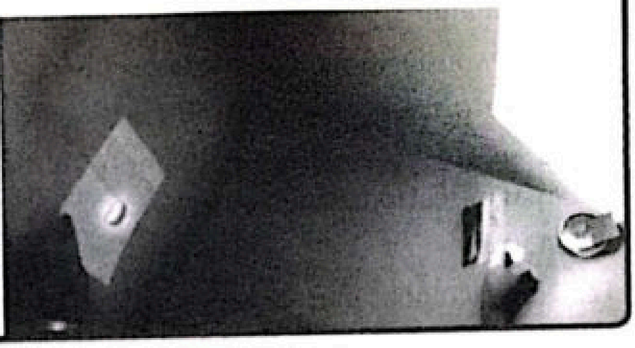
1. A glass slab is dipped in a transparent liquid having same refractive index as that of glass slab. We cannot see the boundary of the two media (glass and liquid) due to ___ refraction.
   A. Maximum B. Minimum C. Zero D. Unit
2. An incident ray makes an angle of 45° with a plane mirror. The angle of reflection is:
   A. 30° B. 45° C. 60° D. 90°
3. Two plane mirrors are arranged parallel facing each other. The image(s) formed may be:
   A. One B. Two C. Four D. Infinite
4. The apparent flattening of the Sun at the dawn and dusk is due to phenomenon of:
   A. Refraction B. Reflection C. Dispersion D. Polarization
5. On summer days you see the reflections on roads which is called mirage. It is due to:
   A. Refraction B. Reflection C. Dispersion D. Total internal reflection
6. The colors in the rainbow are formed by:
   A. Refraction B. Reflection C. Dispersion D. Total internal reflection
7. The lenses in your eyes produce image on retina:
   A. Inverted and virtual B. Inverted and real
   C. Erect and virtual D. Erect and real
8. What is the speed of light in diamond if its refractive index is 2.5?
   A. 1.2×10^8 m/s B. 2.5×10^8 m/s C. 2.1×10^8 m/s D. 5.2×10^8 m/s
9. In a convex mirror when the object is placed at 'c' the image formed will be:
   A. Smaller B. Larger C. Same size D. Zero size
10. The working principle of optical fibers is:
    A. Refraction B. Diffraction C. Reflection D. Total internal reflection
11. If an object is placed at 10 cm from the convex lens having focal length 5 cm. the linear magnification of convex lens is?
    A. 0.5 B. 1 C. 2 D. 5
12. Non-luminous matter which can be studied with the help of gravitational lensing is called:
    A. Visible Matter B. Red matter C. Dark matter D. White matter

13. Image formed by plane mirror is always:
A. Real and inverted B. Virtual and erect C. Real and erect D. Virtual and inverted
14. Einstein rings are seen due to a phenomenon:
A. Converging lensing B. Diverging lensing C. Gravitational lensing D. Acoustic lensing
15. The ________________ phenomenon is used in non-destructive testing of materials for voids and cracks in opaque materials?
A. Converging lensing B. Diverging lensing C. Gravitational lensing D. Acoustic lensing
16. All waves exhibit the phenomenon of reflection but light waves are the only waves which exhibit the phenomenon of:
A. Refraction B. Diffraction C. Reflection D. Total internal reflection
17. The working principle of optical fibers is:
A. Refraction B. Diffraction C. Reflection D. Total internal reflection
18. The white light passing through the prism, due to refraction shows a behavior of ______light:
A. Interference B. Dispersion C. Reflection D. Diffraction
19. The visible light spectrum lies in the range of__________ nm of wavelength:
A. 400-850 B. 500-700 C. 400-750 D. 700-900
20. The rods and cones a human eye has are:
A. 6 million and 100 million B. 100 million and 6 million
C. 6 million and 6 million D. 100 million and 100 million

CONSTRUCTED RESPONSE QUESTIONS

QII. Follow the directions to respond to the following questions.

1. Take some water in the bowl and put a small mirror in it such that some part of mirror is dipped in the water. Fall sunlight on the mirror in such a way that the reflection of mirror appears on the wall or white board of the class.



(a) Why the seven color pattern is shown on the wall?

(b) What is the role of water in this phenomenon?

(c) Discuss the basic principle used here which converts the white sunlight into seven colors?

SHORT RESPONSE QUESTIONS

QIII. Give a short response to the following questions.

1. Why is the index of refraction always greater than or equal to unity?
2. Which physical process is responsible for the decrease in the speed of light in material mediums?
3. How powder takes the shine off of a person's nose?
4. Why an object in water always appears to be elevated to its real depth?
5. Refractive index of air is lower for air at high temperatures, explain.
6. Rainbow forms due to dispersion of light by the rain drops suspended in air. How double rainbow form? Can a triple rainbow be formed?
7. Can you photograph a virtual image? Explain.
8. What is meant by the negative magnification?
9. Can a flat transparent glass be considered as a lens of infinite focal length? If yes, where does it form an image?
10. If we dip a lens in water what would happened to its focal length? Elaborate.
11. When you open your eyes in water why the things look blurry?
12. Evaluate the statement that "a real image is always inverted"?
13. Argue about the nature of gravitational lensing as optical or not?
14. Inspect the reason for the curved ceilings of school halls?
15. Propose a reason for producing more sound by an empty container as compared to a filled one.

LONG RESPONSE QUESTIONS

QIV. Give a detailed response to the following questions.

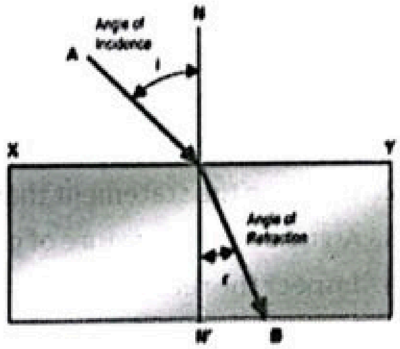
1. What is reflection of light? Also explain the laws of reflection.
2. Discuss the types of reflection.
3. How images are formed in plane mirrors? Explain.
4. Describe the position and characteristics of images formed by plane mirrors.
5. Elaborate the refraction of light and the laws of refractions.
6. Analyze the speed of light in material medium.
7. What is refractive index? Elaborate your answer.
8. Differentiate total internal reflection from reflection. Also derive a relation for critical angle.
9. Enlist the uses of fiber optics in telecommunication system.
10. Illustrate thin lenses. Also explain behavior of converging and diverging lens to parallel beam of light.
11. Evaluate how images are formed by converging lens using ray diagram.

12. Differentiate between real and virtual images.
13. Assess linear magnification as a property of thin lenses.
14. Discuss the dispersion of light through a prism.
15. Design some single lens optical devices.
16. Analyze the visible spectrum of electromagnetic radiations.
17. Illustrate human eye and color perception.
18. Outline short-sightedness and long-sightedness also explain how they can be fixed?
19. Define and explain gravitational lensing.
20. Explain acoustic lensing and its applications.

NUMERICAL RESPONSE QUESTIONS

QV. Solve the questions given below.

1. Calculate the angle of refraction at the boundary of two media if the angle of incidence is 37°.



(Ans. 53°)

2. Calculate the speed of light in a medium if its refractive index is 1.7.

(Ans. 1.76×10^8 m s^{-1})

3. A light ray moving through a medium of refractive index 1.6 enters at an angle of incidence 21° into the other medium of refractive index 1.7. Calculate the angle of refraction.

(Ans. 19.71°)

4. Assess the value of the critical angle if light travels from a medium of refractive index 1.63 into a medium of refractive index 1.35.

(Ans. 55.9°)

5. Measure the distance and height of image of an object with height and distance of 3 cm and 5 cm respectively from a lens having magnification as 3.

(Ans. 15 cm, 9 cm)