

Chapter 10

OPTICAL INSTRUMENTS

Learning Objectives

At the end of this chapter the students will be able to:

1. Recognize the term of least distance of distinct vision.
2. Understand the terms magnifying power and resolving power.
3. Derive expressions for magnifying power of simple microscope, compound microscope and astronomical telescope.
4. Understand the working of spectrometer.
5. Describe Michelson rotating mirror method to find the speed of light.
6. Understand the principles of optical fibre.
7. Identify the types of optical fibres.
8. Appreciate the applications of optical fibres.

In this chapter, some optical instruments that are based on the principles of reflection and refraction, will be discussed. The most common of these instruments are the magnifying glass, compound microscope and telescopes. We shall also study magnification and resolving powers of these optical instruments. The spectrometer and an arrangement for measurement of speed of light are also described. An introduction to optical fibres, which has developed a great importance in medical diagnostics, telecommunication and computer networking, is also included.

10.1 LEAST DISTANCE OF DISTINCT VISION

The normal human eye can focus a sharp image of an object on the eye if the object is located anywhere from infinity to a certain point called the near point.

The minimum distance from the eye at which an object appears to be distinct is called the least distance of distinct vision or near point.

This distance represented by d is about 25 cm from the eye. If the object is held closer to the eye than this distance the image formed will be blurred and fuzzy. The location of the near point, however, changes with age.

10.2 MAGNIFYING POWER AND RESOLVING POWER OF OPTICAL INSTRUMENTS

When an object is placed in front of a convex lens at a point beyond its focus, a real and inverted image of the object is formed as shown in the Fig. 10.1.

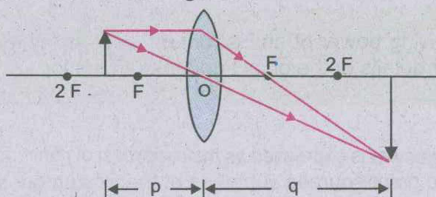


Fig. 10.1

The ratio of the size of the image to the size of the object is called magnification.

As the object is brought from a far off point to the focus, the magnification goes on increasing. The apparent size of an object depends on the angle subtended by it at the eye. Thus, the closer the object is to the eye, the greater is the angle subtended and larger appears the size of the object (Fig. 10.2). The maximum size of an object as seen by naked eye is obtained when the object is placed at the least distance of distinct vision. For lesser distance, the image formed looks blurred and the details of the object are not visible.

The magnifying power or angular magnification is defined as the ratio of the angles subtended by the image as seen through the optical device to that subtended by the object at the unaided eye.

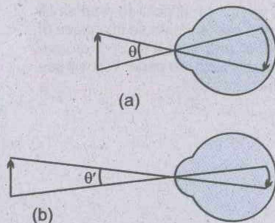


Fig. 10.2

When the same object is viewed at a shorter distance, the image on the retina of the eye is greater; so the object appears larger and more details can be seen. The angle θ the object subtends in (a) is greater than θ' in (b).

The optical resolution of a microscope or a telescope tells us how close together the two point sources of light can be so that they are still seen as two separate sources. If two point sources are too close, they will appear as one because the optical instrument makes a point source look like a small disc or spot of light with circular diffraction fringes.

Although the magnification can be made as large as one desires by choosing appropriate focal lengths, but the magnification alone is of no use unless we can see the details of the object distinctly.

The resolving power of an instrument is its ability to reveal the minor details of the object under examination.

Tid-bits

If you find it difficult to read small print, make a pinhole in a piece of paper and hold it in front of your eye close to the page. You will see the print clearly.

Resolving power is expressed as the reciprocal of minimum angle which two point sources subtends at the instrument so that their images are seen as two distinct spots of light rather than one. Raleigh showed that for light of wavelength λ through a lens of diameter D , the resolving power is given by $R = \frac{1}{\alpha_{\min}} = \frac{D}{1.22\lambda}$

Where $\alpha_{\min} = 1.22 \frac{\lambda}{D}$ (10.1)

The smaller the value of $\alpha_{\min}$, greater is the resolving power because two distant objects which are close together can then be seen separated through the instrument. In the case of a grating spectrometer, the resolving power R of the grating is defined as

$$R = \frac{\lambda}{\lambda_2 - \lambda_1} = \frac{\lambda}{\Delta\lambda} \quad \text{..... (10.2)}$$

where $\lambda \approx \lambda_1 \approx \lambda_2$ and $\Delta\lambda = \lambda_2 - \lambda_1$. Thus, we see that a grating with high resolving power can distinguish small difference in wavelength. If N is the number of rulings on the grating, it can be shown that the resolving power in the m th-order diffraction equals the product $N \times m$, i.e.

$$R = N \times m \quad \text{..... (10.3)}$$

10.3 SIMPLE MICROSCOPE

As discussed above, a converging or convex lens can be used to help the eye to see small objects distinctly. A watch maker uses convex lens to repair the watches. The object is placed inside the focal point of the lens. The magnified and virtual image is formed at least distance of distinct vision d or much farther from the lens.

Let us, now, calculate the magnification of a simple microscope. In Fig. 10.3 (a), the image formed by the object, when placed at a distance d , on the eye is shown. In Fig. 10.3 (b), a lens is placed just in front of the eye and the object is placed in front of the lens in such a way that a virtual image of the object is formed at a distance d from the eye. The size of the image is now much larger than without the lens.

If β and α are the respective angles subtended by the object when seen through the lens (simple microscope) and when viewed directly, then angular magnification M is defined as

$$M = \frac{\beta}{\alpha} \quad \dots\dots\dots (10.4)$$

When angles are small, then they are nearly equal to their tangents. From Fig. 10.3 (a) and (b), we find

$$\alpha = \tan \alpha = \frac{\text{Size of the object}}{\text{Distance of the object}} = \frac{O}{d}$$

and
$$\beta = \tan \beta = \frac{\text{Size of the image}}{\text{Distance of the image}} = \frac{I}{q}$$

Since the image is at the least distance of distinct vision, hence,

$$q = d$$

Therefore,
$$\beta = \frac{I}{q} = \frac{I}{d}$$

the angular magnification
$$M = \frac{I/d}{O/d} = \frac{I}{O}$$

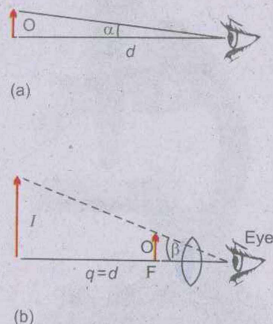


Fig. 10.3

Simple Microscope

As we already know that

$$\frac{I}{O} = \frac{\text{Size of the image}}{\text{Size of the object}} = \frac{\text{Distance of the image}}{\text{Distance of the object}} = \frac{q}{p}$$

Therefore, $M = \frac{q}{p} = \frac{d}{p}$ (10.5)

For virtual image, the lens formula is written as

$$\frac{1}{f} = \frac{1}{p} - \frac{1}{q} \quad \text{But} \quad q = d$$

Hence $\frac{1}{f} = \frac{1}{p} - \frac{1}{d}$ or $\frac{d}{p} = 1 + \frac{d}{f}$

Hence the magnification of a convex lens (simple microscope) can be expressed as

$$M = \frac{d}{p} = 1 + \frac{d}{f} \quad \text{.....(10.6)}$$

It is, thus, obvious that for a lens of high angular magnification the focal length should be small. If, for example, $f = 5$ cm and $d = 25$ cm, then $M = 6$, the object would look six times larger when viewed through such a lens.

10.4 COMPOUND MICROSCOPE

Whenever high magnification is desired, a compound microscope is used. It consists of two convex lenses, an object lens of very short focal length and an eye-piece of comparatively longer focal length. The ray diagram of a compound microscope is given in Fig. 10.4 (a).

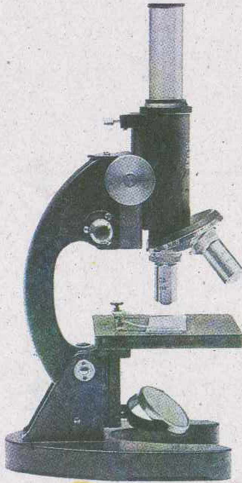


Fig. 10.4 (b).

A Compound Microscope

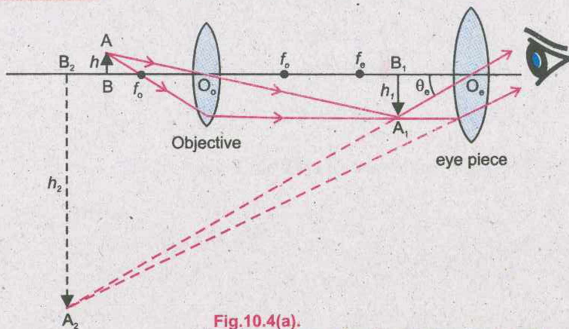


Fig.10.4(a).

Ray diagram of a Compound Microscope

The object of height h is placed just beyond the principal focus of the objective. This produces a real, magnified image of height h_1 of the object at a place situated within the focal point of the eye-piece. It is then further magnified by the eye-piece. In normal adjustment, the eye-piece is positioned so that the final image is formed at the near point of the eye at a distance d .

The angular magnification M of a compound microscope is defined to be the ratio $\tan \theta_e / \tan \theta$, where θ_e is the angle subtended by the final image of height h_2 and θ is the angle that the object of height h would subtend at the eye if placed at the near point d (Fig. 10.3 a). Now

$$\tan \theta = \frac{h}{d} \quad \text{and} \quad \tan \theta_e = \frac{h_2}{d}$$

Thus, magnification
$$M = \frac{\tan \theta_e}{\tan \theta} = \frac{h_2}{d} \times \frac{d}{h} = \frac{h_2}{h}$$

or
$$M = \frac{h_1}{h} \times \frac{h_2}{h_1}$$

where ratio h_1/h is the linear magnification M_1 of the objective and h_2/h_1 is the magnification M_2 of the eyepiece. Hence, total magnification is

$$M = M_1 M_2$$

By Eq. 10.5 and Eq. 10.6, $M_1 = q/p$ and $M_2 = 1 + d/f_e$

Hence,
$$M = \frac{q}{p} \left(1 + \frac{d}{f_e} \right) \dots \dots \dots (10.7)$$

It is customary to refer the values of M as multiples of 5, 10, 40 etc., and are marked as x5, x10, x40 etc., on the instrument.

The limit to which a microscope can be used to resolve details, depends on the width of the objective. A wider objective and use of blue light of short wavelength produces less diffraction and allows more details to be seen.

For Your Information



A seventeenth century microscope which could be moved up and down in its support ring (Courtesy of the Museum of the History of Science, Florence).

Example 10.1: A microscope has an objective lens of 10 mm focal length, and an eye piece of 25.0 mm focal length. What is the distance between the lenses and its magnification, if the object is in sharp focus when it is 10.5 mm from the objective?

Solution: If we consider the objective alone

$$\frac{1}{10.5 \text{ mm}} + \frac{1}{q} = \frac{1}{10 \text{ mm}} \quad \text{or} \quad q = 210 \text{ mm}$$

If we consider the eye piece alone, with the virtual image at the least distance of distinct vision $d = -250 \text{ mm}$

$$\frac{1}{p} + \frac{1}{-250 \text{ mm}} = \frac{1}{25 \text{ mm}} \quad \text{or} \quad p = 22.7 \text{ mm}$$

Distance between Lenses $= q + p = 210 \text{ mm} + 22.7 \text{ mm} \approx 233 \text{ mm}$

Magnification by objective

$$M_1 = \frac{q}{p} = \frac{210 \text{ mm}}{10.5 \text{ mm}} = 20.0$$

Magnification by eye piece

$$M_2 = \frac{-250 \text{ mm}}{22.7 \text{ mm}} = -11.0$$

Total magnification

$$\begin{aligned} M &= M_1 \times M_2 \\ &= 20 \times (-11.0) = -220 \end{aligned}$$

-ive sign indicates that the image is virtual.

10.5 ASTRONOMICAL TELESCOPE

Telescope is an optical device used for viewing distant objects. The image of a distant object viewed through a telescope appears larger because it subtends a bigger visual angle than when viewed with the naked eye. Initially the extensive use of the telescopes was for astronomical observations. These telescopes are called astronomical telescopes. A simple astronomical telescope consists of two convex lenses, an objective of long focal length f_o and

an eye piece of short focal length f_e . The objective forms a real, inverted and diminished image $A'B'$ of a distant object AB . This real image $A'B'$ acts as object for the eye piece which is used as a magnifying glass. The final image seen through the eye-piece is virtual, enlarged and inverted. Fig. 10.5 shows the path of rays through an astronomical telescope.

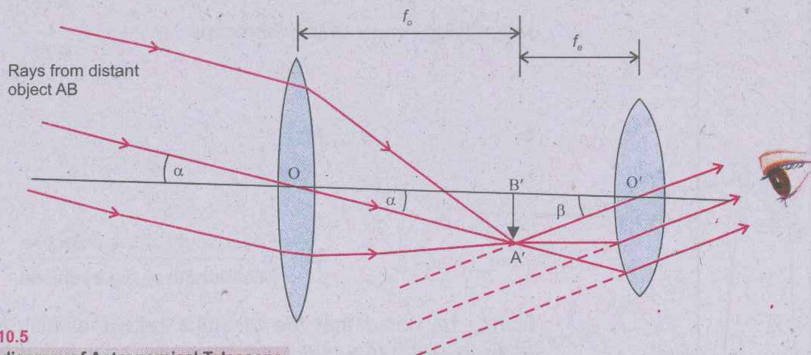


Fig.10.5

Ray diagram of Astronomical Telescope

When a very distant object is viewed, the rays of light coming from any of its point (say its top) are considered parallel and these parallel rays are converged by the objective to form a real image $A'B'$ at its focus. If it is desired to see the final image through the eye-piece without any strain on the eye, the eye-piece must be placed so that the image $A'B'$ lies at its focus. The rays after refraction through the eye-piece will become parallel and the final image appears to be formed at infinity. In this condition the image $A'B'$ formed by the objective lies at the focus of both the objective and the eye-piece and the telescope is said to be in normal adjustment.

Let us now compute the magnifying power of an astronomical telescope in normal adjustment. The angle α subtended at the unaided eye is practically the same as subtended at the objective and it is equal to $\angle A'OB'$. Thus

$$\alpha = \tan \alpha = \frac{A'B'}{OB'} = \frac{A'B'}{f_o}$$

The angle β subtended at the eye by the final image is equal to $\angle A'O'B'$. Thus

$$\beta = \tan \beta = \frac{A'B'}{O'B'} = \frac{A'B'}{f_e}$$

$$\text{Magnifying power of the telescope} = \frac{\beta}{\alpha} = \frac{A'B'/f_e}{A'B'/f_o}$$

or $M = \frac{f_o}{f_e} \dots\dots\dots (10.8)$

$$M = \frac{\text{Focal length of the objective}}{\text{Focal length of the eyepiece}}$$

It may be noted that the distance between the objective and eye-piece of a telescope in normal adjustment is $f_o + f_e$ which equals the length of the telescope.

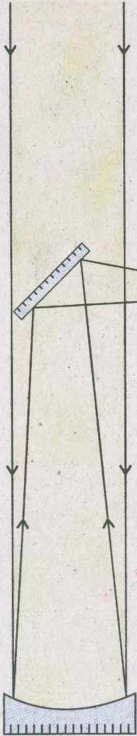
Besides having a high magnifying power another problem which confronts the astronomers while designing a telescope to see the distant planets and stars is that they would like to gather as much light from the object as possible. This difficulty is overcome by using the objective of large aperture so that it collects a great amount of light from the astronomical objects. Thus a good telescope has an objective of long focal length and large aperture.

10.6 SPECTROMETER

A spectrometer is an optical device used to study spectra from different sources of light. With the help of a spectrometer, the deviation of light by a glass prism and the refractive index of the material of the prism can be measured quite accurately. Using a diffraction grating, the spectrometer can be employed to measure the wave length of the light.

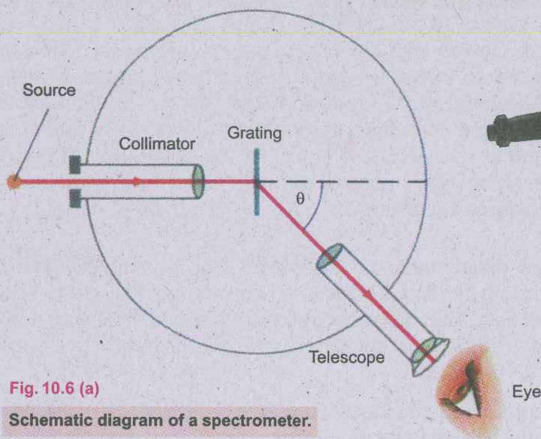
The essential components of a spectrometer are shown in Fig. 10.6 (a).

For Your Information



Reflecting Telescope

Large astronomical telescopes are reflecting type made from specially shaped very large mirrors used as objectives. With such telescopes, astronomers can study stars which are millions light year away.



Collimator

It consists of a fixed metallic tube with a convex lens at one end and an adjustable slit, that can slide in and out of the tube, at the other end. When the slit is just at the focus of the convex lens, the rays of light coming out of the lens become parallel. For this reason, it is called a collimator.

Turn Table

A prism or a grating is placed on a turn table which is capable of rotating about a fixed vertical axis. A circular scale, graduated in half degrees, is attached with it.

Telescope

A telescope is attached with a vernier scale and is rotatable about the same vertical axis as the turn table.

Before using a spectrometer, one should be sure that the collimator is so adjusted that parallel rays of light emerge out of its convex lens. The telescope is adjusted in such a way that the rays of light entering it are focussed at the cross wires near the eye-piece. Finally, the refracting edge of the prism must be parallel to the axis of rotation of the telescope so that the turn table is levelled. This can be done by using the levelling screws.

10.7 SPEED OF LIGHT

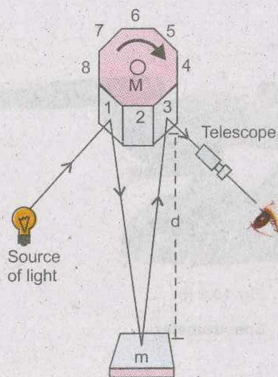


Fig. 10.7

Michelson's method for measurement of speed of light.

Light travels so rapidly that it is very difficult to measure its speed. Galileo was the first person to make an attempt to measure its speed. Although he did not succeed in the measurement of the speed of light, yet he was convinced that the light does take some time to travel from one place to another. Given below is one of the accurate methods of determining the speed of light which is known as Michelson's experiment.

In this experiment, the speed of light was determined by measuring the time it took to cover a round trip between two mountains. The distance between the two mountains was measured accurately. The experimental set up is shown in Fig.10.7.

An eight-sided polished mirror M is mounted on the shaft of a motor whose velocity can be varied. Suppose the mirror is stationary in the position shown in the figure. A beam of light from the face 1 of the mirror M falls at the plane mirror m placed at a distance d from M. The beam is reflected back from the mirror m and falls on the face 3 of the mirror M. On reflection from face 3, it enters the telescope.

If the mirror M is rotated clockwise, initially the source will not be visible through the telescope. When the mirror M gains a certain speed, the source S becomes visible. This happens when the time taken by light in moving from M to m and back to M is equal to the time taken by face 2 to move to the position of face 1.

Angle subtended by any side of the eight-sided mirror at the centre is $2\pi/8$. If f is the frequency of the mirror M, when the source S is visible through the telescope, then the time taken by the mirror to rotate through an angle 2π is $1/f$. So, the time taken by the mirror M to rotate through an angle $2\pi/8$ is

$$t = \frac{1}{2\pi f} \times \frac{2\pi}{8} = \frac{1}{8f}$$

The time taken by light for its passage from M to m and back is $2d/c$, where c is the speed of light. These two times are equal,

so

$$\frac{1}{8f} = \frac{2d}{c}$$

$$c = 16fd \quad \dots\dots\dots (10.9)$$

This equation was used to determine the speed of light by Michelson. Presently accepted value for the speed of light in vacuum is

$$c = 2.99792458 \times 10^8 \text{ ms}^{-1}$$

we usually round this off to $3.00 \times 10^8 \text{ ms}^{-1}$.

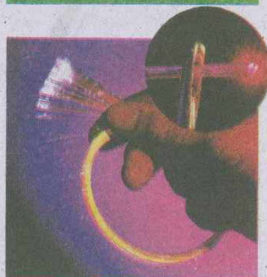
The speed of light in other materials is always less than c . In media other than vacuum, it depends upon the nature of the medium. However, the speed of light in air is approximately equal to that in vacuum and generally taken so in calculations.

10.8 INTRODUCTION TO FIBRE OPTICS

For hundreds of years man has communicated using flashes of reflected sunlight by day and lanterns by night. Navy signalmen still use powerful blinker lights to transmit coded messages to other ships during periods of radio-silence. Light communication has not been confined to simple dots and dashes. It is an interesting but little known fact that Alexander Graham Bell invented a device known as "photo phone" shortly after his invention of telephone. Bell's photo phone used a modulated beam of reflected sunlight, focussed upon a Selenium detector several hundred metres away. With the device, Bell was able to transmit a voice message via a beam of light. The idea remained dormant for many years. During the recent past the idea of transmission of light through thin optical fibres has been revived and is now being used in communication technology.

The use of light as a transmission carrier wave in fibre optics has several advantages over radio wave carriers such as a much wider bandwidth capability and immunity from electromagnetic interference.

Point to Ponder



Each of the thin optical fibres is small enough to fit through the eye of a needle. Why is the size of the fibre important?



Fig. 10.8 (a)

Optical fibre image



Fig. 10.8 (b)

A precision diamond scalpel for use in eye surgery. The illumination is obtained by light passing through a fibre optic light guide.

It is also used to transmit light around corners and into inaccessible places so that the formerly unobservable could be viewed. The use of fibre optic tools in industry is now very common, and their importance as diagnostic tools in medicine has been proved (Fig. 10.8 a and b).

Recently the fibre optic technology has evolved into something much more important and useful -- a communication system of enormous capabilities.

One feature of such a system is its ability to transmit thousands of telephone conversations, several television programs and numerous data signals between stations through one or two flexible, hair-thin threads of optical fibre. With the tremendous information carrying capacity called the bandwidth, fibre optic systems have undoubtedly made practical such services as two way television which was too costly before the development of fibre optics. These systems also allow word processing, image transmitting and receiving equipment to operate efficiently.

In addition to giving an extremely wide bandwidth, the fibre optic system has much thinner and light weight cables. An optical fibre with its protective case may be typically 6.0 mm in diameter, and yet it can replace a 7.62 cm diameter bundle of copper wires now used to carry the same amount of signals.

10.9 FIBRE OPTIC PRINCIPLES

Propagation of light in an optical fibre requires that the light should be totally confined within the fibre.

This may be done by total internal reflection and continuous refraction.

Total Internal Reflection

One of the qualities of any optically transparent material is the speed at which light travels within the material, i.e., it depends upon the refractive index n of the material. The index of refraction is merely the ratio of the speed of light c in vacuum to the speed of light v in that material.

Expressed mathematically,

$$n = \frac{c}{v} \quad \dots\dots\dots (10.10)$$

The boundary between two optical media, e.g. glass and air having different refractive indices can reflect or refract light rays. The amount and direction of reflection or refraction is determined by the amount of difference in refractive indices as well as the angle at which the rays strike the boundary. At some angle of incidence, the angle of refraction is equal to 90° when a ray of light is passing through glass to air. This angle of incidence is called the critical angle θ_c , shown in Fig.10.9(a). We are already familiar with Snell's law

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

From Fig. 10.9 (a), when $\theta_1 = \theta_c$, $\theta_2 = 90^\circ$

thus, $n_1 \sin \theta_c = n_2$ or $\sin \theta_c = n_2 / n_1$

For incident angles equal to or greater than the critical angle, the glass - air boundary will act as a mirror and no light escapes from the glass (Fig. 10.9 b). For glass-air boundary,

$$\text{we have } \sin \theta_c = \frac{n_2}{n_1} = \frac{1.0}{1.5} \quad \text{or} \quad \theta_c = 41.8^\circ$$

Let us now assume that the glass is formed into a long, round rod. We know that all the light rays striking the internal surface of the glass at angles of incidence greater than 41.8° (critical angle) will be reflected back into the glass, while those with angles less than 41.8° will escape from the glass (Fig.10.10a). Ray 1 is injected into the rod so that it strikes the glass air boundary at an angle of incidence about 30° .

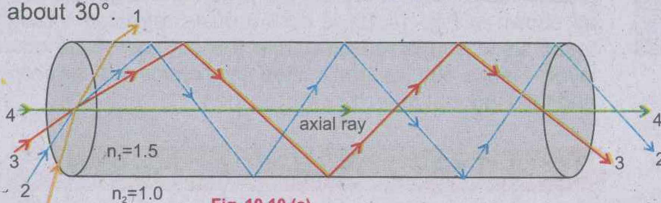


Fig. 10.10 (a)

Propagation of light within a glass rod.

Since this is less than the critical angle, it will escape from the rod and be lost. Ray 2 at 42° will be reflected back into the rod, as will ray 3 at 60° . Since the angle of reflection equals the angle of incidence, these two rays will continue to propagate down the rod, along paths determined by the original angles of incidence. Ray 4 is called an axial

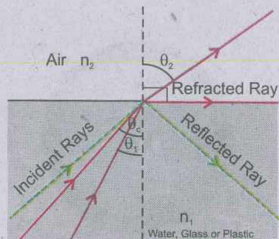


Fig. 10.9 (a)

If the angle of refraction in the air is 90° the angle of incidence is called the critical angle.

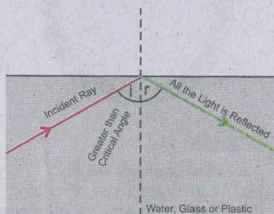


Fig. 10.9(b)

For angles of incidence greater than the critical angle, all the light is reflected; none is refracted into the air.

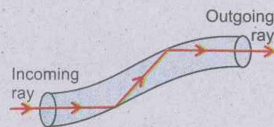


Fig. 10.10 (b)

Light propagation within a flexible glass fibre.

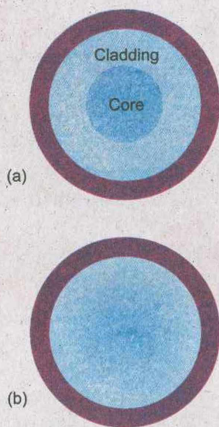


Fig. 10.11

Cross sectional view of

(a) Multi-mode step index fibre

(b) Multi-mode graded index fibre



Fig.10.12

Light propagation within a hypothetical multi layer fibre.

ray since its path is parallel to the axis of the rod. Axial rays will travel directly down this straight and rigid rod. However, in a flexible glass fibre they will be subjected to the laws of reflection (Fig.10.10b).

Optical fibres that propagate light by total internal reflection are the most widely used.

Continuous Refraction

There is another mode of propagation of light through optical fibres in which light is continuously refracted within the fibre. For this purpose central core has high refractive index (high density) and over it is a layer of a lower refractive index (less density). This layer is called cladding. Such a type of fibre is called multi-mode step index fibre whose cross sectional view is shown in Fig.10.11(a).

Now a days, a new type of optical fibre is used in which the central core has high refractive index (high density) and its density gradually decreases towards its periphery. This type of optical fibre is called a multi mode graded index fibre. Its cross sectional view is shown in Fig. 10.11 (b).

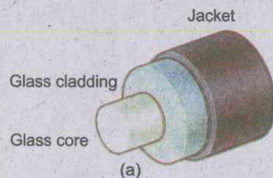
In both these fibres the propagation of light signal is through continuous refraction. We already know that a ray passing from a denser medium to a rarer medium bends away from the normal and vice versa. In step index or graded index fibre, a ray of light entering the optical fibre, as shown in Fig. 10.12, is continuously refracted through these steps and is reflected from the surface of the outer layer. Hence light is transmitted by continuous refraction and total internal reflection.

10.10 TYPES OF OPTICAL FIBRES

There are three types of optical fibres which are classified on the basis of the mode by which they propagate light. These are (i) single mode step index (ii) multi mode step index and (iii) multi mode graded index. The term 'mode' is described as the method by which light is propagated within the fibre, i.e. the various paths that light can take in travelling down the fibre. The optical fibre is also covered by a plastic jacket for protection.

(i) Single Mode Step Index Fibre

Single mode or mono mode step index fibre has a very thin core of about $5\text{ }\mu\text{m}$ diameter and has a relatively larger cladding (of glass or plastic) as shown in Fig. 10.13. Since it has a very thin core, a strong monochromatic light source i.e., a Laser source has to be used to send light signals through it. It can carry more than 14 TV channels or 14000 phone calls.



(ii) Multimode Step Index Fibre

This type of fibre has a core of relatively larger diameter such as $50\text{ }\mu\text{m}$. It is mostly used for carrying white light but due to dispersion effects, it is useful for a short distance only. The fibre core has a constant refractive index n_1 , such as 1.52, from its centre to the boundary with the cladding as shown in Fig. 10.14. The refractive index then changes to a lower value n_2 , such as 1.48, which remains constant throughout the cladding.

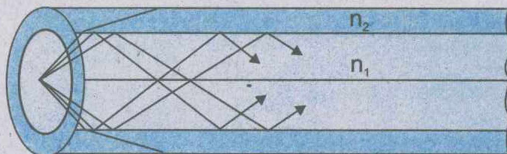


Fig. 10.14

Light propagation through Multi-mode step-index fibre.

This is called a step-index multimode fibre, because the refractive index steps down from 1.52 to 1.48 at the boundary with the cladding.

(iii) Multimode Graded Index Fibre

Multi mode graded index fibre has core which ranges in diameter from 50 to $1000\text{ }\mu\text{m}$. It has a core of relatively high refractive index and the refractive index decreases gradually from the middle to the outer surface of the fibre. There is no noticeable boundary between core and cladding. This type of fibre is called a multi mode graded-index fibre (Fig. 10.15) and is useful for long distance applications in which white light is used. The mode of transmission of light through this type of fibre is also the same, i.e., continuous refraction from

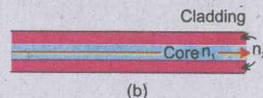


Fig. 10.13

Single-mode step-index fibre.



Fig. 10.15

Light propagation through Multi-mode graded-index fibre

the surfaces of smoothly decreasing refractive index and the total internal reflection from the boundary of the outer surfaces.

Example 10.2: Calculate the critical angle and angle of entry for an optical fibre having core of refractive index 1.50 and cladding of refractive index 1.48.

Solution: We have $n_1 = 1.50$, $n_2 = 1.48$

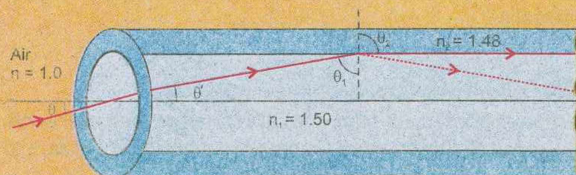


Fig. 10.16

From Snell's law $n_1 \sin \theta_1 = n_2 \sin \theta_2$

When $\theta_2 = 90^\circ$, $\theta_1 = \theta_c$

So, $1.50 \sin \theta_c = 1.48 \sin 90^\circ$

Which gives $\theta_c = 80.6^\circ$

From the Fig. 10.16, $\theta' = 90^\circ - \theta_c = 9.4^\circ$

Again using Snell's law, we have $\frac{\sin \theta}{\sin \theta'} = \frac{n_1}{n} = \frac{1.5}{1}$

which gives $\sin \theta = 1.50 \sin \theta'$ or $\theta = 14.2^\circ$

If light beam is incident at the end of the optical fibre at an angle greater than 14.2° , total internal reflection would not take place.

10.11 SIGNAL TRANSMISSION AND CONVERSION TO SOUND

A fibre optic communication system consists of three major components: (i) a transmitter that converts electrical signals to light signals, (ii) an optical fibre for guiding the signals and (iii) a receiver that captures the light signals at the other end of the fibre and reconverts them to electric signals.

The light source in the transmitter can be either a semiconductor laser or a light emitting diode (LED). With either device, the light emitted is an invisible infra-red signals. The typical wavelength is $1.3 \mu\text{m}$.

Such a light will travel much faster through optical fibres than will either visible or ultra-violet light. The lasers and LEDs used in this application are tiny units (less than half the size of the thumbnail) in order to match the size of the fibres. To transmit information by light waves, whether it is an audio signal, a television signal or a computer data signal, it is necessary to modulate the light waves. The most common method of modulation is called digital modulation in which the laser or LED is flashed on and off at an extremely fast rate. A pulse of light represents the number 1 and the absence of light represents zero. In a sense, instead of flashes of light travelling down the fibre, ones (1s) and zeros (0s) are moving down the path.

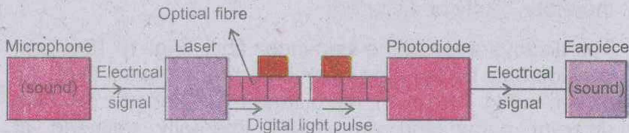


Fig. 10.17

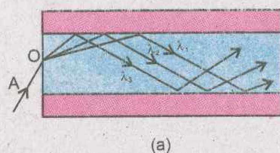
With computer type equipment, any communication can be represented by a particular pattern or code of these 1s and 0s. The receiver is programmed to decode the 1s and 0s, thus it receives, the sound, pictures or data as required. Digital modulation is expressed in bits (binary digit) or megabits (10^6 bits) per second, where a bit is a 1 or a 0.

Despite the ultra-purity (99.99% glass) of the optical fibre, the light signals eventually become dim and must be regenerated by devices called repeaters. Repeaters are typically placed about 30km apart, but in the newer systems they may be separated by as much as 100 km.

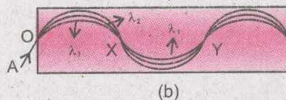
At the end of the fibre, a photodiode converts the light signals, which are then amplified and decoded, if necessary, to reconstruct the signals originally transmitted (Fig. 10.17).

10.12 LOSSES OF POWER

When a light signal travels along fibres by multiple reflection, some light is absorbed due to impurities in the glass. Some of it is scattered by groups of atoms which are formed at places such as joints when fibres are joined together. Careful manufacturing can reduce the power loss by scattering and absorption.



(a)



(b)

Fig. 10.18

Light paths in (a) step-index and (b) graded-index fibre.

The information received at the other end of a fibre can be inaccurate due to dispersion or spreading of the light signal. Also the light signal may not be perfectly monochromatic. In such a case, a narrow band of wave-lengths are refracted in different directions when the light signal enters the glass fibre and the light spreads.

Fig. 10.18 (a) shows the paths of light of three different wavelengths λ_1 , λ_2 and λ_3 . λ_1 meets the core-cladding at the critical angle and λ_2 and λ_3 at slightly greater angles. All the rays travel along the fibre by multiple reflections as explained earlier. But the light paths have different lengths. So the light of different wavelengths reaches the other end of the fibre at different times. The signal received is, therefore, faulty or distorted.

The disadvantage of the step-index fibre (Fig. 10.18 a) can considerably be reduced by using a graded index fibre. As shown in Fig. 10.18 (b), the different wavelengths still take different paths and are totally internally reflected at different layers, but still they are focussed at the same point like X and Y etc. It is possible because the speed is inversely-proportional to the refractive index. So the wavelength λ_1 travels a longer path than λ_2 or λ_3 but at a greater speed.

In spite of the different dispersion, all the wavelengths arrive at the other end of the fibre at the same time. With a step-index fibre, the overall time difference may be about 33ns per km length of fibre. Using a graded index fibre, the time difference is reduced to about 1 ns per km.

SUMMARY

- Least distance of distinct vision is the minimum distance from the eye at which an object appears to be distinct.
- Magnification is the ratio of the size of the image to the size of the object, which equals to the ratio of the distance of the image to the distance of the object from the lens or mirror.
- Magnifying power or angular magnification is the angle subtended by the image as seen through the optical device to that subtended by the object at the unaided eye.
- Resolving power is the ability of an instrument to reveal the minor details of the object under examination.

- Simple microscope is in fact a convex lens used to help the eye to see small objects distinctly. The magnifying power of a simple microscope is given by

$$M = \frac{d}{p} = 1 + \frac{d}{f}$$

- Compound microscope consists of two convex lenses, an objective lens of very short focal length and an eye piece of moderate focal length. The magnifying power of a compound microscope is given by

$$M = \frac{q}{p} \left(1 + \frac{d}{f_e} \right)$$

- Telescope is an optical instrument used to see distant object. The magnifying power of the telescope is given by

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

- Spectrometer is an optical device used to study spectra from different sources of light.
- Index of refraction is the ratio of speed of light in vacuum to the speed of light in the material.
- Critical angle is the angle of incidence in the denser medium for which the angle of refraction in the rarer medium is equal to 90° .
- When the angle of incidence becomes greater than the critical angle of that material, the incident ray is reflected in the same material, which is called total internal reflection.
- Cladding is a layer of lower refractive index (less density) over the central core of high refractive index (high density).
- Multi mode step index fibre is an optical fibre in which a layer of lower refractive index is over the central core of high refractive index.
- Multi mode graded index fibre is an optical fibre in which the central core has high refractive index and its density gradually decreases towards its periphery.

QUESTIONS

- What do you understand by linear magnification and angular magnification? Explain how a convex lens is used as a magnifier?
- Explain the difference between angular magnification and resolving power of an optical instrument. What limits the magnification of an optical instrument?
- Why would it be advantageous to use blue light with a compound microscope?
- One can buy a cheap microscope for use by the children. The images seen in such a microscope have coloured edges. Why is this so?

- 10.5** Describe with the help of diagrams, how (a) a single biconvex lens can be used as a magnifying glass. (b) biconvex lenses can be arranged to form a microscope.
- 10.6** If a person was looking through a telescope at the full moon, how would the appearance of the moon be changed by covering half of the objective lens.
- 10.7** A magnifying glass gives a five times enlarged image at a distance of 25 cm from the lens. Find, by ray diagram, the focal length of the lens.
- 10.8** Identify the correct answer.
- (i) The resolving power of a compound microscope depends on;
 - a. Length of the microscope.
 - b. The diameter of the objective lens.
 - c. The diameter of the eyepiece.
 - d. The position of an observer's eye with regard to the eye lens.
 - (ii) The resolving power of an astronomical telescope depends on;
 - a. The focal length of the objective lens.
 - b. The least distance of distinct vision of the observer.
 - c. The focal length of the eye lens.
 - d. The diameter of the objective lens.
- 10.9** Draw sketches showing the different light paths through a single-mode and a multi mode fibre. Why is the single-mode fibre preferred in telecommunications?
- 10.10** How the light signal is transmitted through the optical fibre?
- 10.11** How the power is lost in optical fibre through dispersion? Explain.

NUMERICAL PROBLEMS

- 10.1** A converging lens of focal length 5.0 cm is used as a magnifying glass. If the near point of the observer is 25 cm and the lens is held close to the eye, calculate (i) the distance of the object from the lens (ii) the angular magnification. What is the angular magnification when the final image is formed at infinity?
[Ans: (i) 4.2 cm (ii) 6.0 ; 5.0]
- 10.2** A telescope objective has focal length 96 cm and diameter 12 cm. Calculate the focal length and minimum diameter of a simple eye piece lens for use with the telescope, if the linear magnification required is 24 times and all the light transmitted by the objective from a distant point on the telescope axis is to fall on the eye piece.
(Ans: $f_e = 4.0$ cm, dia = 0.50 cm)

- 10.3** A telescope is made of an objective of focal length 20 cm and an eye piece of 5.0 cm, both convex lenses. Find the angular magnification.

(Ans: 4.0)

- 10.4** A simple astronomical telescope in normal adjustment has an objective of focal length 100 cm and an eye piece of focal length 5.0 cm. (i) Where is the final image formed? (ii) Calculate the angular magnification.

[Ans: (i) infinity (ii) 20]

- 10.5** A point object is placed on the axis of and 3.6 cm from a thin convex lens of focal length 3.0 cm. A second thin convex lens of focal length 16.0 cm is placed coaxial with the first and 26.0 cm from it on the side away from the object. Find the position of the final image produced by the two lenses.

(Ans: 16 cm from second lens)

- 10.6** A compound microscope has lenses of focal length 1.0 cm and 3.0 cm. An object is placed 1.2 cm from the object lens. If a virtual image is formed, 25 cm from the eye, calculate the separation of the lenses and the magnification of the instrument.

(Ans: 8.7 cm, 47)

- 10.7** Sodium light of wavelength 589 nm is used to view an object under a microscope. If the aperture of the objective is 0.90 cm, (i) find the limiting angle of resolution, (ii) using visible light of any wavelength, what is the maximum limit of resolution for this microscope.

[Ans: (i) 8.0×10^{-5} rad, (ii) 5.4×10^{-5} rad]

- 10.8** An astronomical telescope having magnifying power of 5 consist of two thin lenses 24 cm apart. Find the focal lengths of the lenses.

[Ans: 20 cm, 4 cm]

- 10.9** A glass light pipe in air will totally internally reflect a light ray if its angle of incidence is at least 39° . What is the minimum angle for total internal reflection if pipe is in water? (Refractive Index of water = 1.33)

[Ans: 57°]

- 10.10** The refractive index of the core and cladding of an optical fibre are 1.6 and 1.4 respectively. Calculate (i) the critical angle for the interface (ii) the maximum angle of incidence in the air of a ray which enters the fibre and is incident at the critical angle on the interface.

[Ans: (i) 61° , (ii) 51°]