

OPTICAL INSTRUMENT

LEARNING OBJECTIVES

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

Recognize the term of least distance of distinct vision.

Understand the terms magnifying power and resolving power.

Understand the working of spectrometer.

Describe Michelson rotating mirror method to find the speed of light.

Understand the principles of optical fibre.

Identify the types of optical fibres.

Appreciate the applications of optical fibres.

INTRODUCTION

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.

Q.1 Define least distance of distinct vision.

Ans. **LEAST DISTANCE OF DISTINCT VISION**

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

The distance is about 25 cm from the eye. It is denoted by 'd'. 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.

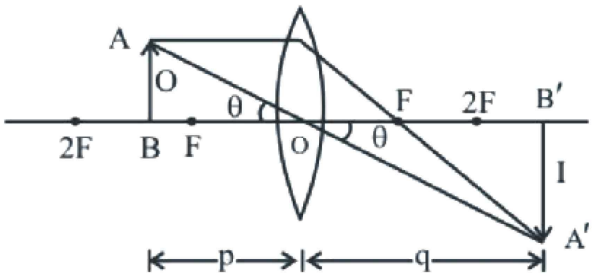
Q.2 Define linear magnification.

It is denoted by 'M'.

$$\therefore \qquad M = \frac{I}{O}$$

Q. Show that $M = \frac{I}{O} = \frac{q}{p}$ $\left(\text{OR } M = \frac{q}{p} \right)$

Ans. 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 figure.



ΔABO and $\Delta A'B'O$ are similar triangles.

For similar triangles the ratio of the length of the corresponding sides is equal i.e.,

$$\frac{I}{O} = \frac{OB'}{OB}$$

$$\frac{I}{O} = \frac{q}{p} \quad \begin{cases} \because OB' = q = \text{image distance} \\ OB = p = \text{object distance} \end{cases}$$

As, $$M = \frac{I}{O}$$

$$\therefore \qquad M = \frac{I}{O} = \frac{q}{p}$$

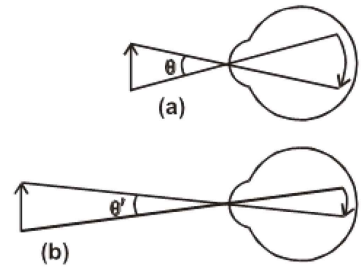


Fig. When the same object is viewed at a shorter distance, the image on the retina of the eye is greater; so the object appears larger and more details can be seen. The angle θ the object subtends in (a) is greater than θ′ in (b).

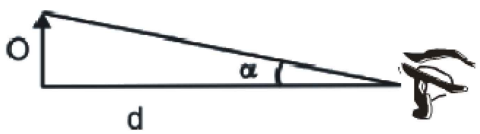
1. Visual Angle

The angle subtended by an object at the eye, is called visual angle.

The apparent size of an object depends upon its actual size and 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.

2. Object Angle

"When the object is placed at 'd', then the angle subtended at a naked (unaided) eye, by the object is called object angle".

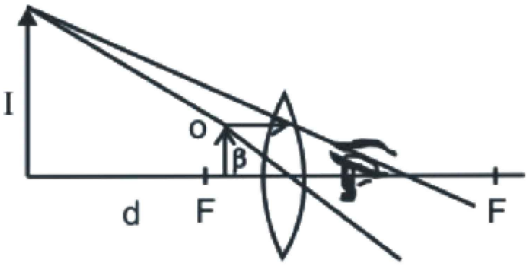


It is denoted by α.

3. Image Angle

"When the angle subtended by the image, formed at 'd', on the eye, is called image angle".

It is denoted by β.



Q.3 Define angular magnification.

Ans. **ANGULAR MAGNIFICATION**

"The ratio of the angles subtended by the image as seen through the optical device (aided eye) to that subtended by the object at the unaided eye, is called angular magnification".

It is also called magnifying power.

$$\therefore \quad M = \frac{\beta}{\alpha}$$

Tid-bits

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

Q.4 Define resolving power.

Ans. **RESOLVING POWER**

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

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

$$R = \frac{1}{\alpha_{min}} = \frac{D}{1.22\,\lambda}$$

where $\alpha_{min} = 1.22\,\frac{\lambda}{D}$

$$\therefore \quad R = \frac{1}{1.22\,\lambda/D} = \frac{D}{1.22\,\lambda}$$

The smaller the value of α_{min} greater is the resolving power because two distant objects which one close together can be seen separated through the instrument.

In case of a grating spectrometer, the resolving power 'R' of the grating is defined as;

$$R = \frac{\lambda}{\lambda_2 - \lambda_1} = \frac{\lambda}{\Delta\lambda}$$

Thus we see that a grating with high resolving power can distinguished small difference in wavelength. If 'N' is the number on rulings of the gratings, it can be shown that the resolving power in the mth order (m) diffraction equals the product i.e., $N \times m$.

Q.5 What is simple microscope? Derive an expression for the magnifying power of simple microscope.

Ans. **SIMPLE MICROSCOPE OR (MAGNIFYING GLASS) OR (MAGNIFIER)**

Definition

"An optical instrument, which is used to see small objects distinctly, is called simple microscope."

Construction

It consist of a biconvex lens.

Principle

When the object is placed inside the focal point of the lens, then erect, magnified and virtual image is formed at 'd' (near point or 25 cm).

Magnification

The image formed by the object, when placed at 'd' on the eye as shown in Fig. 2 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 is formed at 'd', from the eye. The size of the image is now much larger than without the lens.



Fig 1

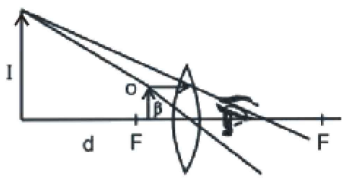


Fig 2

If 'β' and 'α' are the respective angles subtended by the object when seen through the lens and when viewed directly, then,

$$M = \frac{\beta}{\alpha} \qquad \ldots\ldots\ldots (1)$$

From Fig. 1

$$\tan \alpha = \frac{o}{d}$$

and from Fig. 2

$$\tan \beta = \frac{I}{d}$$

If α and β are very small then,

$$\tan \alpha \approx \alpha$$

$$\tan \beta \approx \beta$$

$$\therefore \quad \alpha = \frac{o}{d}$$

$$\beta = \frac{I}{d}$$

Putting the values of 'α' and 'β' in equation (1).

$$\therefore \quad M = \frac{I/d}{o/d}$$

$$M = \frac{I}{d} \times \frac{d}{o}$$

$$M = \frac{I}{o}$$

As, $$\frac{I}{o} = \frac{q}{p}$$

$$\therefore \quad M = \frac{q}{p}$$

Since the image is at the least distance of distinct vision i.e., q = d.

$$\therefore \quad M = \frac{d}{p} \quad \ldots\ldots\ldots (2)$$

The lens formula is,

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

For virtual image

$$q = -q$$

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

Since $q = d$

So, $$\frac{1}{f} = \frac{1}{p} - \frac{1}{d}$$

Multiply by 'd' both sides

$$\frac{d}{f} = \frac{d}{p} - \frac{d}{d}$$

$$\frac{d}{f} = M - 1 \qquad \left(\because \text{ from eq. (2) } M = \frac{d}{p}\right)$$

$$\therefore \quad M = 1 + \frac{d}{f}$$

It is clear for a lens of high angular magnification, the focal length will be small.

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).

Ans. COMPOUND MICROSCOPE

Whenever high magnification is desired, a compound microscope is used.

Construction

It consists of two convex lenses, an objective lens (lens towards the object) of very short focal length and an eye piece (lens towards the eye) of comparatively longer focal length. The ray diagram is shown.

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' at a place situated with in the focal point of the eye piece. The eye piece is used as a magnifying glass to see the image formed by the objective, which becomes object for eye piece. The final image seen by the eye through microscope is virtual and very much enlarged. In normal adjustment, the eye piece is positioned so that the final image is formed at the near point of the eye i.e., at 'd'.

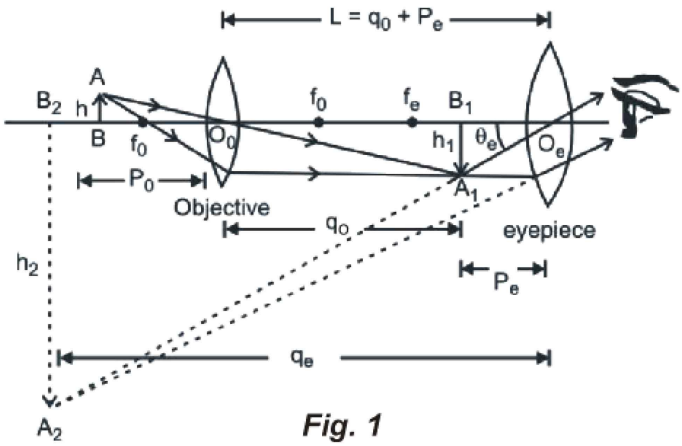


Fig. 1

Magnification

Here, $$M = \frac{\tan\theta_e}{\tan\theta}$$

Where 'θ_e' is the angle subtended by the final image 'h_2' and 'θ' is the angle subtended by the object at eye h, if placed at 'd'.

From Fig. '1' and '2'.

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

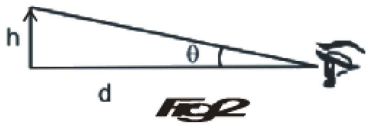


Fig. 2

$$\therefore \quad M = \frac{h_2 / d}{h / d}$$

$$M = \frac{h_2}{d} \times \frac{h}{d}$$

$$M = \frac{h_2}{h}$$

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

Where '$\frac{h_1}{h}$' is the linear magnification 'M_1' of the objective and '$\frac{h_2}{h_1}$' is the magnification 'M_2' of the eye piece.

Since $M_1 = \frac{q_0}{p_0}$

and $M_2 = 1 + \frac{d}{f_e}$ ($\because$ eye piece is working as a simple microscope)

$\therefore$ $M = \frac{q_0}{p_0}\left(1 + \frac{d}{f_e}\right)$

Note Since the object is placed just beyond the principle focus of the objective.

$\therefore$ $P_0 \approx f_0$

As, $L = q_0 + p_e$

As the image h_1 is placed very closed to eye piece

$\therefore$ $p_e \approx 0$

$\therefore$ $L = q_0$

$\therefore$ $M = \frac{L}{f_0}\left(1 + \frac{d}{f_e}\right)$

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.

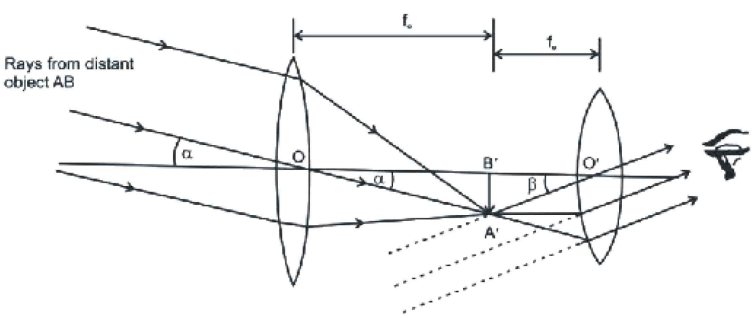
Q.7 What is astronomical telescope? Describe the construction and magnifying power of astronomical telescope.

Ans. **ASTRONOMICAL TELESCOPE**

"An optical device, which is used to see the heavenly objects like moon and stars."

It is a refracting telescope.

A simple astronomical telescope consists of two convex lenses, an **objective** of long focal length 'f_0' 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, as shown in the figure.

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 becomes 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 eye–piece and the telescope is said to be in normal adjustment.

Magnification

The angle 'α' subtended at the unaided eye is practically same as subtended at the objective.

Consider $\Delta OA'B'$

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

$$\therefore \quad \alpha = \frac{A'B'}{f_0}$$

Considering $\Delta O'A'B'$

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

$$\therefore \quad \beta = \frac{A'B'}{f_e}$$

Hence magnifying power of telescope is

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

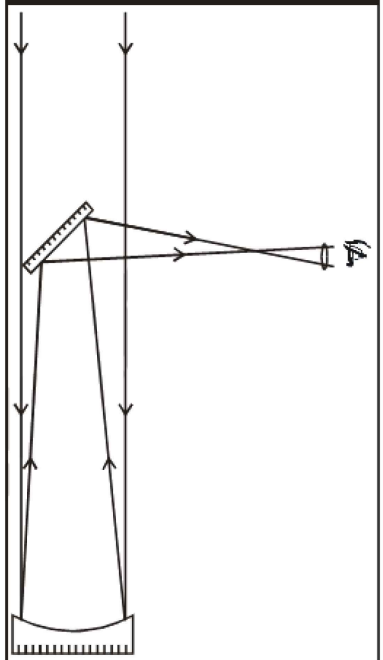
Putting values of 'α' and 'β'.

$$\therefore \quad M = \frac{A'B'/f_e}{A'B'/f_0}$$

$$M = \frac{A'B'}{f_e} \times \frac{f_0}{A'B'}$$

$$M = \frac{f_0}{f_e}$$

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.

The length of telescope is the distance between objective and eye–piece of a telescope in normal adjustment.

$$\therefore \quad L = f_0 + f_e$$

Note: 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 form 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.

Q.8 What is spectrometer? Also discuss its three parts.

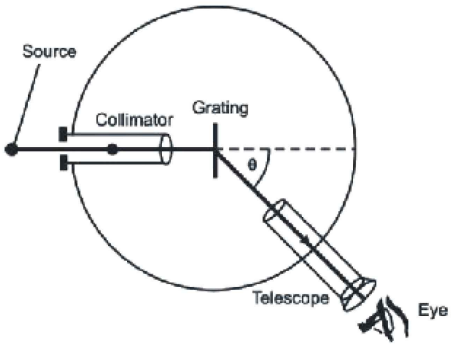
Ans. SPECTROMETER

Definition

"A spectrometer is an optical device used to study spectra from different sources of light."

Explanation

The essential components of a spectrometer are shown in the figure.



Collimator

It consists of a fixed metallic tube with a convex lens at one end and an adjustable slit at the other end.

The width of the slit can be adjusted. When the slit is just at the focus of the convex lens then the rays coming out of the lens become parallel.

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 venire scale and is rotate-able about the same vertical axis as the turn table. A circular scale graduated in half degrees is attached with it.

The telescope is adjusted in such a way that the rays of light entering it, are focused at the cross wires near the eye–piece.

Note: *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 focused 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.*

Q.9 Describe Michelson's experiment to determine the speed of light.

Ans. SPEED OF LIGHT

Light travels very fast and rapidly. Therefore, it is very difficult to measure its speed. Galileo was the first man who made an attempt to measure the speed of light but he got a failure in his attempt to measure the speed of light. Yet he agreed with the fact that light does take sometime to travel from one point to another. Michelson performed an experiment for the determination of the speed of light.

Michelson's Experiment

In this experiment, the speed of light was measured by measuring the time taken by light to cover a round trip between two mountains. The distance between two mountains was measure accurately. The experimental setup is shown in figure.

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 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 light is reflected back from the mirror 'm' and falls on the face '3' of 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 'M' gains a certain speed the source 'S' becomes visible. This happens when the time taken by the 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'.

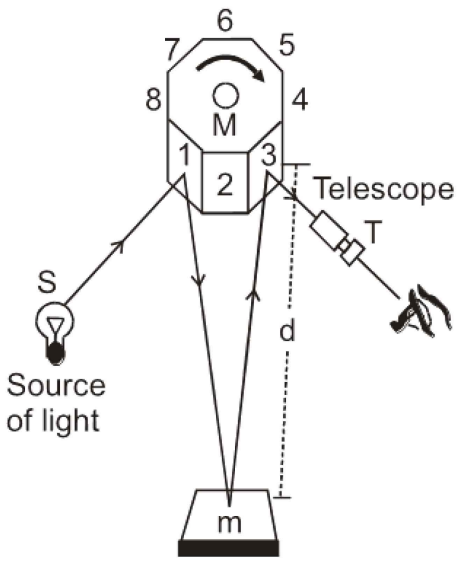


Fig. Michelson's method for measurement of speed of light.

Angle subtended by any side of eight sided mirror at the centre is $\frac{2\pi}{8}$. If 'f' is the frequency of the 'M' when the source 'S' is visible through the telescope, then the time taken by the mirror to complete 1 revolution $= \frac{1}{f}$.

Time to complete $\frac{1}{8}$ vibration $= \frac{1}{8f}$.

$$\therefore \quad t = \frac{1}{8f}$$

The time taken by the light from 'M' to 'm' and back to 'M' is;

Using $S = V\,t$

$S = Ct \ (\because V = C)$

$2d = Ct$

$$\therefore \quad t = \frac{2d}{C}$$

These two times are equal.

$$\therefore \quad \frac{2d}{C} = \frac{1}{8f}$$

$$C = 2d \times 8f$$

$$C = 16\,d\,f$$

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

As	θ	=	wt
	t	=	$\frac{\theta}{w}$
$\therefore$	w	=	$2\pi f$
$\therefore$	t	=	$\frac{\theta}{2\pi f}$
	t	=	$\frac{2\frac{\pi}{8}}{2\pi f}$
	t	=	$\frac{1}{8f}$

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.

Q.10 Write a note on the fibre optics.

Ans. **INTRODUCTION TO FIBRE OPTICS**

For hundred of years man has communicated using flashes of reflected sunlight by day and lanterns by night. Navy signalmen still use powerful blinder 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 focused upon a Selenium detector several hundred metres away. With a 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 transmission carries wave in fiber optics has several advantages over radio wave carries these advantages are (a) wide band-width capability and (b) immunity from electromagnetic interference.

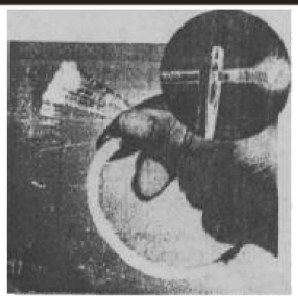
It is also used to transmit light around corners and into inaccessible places so that the formerly unobservable could be viewed. The use of fibre optic tools in industry is now very common, and their importance as diagnostic tools in medicine has been proved.

Recently the fibre optic technology has evolved into something much more important and useful and 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 ways 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 give 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 wire now used to carry the same amount of signals.

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. (a) Optical fibre image



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

Q.11 What are the basic principles of optical fibre? Explain then.

Total Internal Reflection

One of the qualities of any optically transparent material is the speed at which light travels within the materials, 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,

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

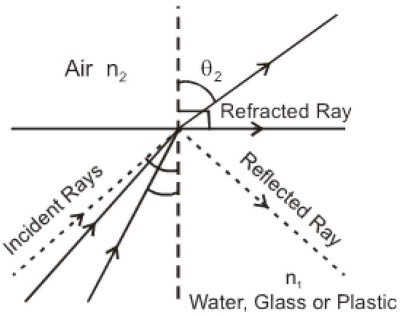


Fig. (a) If the angle of refraction in the air is 90° the angle of incidence is called the critical angle.

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^o when a ray of light is passing through glass to air. This angle of incidence is called the angle θ_c, shown in figure.

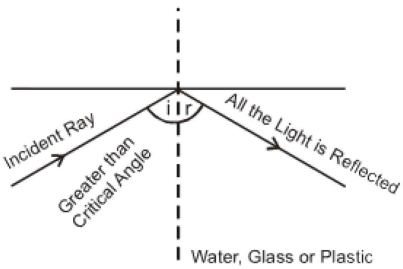


Fig. (b) For angles of incidence greater than the critical angle, all the light is reflected; none is refracted into the air.

We are already familiar with Snell's law;

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

From Fig.

when $\theta_1 = \theta_c$, $\theta_2 = 90^o$

thus, $n_1 \sin\theta_c = n_2$ or $\sin\theta_c = \frac{n_2}{n_1}$

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. For glass–air boundary, we have

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

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^o (critical angle) will be reflected back into the glass while those with angle less than 41.8^o will escape from the glass Fig. Ray 1 is injected into the rod so that it strikes the glass air boundary at an angle of incidence about 30^o.

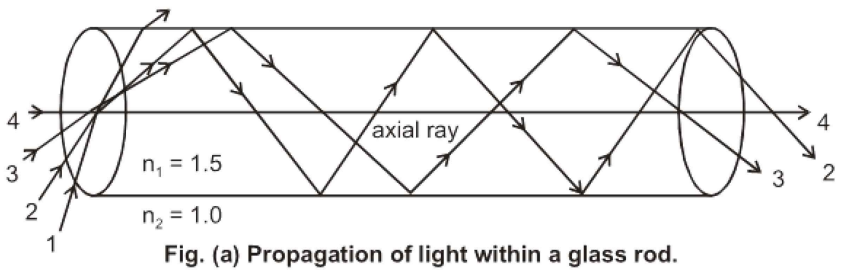


Fig. (a) Propagation of light within a glass rod.

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 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 figure.

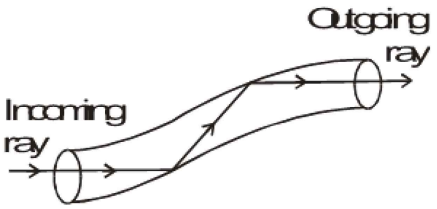


Fig. (b) Light propagation within a flexible glass fibre.

Optical fibres that propagate light by total internal reflection are the most wisely 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). This layer is called cladding. Such a type of fibre is called multi-mode step index fibre whose cross sectional view is shown in figure.

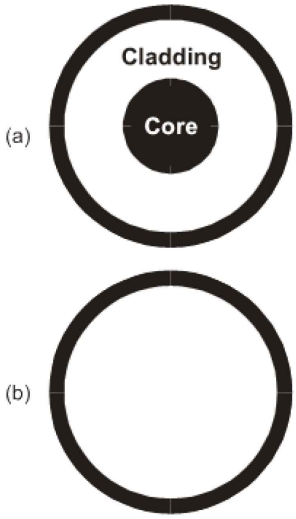


Fig. Cross sectional view of
(a) Multi-mode step index fibre
(b) Multi-mode graded index fibre

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.

In both these fibres, the propagation of light signal is through continuous refraction. We already know that a ray passing 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. 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 refraction.

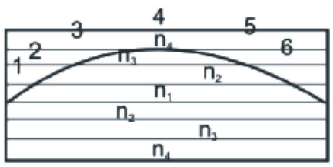


Fig. Light propagation within a hypothetical multi layer fibre.

Q.12 What are different types of optical fibre?

Ans. **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

(i) Single Mode Step Index Fibre

Single mode or mono mode step index fibre has a very thin core of about 5 μm diameter and has a relatively larger cladding (of glass or plastic) as shown in the figure. 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.

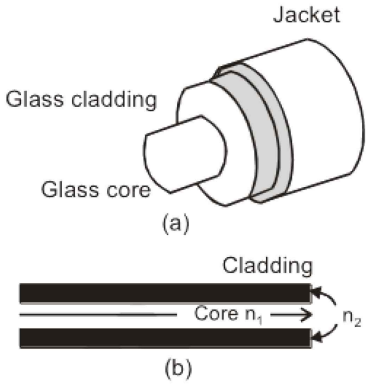


Fig. Single-mode step-index fibre.

(ii) Multi Mode Step Index Fibre

This type of fiber has a core of relatively larger diameter such as 50 μm. 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 of boundary with the cladding as shown in Fig. The refractive index then changes to a lower value n_2, such as 1.48, which remains constant through out the cladding.

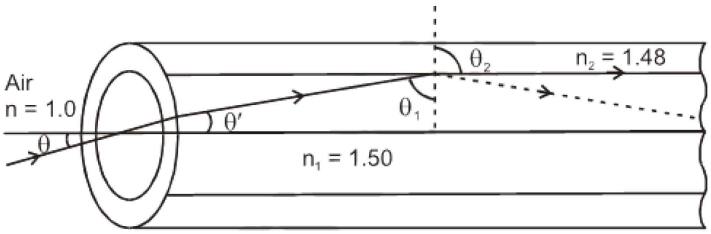
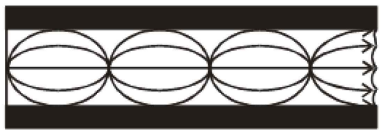


Fig. Light propagation through multi-mode step-index fibre.

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

(iii) Multimode Graded Index Fibre

Multi mode graded index fibre has core which ranges in diameter from 50 to 1000 μm. 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.


Fig. Light propagation through multi-mode graded index fibre

This type of fibre is called multi mode graded–index fibre (Fig.) and is useful for long distance application 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 the surfaces of smoothly decreasing refractive index and total internal reflection from the boundary of the outer surfaces.

Q.13 Explain the signal transmission and conversion to sound in fibre optics.

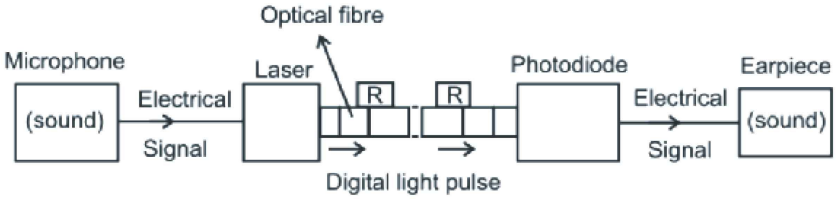
Ans. SIGNAL TRANSMISSION AND CONVERSION TO SOUND

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.

A 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 infrared signals. The typical wavelength is 1.3 μm.

Such a light will travel much faster through optical fibres than will either visible 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 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 traveling down the fibre, ones (1s) and zeros (0s) are moving down the path.



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 30 km 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 (figure).

Q.14 Explain how the power of light signals is lost by scattering and absorption during propagation?

Ans. **LOSSES OF POWER**

When a light signals travel along fibre 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.

The disadvantage of the step-index fibre Fig. (a) can considerably be reduced by using a graded index fibre. As shown in the Fig. (b), the different wavelengths still take different paths and are totally internally reflected at different layers, but still they are focused at the same points 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

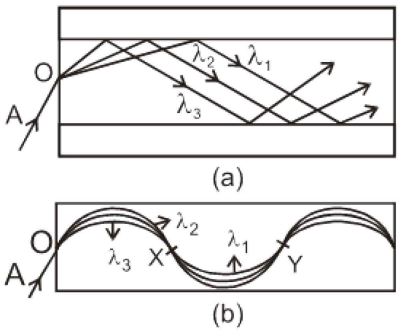


Fig. Light paths in (a) step-index and (b) graded-index fibre.

Inspite 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 of difference may be about 33ns per km length of fibre. Using in a graded index fiber, the time difference is reduced to about 1ns per km.

SOLVED EXAMPLES

EXAMPLE 10.1

A microscope has an objective lens of focal length 10 mm. And an eye piece of 25 mm focal length. What is the distance between lenses and its magnification, if the object is in sharp focus when it is 10.5 mm from objective?

Data

$$f_0 = 10 \text{ mm}$$
$$f_e = 25 \text{ mm}$$
$$p_0 = 10.5 \text{ mm}$$

To Find

Distance between lenses = L = ?

Magnification = M = ?

SOLUTION

Using

$$\frac{1}{p_0} + \frac{1}{q_0} = \frac{1}{f_0}$$

$$\frac{1}{10.5} + \frac{1}{q_0} = \frac{1}{10}$$

$$\frac{1}{q_0} = \frac{1}{10} - \frac{1}{10.5}$$

$$\frac{1}{q_0} = \frac{1}{10} - \frac{10}{105}$$

$$\frac{1}{q_0} = \frac{1}{10} - \frac{2}{21}$$

$$\frac{1}{q_0} = \frac{21 - 20}{210}$$

$$\frac{1}{q_0} = \frac{1}{210}$$

So, $q_0 = 210 \text{ mm}$

Now using

$$\frac{1}{\quad} \quad \frac{1}{\quad} \quad \frac{1}{\quad}$$

$$\frac{1}{p_e} = \frac{1}{f_e} - \frac{1}{q_e}$$

For eye piece $q_e = d$ and image is virtual

$$\therefore \quad q_e = -d$$

$$= -25 \text{ cm}$$

$$q_e = -250 \text{ mm}$$

$$\therefore \quad \frac{1}{p_e} = \frac{1}{25} - \frac{1}{-250}$$

$$= \frac{1}{25} + \frac{1}{250}$$

$$= \frac{10+1}{250}$$

$$\frac{1}{p_e} = \frac{11}{250}$$

$$p_e = \frac{250}{11}$$

$$= 22.7 \text{ mm}$$

Now using

$$L = q_0 + p_e$$

$$= 210 + 22.7$$

$$= 232.7 \text{ mm}$$

Magnification by objective $= M_1 = \frac{q_o}{p_o}$

$$= \frac{210}{10.5}$$

$$= 20$$

Magnification by eye-piece $= M_2 = \frac{-250}{22.7}$

$$= -11.0$$

Total magnification $= M = M_1 \times M_2$

$$= 20(-11)$$

$$= -220$$

Result

Distance between lenses $= L = 232.7$ mm

Magnification $= M = 220$

EXAMPLE 10.2

Data

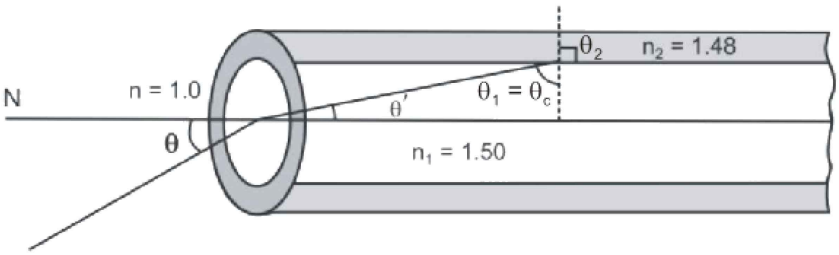
Refractive index of core = n_1 = 1.50

Refractive index of cladding = n_2 = 1.48

To Find

Critical angle = θ_c = ?

Angle of entry = θ = ?



SOLUTION

For core-cladding interface.

From Snell's law

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

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

So, $1.5 \sin\theta_c = 1.48 \sin 90^o$

$$\sin\theta_c = \frac{1.48 \times 1}{1.5}$$

$$= 0.986$$

$$\theta_c = \sin^{-1}(0.986)$$

$$= 80.6^o$$

Now using Snell's law for air-core interface.

$$n \sin\theta = n_1 \sin\theta'$$

$$1 \sin\theta = 1.5 \sin\theta' \quad \ldots\ldots\ldots (1)$$

From figure

$$\theta' + \theta_c + 90^o = 180^o$$

$$\theta' + 80.6 + 90^o = 180^o$$

$$\theta' = 180^o - 170.6$$

$$= 9.4^o$$

Put in equation (1)

$$\therefore \quad \sin\theta = 1.5 \sin 9.4^o$$

$$\theta = \sin^{-1}(0.245)$$

Critical angle = θ_c = 80.6°

Angle of entry = θ = 14.2°

Note: *If light beam is incident at the end of the optical fibre at an angle greater than 14.20, the total internal reflection would not take plane.*



OPTICAL INSTRUMENT

Each question has four possible answers, encircled the correct answer:

1. Any transparent medium bounded by one or two spherical surface, is called:

(a) Lens **(b)** Mirror

(c) Prism **(d)** None of these

2. The minimum distance from the eye at which an object appears to be distinct is called the least distance of:

(a) Focal length **(b)** Distinct vision

(c) Focus **(d)** All of above

3. A lens which is thicker from middle and thinner from edges called:

(a) Convex lens **(b)** Concave lens

(c) Convex mirror **(d)** Concave mirror

4. A lens which is thinner from middle and thicker from edges called:

(a) Convex lens **(b)** Concave mirror

(c) Convex mirror **(d)** Concave lens

5. The ratio of the size of image to the size of object is called:

(a) Magnification **(b)** Angular magnification

(c) Classification **(d)** None of these

6. The ratio of the angles subtended by the image as seen through the optical device to that angle subtended by the object at the eye is called:

(a) Linear magnification **(b)** Angular magnification

(c) Tabulation **(d)** Calculation

7. A straight line joining the centers of curvature of two surfaces is called:

(a) Principal axis **(b)** Radius of lens

(c) Diameter of lens **(d)** Principal focus

8. A point where the incident rays of light converge or appears to diverge after passing through the lens is called:

(a) Aperture **(b)** Focus

(c) Optical centre **(d)** Pole of lens

9. When light passes from one medium to another medium, it is bend away from the normal. This phenomenon is called:

(a) Diffraction **(b)** Refraction

(c) Dispersion **(d)** Polarization

10. The distance of near point from the eye is about:

(a) 25 cm **(b)** 25 m

(c) 10 cm **(d)** 10 cm

11. A fixed point inside the lens through which a ray of light does not change its path is called:

(a) Pole **(b)** Principal focus

(c) Optical centre **(d)** None of these

12. The distance between the principal focus and the optical centre of the lens is called:

(a) Aperture **(b)** Focal length

(c) Radius of curvature **(d)** None of these

13. When an object is brought from a far point to the focal point of a convex lens, the size of image is:

(a) Unchanged **(b)** Decreasing

(c) Increasing **(d)** All of above

14. The apparent size of the object depends upon its actual size and angle subtended by it at the:

(a) Eye **(b)** Face

(c) Mouth **(d)** Near point at eye

15. When an object is viewed at a shorter distance, the image on the retina of the eye is:

(a) Greater **(b)** Smaller

(c) Unchanged **(d)** None of these

16. The reciprocal of the focal length of a lens is expressed in metres is called:

(a) Power of lens **(b)** Focus of lens

(c) Aperture of lens **(d)** None of these

17. The unit of power of a lens is:

(a) Newton **(b)** Watt

(c) Dioptre **(d)** None of above

18. The power of a convex lens of focal length 50 cm will be:

(a) 2 dioptre **(b)** 5 dioptre

(c) 1.5 dioptre **(d)** None of these

19. The focal length of concave lens is:

(a) Positive **(b)** Negative

(c) Positive and negative **(d)** None of these

20. The focal length of convex lens is:

(a) Positive **(b)** Negative

(c) Positive and negative **(d)** None of these

21. In case of concave lens, the image of the real object is:

(a) Real, magnified and inverted **(b)** Virtual, diminished and erect

(c) Virtual, magnified and erect **(d)** None of these

22. The resolving power of an instrument can be expressed as:

(a) α_{min} **(b)** α_{max}

(c) α **(d)** None of these

23. Raleigh showed that for a light of wavelength λ through a lens of diameter D, the resolving power is:

(a) $\alpha_{min} = 1.22 \frac{\lambda}{D}$ **(b)** $\alpha_{min} = 1.22 \frac{D}{\lambda}$

(c) $\alpha_{min} = \frac{1.22}{\lambda D}$ **(d)** $\alpha_{min} = 1.22\ \lambda D$

24. In case of grating spectrometer, the resolving power R of the grating is defined as:

(a) $R = \lambda \,.\, \Delta\lambda$ **(b)** $R = \frac{\lambda}{\Delta\lambda}$

(c) $R = \frac{\Delta\lambda}{\lambda}$ **(d)** None of these

25. The resolving power in the mth order grating equals to:

(a) $R = N \times m$ **(b)** $R = \frac{N}{m}$

(c) $R = \frac{m}{N}$ **(d)** $R = \frac{1}{N\text{-}m}$

26. If an object is placed in front of convex lens then the image will be:

(a) Real and erect **(b)** Real and inverted

(c) Virtual and erect **(d)** Virtual

27. If an object is placed in front of concave lens then the image will be:

(a) Virtual and erect **(b)** Real and inverted

(c) Real and erect **(d)** Virtual

28. If an object is placed at 2F from convex lens, the image is located behind the lens:

(a) Between lens and focus **(b)** At 2F

(c) Between F and 2F **(d)** At the focus

29. Convex lens forms:

(a) Real and erect image **(b)** Virtual and inverted image

(c) Real and inverted image **(d)** None of these

30. If an object is placed slightly more than 2F from a converging lens, the image is located behind the lens:

(a) At 2F **(b)** Between F and 2F

(c) At the focus **(d)** None of these

31. Magnification of a lens is positive when the image is:

(a) Real and inverted **(b)** Virtual and inverted

(c) Real and erect **(d)** None of these

32. Magnification of a lens is negative when the image is:

(a) Real and inverted **(b)** Virtual and inverted

(c) Virtual and erect **(d)** None of these

33. Magnifying power of an optical instrument is given by the ratio of:

(a) $\frac{\beta}{\alpha}$ **(b)** $\frac{\alpha}{\beta}$

(c) $\frac{2\beta}{\alpha}$ **(d)** $\frac{2\alpha}{\beta}$

34. The magnification of the simple microscope if α and β are the angles subtended by the object when seen through the lens and when viewed directly is:

(a) $M = \frac{\beta}{\alpha}$ **(b)** $M = \frac{\alpha}{\beta}$

(c) $M = \alpha\beta$ **(d)** $M = \frac{1}{\alpha\beta}$

35. The magnifying power of a simple microscope is:

(a) $M = 1 + \frac{f}{d}$ **(b)** $M = 1 + \frac{d}{f}$

(c) $M = 1 + fd$ **(d)** None of these

36. An optical device used for the large magnification of a very minute object is called:

(a) Simple microscope **(b)** Compound microscope

(c) Convex lens **(d)** Telescope

37. The convex lens used in compound microscope as objective has focal length:

(a) Large **(b)** Short

(c) Same as eye-piece **(d)** None of these

38. If a single convex lens is placed close to the eye then it can be used as:

(a) Simple microscope **(b)** Compound microscope

(c) Spectrometer **(d)** Telescope

39. The final image produced by the eye-piece of compound microscope is:

(a) Real and inverted **(b)** Real and erect

(c) Virtual and inverted **(d)** Virtual and erect

40. The magnifying power of a compound microscope is:

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

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

41. The magnifying power of a compound microscope is:

(a) Magnification of objective ÷ Magnification of eye-piece

(b) Magnification of objective + Magnification of eye-piece

(c) Magnification of objective × Magnification of eye-piece

(d) Magnification of objective – Magnification of eye-piece

42. In compound microscope, the focal length of eye-piece is:

(a) Large **(b)** Small

(c) Same as objective **(d)** None of these

43. The eye-piece of a compound microscope acts as:

(a) Converging mirror **(b)** Converging lens

(c) Diverging mirror **(d)** Diverging lens

44. If focal length of objective is increased:

(a) Magnifying power of compound microscope decreased

(b) Magnifying power of astronomical telescope increases

(c) Length of astronomical telescope increases

(d) All of above

45. The resolving power of a compound microscope depends upon:

(a) The refractive index of the medium in which the object is placed

(b) The angle subtended by the objective lens at the object

(c) The diameter of the objective lens

(d) None of these

46. It is an optical instrument used to very far off objects is called:

(a) Telescope **(b)** Microscope

(c) Convex lens **(d)** Spectrometer

47. A simple astronomical telescope consists of:

(a) Two convex lens **(b)** Two concave lens

(c) One convex and one concave **(d)** None of these

48. The image of a distant object viewed through telescope appears:

(a) Larger **(b)** Brighter

(c) Smaller **(d)** Dull

49. The distance between the objective and eye-piece of a telescope in normal adjustment is:

(a) $f_0 - f_e$ **(b)** $f_0 + f_e$

(c) $f_e - f_0$ **(d)** None of these

50. The magnifying power of astronomical telescope is:

(a) $M = \frac{f_e}{f_0}$ **(b)** $M = f_e f_0$

(c) $M = \frac{1}{f_e f_0}$ **(d)** $M = \frac{f_0}{f_e}$

51. The resolving power of an astronomical telescope depends upon:

(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-piece **(d)** The diameter of the objective lens

52. The magnifying power of an instrument is expressed in:

(a) Radians **(b)** Degrees

(c) No units **(d)** None of these

53. For an astronomical telescope $f_0 + f_e = 105$ cm, $\frac{f_0}{f_e} = 20$ the focal lengths of objective and eye-piece are:

(a) 50 cm, 5 cm **(b)** 210 cm, 25 cm

(c) 100 cm, 5 cm **(d)** None of these

54. The final image obtained by astronomical telescope is:

(a) Erect **(b)** Virtual

(c) Magnified **(d)** All of them

55. Lenses of focal lengths 100 cm and 5 cm are used as objective and eye-piece of an astronomical telescope, its length for normal adjustment is:

(a) 95 cm **(b)** 105 cm

(c) 20 cm **(d)** None of these

56. An optical instrument used to study the properties of light:

(a) Spectrometer **(b)** Simple microscope

(c) Telescope **(d)** None of these

57. A grating is placed on the turn table which is capable of rotating about a fixed:

(a) Vertical axis **(b)** Horizontal axis

(c) Both (a) and (b) **(d)** None of these

58. The component of the spectrometer which consists of a fixed metallic tube with a convex lens at one end and an adjustable slit is called:

(a) Telescope **(b)** Collimator

(c) Turntable **(d)** Grating

59. An instrument which consists of three parts that is collimator, telescope and turn table is called:

(a) Compound microscope **(b)** Spectrometer

(c) Telescope **(d)** None of these

60. In spectrometer, the function of collimator is to produce:

(a) Parallel beam of light **(b)** Converging beam of light

(c) Diverging beam of light **(d)** None of these

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

(a) Magnification **(b)** Resolution

(c) Resolving power **(d)** None of these

62. The formula $\alpha_{min} = 1.22\ \lambda/\Delta\lambda$ for resolving power was given by:

(a) Einstien **(b)** Newton

(c) Michelson **(d)** Raleigh

63. The scientist who correctly measured the speed of light was:

(a) Einstien **(b)** Michelson

(c) Gallileo **(d)** Newton

64. The scientist who made first attempt to measure the speed of light was:

(a) Huygen **(b)** Young

(c) Einstien **(d)** Gallileo

65. Michelson used the equation to find the speed of light is:

(a) $C = \frac{16}{fd}$ **(b)** $C = \frac{16f}{d}$

(c) $C = 16fd$ **(d)** $C = \frac{fd}{16}$

66. The speed of light in vacuum or in air is:

(a) 3×10^{10} m/s **(b)** 3×10^{7} m/s

(c) 3×10^{9} m/s **(d)** 3×10^{8} m/s

67. The speed of light in other materials is always:

(a) Less than C **(b)** Equal to C

(c) Greater than C **(d)** None of these

68. In Michelson experiment, the angle subtended by the side of eight sided mirror at the centre is:

(a) π **(b)** $\frac{\pi}{2}$

(c) $\frac{\pi}{8}$ **(d)** $\frac{\pi}{4}$

69. The speed at which light travels within the material depends upon:

(a) Refractive index **(b)** Frequency

(c) Wavelength **(d)** Velocity

70. Alexander Bell invented advice known as:

(a) Photo phone **(b)** Telescope

(c) Spectrometer **(d)** Microscope

71. Graham Bell was able to transmit a voice message via:

(a) Telescope **(b)** Beam of light

(c) Spectrometer **(d)** Simple microscope

72. The detector in photo-phone is made of:

(a) Selenium **(b)** Cadmium and Germinium

(c) Codmium and Silicon **(d)** None of these

73. For incident angles equal or greater than the critical angle, the glass air boundary will act as a:

(a) Mirror **(b)** Concave mirror

(c) Convex mirror **(d)** None of these

74. For glass air boundary, the value of critical angle is:

(a) 41° **(b)** 41.5°

(c) 41.8° **(d)** 41.2°

75. Optical fibres are of:

(a) One type **(b)** Two types

(c) Three types **(d)** None of these

76. A fibre optical communication system consists of:

(a) Two major components **(b)** Three major components

(c) Five major components **(d)** Four major components

77. An optical fibre with its protective core may be typically:

(a) 7 mm **(b)** 7.62 cm

(c) 6.0 cm **(d)** None of these

78. Types of optical fibres are:

(a) Single mode step index **(b)** Multimode step index

(c) Multimode graded index **(d)** All of these

79. Multimode step index fibre is useful for:

(a) Short distance **(b)** Long distance

(c) Neither long nor short **(d)** None above

80. Multimode graded index fibre core has diameter of:

(a) 50 – 2000 μm **(b)** 50 – 100 μm

(c) 50 – 1500 μm **(d)** 50 – 300 μm

81. How many phone calls can be carried by single mode step index fibre:

(a) 15000 **(b)** 12000

(c) 16000 **(d)** 14000

82. The optical fibre is covered for protection by a:

(a) Plastic jacket **(b)** Copper jacket

(c) Glass jacket **(d)** Rubber jacket

83. A layer of lower refractive index over the central core of high refractive index is called:

(a) Cladding **(b)** Multimode step index fibre

(c) Multimode graded index fibre **(d)** All of the above

84. Single mode step index fibre has a very thin core of about diameter:

(a) 2.5 μm **(b)** 3.5 μm

(c) 5.0 μm **(d)** None of these

85. Multimode step index fibre has a core of relatively larger diameter such as:

(a) 25 μm **(b)** 75 μm

(c) 100 μm **(d)** 50 μm

86. Light entering glass will not suffer change in:

(a) Velocity **(b)** Direction

(c) Frequency **(d)** Wavelength

87. Fibre optics system can be used for:

(a) Image transmitting **(b)** Word processing

(c) Image processing and receiving **(d)** All of above

88. Use of outer layer in optical fibres called cladding is mainly to:

(a) Produce total internal reflection **(b)** Scatter the light

(c) Transmit the light **(d)** None of these

89. Total internal reflection occurs when the angle of incidence is:

(a) Equal to critical angle **(b)** Greater than critical angle

(c) Less than critical angle **(d)** None of these

90. The disadvantages of step index fibre is:

(a) Quality of the fibre **(b)** Size of the cable

(c) Difference in the wavelength of signals **(d)** None of these

91. Loss of power in optical fibre results into:

(a) Accurate information at the receivers **(b)** Poor reception of signals

(c) Delay in time for reception of signals **(d)** All of these

92. In optical fibres, repeaters are usually laid down after every:

(a) 1000 km **(b)** 10,000 km

(c) 50,000 km **(d)** 100 km

93. Television signals are converted into light signals by:

(a) Optical fibre **(b)** Transistor

(c) Decoder **(d)** Photo diode

94. A convex lens acts as diverging lens when the object is placed:

(a) At 2F **(b)** Within focal length

(c) At forces **(d)** Between F and 2F

95. When the object is between F and 2F, the image formed by a convex lens is:

(a) Real **(b)** Virtual

(c) Erect **(d)** None of these

96. The ratio of the diameters of two convex lenses is ———— the ratio of their focal lengths:

(a) Less than **(b)** Greater than

(c) Equal to **(d)** None of these

97. Conventionally all the distances p, q, f are measured from ———— of the lens:

(a) Focus **(b)** Optical centre

(c) Edges **(d)** None of these

98. A lens of 2 cm focal length is to be used as a magnifying glass. Its magnification is:

(a) 13.5 **(b)** 2.5

(c) 0.5 **(d)** 12.5

99. The working of a compound microscope is based on the principle of:

(a) Reflection **(b)** Refraction

(c) Both (a) and (b) **(d)** None

100. In the formula, $\alpha_{min} = \frac{1.22\lambda}{D}$, where D denotes:

(a) Diameter of lens **(b)** Power of the lens

(c) Distance between source and the object **(d)** None of the

101. Maximum detail of an object can be seen by microscope when the object is illuminated by light of:

(a) Longer wavelength **(b)** Short wavelength

(c) Infrared light **(d)** None of these

102. The limit to which a microscope can be used to resolve details of an object depends upon:

(a) Narrow objective and light of short wavelength

(b) Narrow objective and light of short wavelength

(c) Narrow objective and light of longer wavelength

(d) None of these

103. Snell's law is described as:

(a) $n_1 \sin\theta_1 = n_2 \sin\theta_2$ **(b)** $n_2 \sin\theta_1 = n_1 \sin\theta_2$

(c) $n_1 \sin\theta_2 = n_2 \sin\theta_1$ **(d)** None of these

104. When $\theta_2 = 90°$ and $\theta = \theta_c$ then Snell's law becomes:

(a) $\sin\theta_c = n_1 n_2$ **(b)** $\sin\theta_c = \frac{n_2}{n_1}$

(c) $\sin\theta_c = \frac{n_1}{n_2}$ **(d)** None of these

105. Power of any lens would be one dipotre when its focal length is:

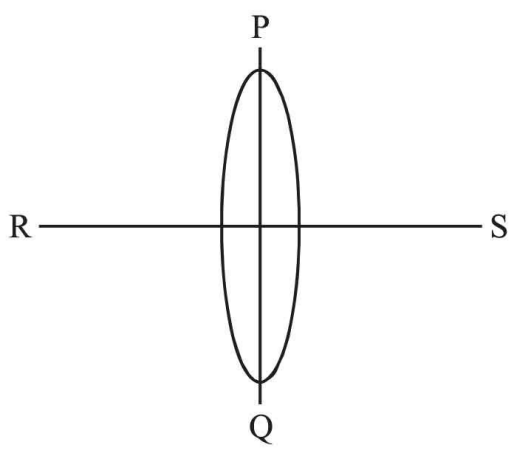
(a) 1.0 m **(b)** 1 cm

(c) 10 cm **(d)** 2 m

106. The figure shows an equi-convex lens of focal length f. If the lens is cut along PQ. The focal length of each help will be:

(a) $\frac{f}{2}$ **(b)** f

(c) 2f **(d)** $\frac{3f}{2}$



107. A spectrometer is used to measure:

(a) Refractive index of material of glass prism

(b) Deviation of light by a glass prism

(c) Wavelength of light

(d) All of the above

108. The unit of power of a lens is:

(a) Metre **(b)** Watt

(c) Newton **(d)** Dioptre

109. The minimum distance between an object and its real image in a convex lens is:

(a) 2f **(b)** 2.5f

(c) 3f **(d)** 4f

110. An object is placed at 18 cm from a converging lens of focal length 6 cm. The image formed is:

(a) Real and inverted **(b)** Real and erect

(c) Virtual and erect **(d)** Virtual and inverted

111. The image formed by a convex lens of focal length 10 cm is twice the size of the object. The position of the object will be:

(a) 20 cm **(b)** 30 cm

(c) 50 cm **(d)** 15 cm

112. In Michelson's experiment, the equation used to find the speed of light is:

(a) $c = 16\ fd$ **(b)** $c = 16\ f/d$

(c) $c = 16d/f$ **(d)** $c = fd/16$

113. The diameter of single mode step fibre core is:

(a) 10 μm **(b)** 30 μm

(c) 5 μm **(d)** 100 μm

114. The focal length 'f' and radius of curvature are related by:

(a) $f = 2R$ **(b)** $R = 2f$

(c) $R = f$ **(d)** None of the above

115. The focal length of objective of telescope is 60 cm. To obtain magnification of 20 focal length of eye piece should be:

(a) 5 cm **(b)** 4 cm

(c) 3 cm **(d)** 2 cm

116. In compound microscope the magnification of object is M_o and magnification of eyepiece is Me. The magnifying power of compound microscope is:

(a) $M_o + M_e$ **(b)** $M_o \times M_e$

(c) $M_e - M_e$ **(d)** M_o/M_e

117. To increase the resolving power of telescope we should use:

(a) Wider objective **(b)** Wider eyepiece

(c) Shorter objective **(d)** Shorter eyepiece

118. An observer moves towards a stationary plane minor at a peed of 4 ms^{-1}, with what speed will what speed will his image move towards him?

(a) 2 ms^{-1} **(b)** 4 ms^{-1}

(c) 8 ms^{-1} **(d)** Image will stay at rest

119. Which mirror should be used to obtain a parallel beam of light from a small lamp?

(a) Plane mirror **(b)** Convex mirror

(c) Concave mirror **(d)** Any one of the above

120. An object of 2 cm tall is placed 15 cm from concave mirror of focal length 10 cm. How far is the image from the mirror?

(a) 10 cm **(b)** –20 cm

(c) –30 cm **(d)** –40 cm

121. Which one of the following phenomena cannot be explained by the wave theory of light?

(a) Refraction **(b)** Total internal reflection

(c) Diffraction **(d)** Photoelectric effect

122. What will be the colour of the sky as seem from the earth if there were no atmosphere?

(a) Black **(b)** Blue

(c) Orange **(d)** Red

123. In vacuum light travels at a speed of 3×10^8 ms^{-1}, what is the speed of light in glass of refractive index 1.5?

(a) 1.5×10^8 ms^{-1} **(b)** 2×10^8 ms^{-1}

(c) 3×10^8 ms^{-1} **(d)** 4.5×10^8 ms^{-1}

124. An object is placed between two parallel mirrors. The number of image formed is:

(a) 2 **(b)** 4

(c) 8 **(d)** Infinite

ANSWERS

1.	(a)	**2.**	(b)	**3.**	(a)	**4.**	(d)
5.	(a)	**6.**	(b)	**7.**	(a)	**8.**	(b)
9.	(b)	**10.**	(a)	**11.**	(a)	**12.**	(b)
13.	(c)	**14.**	(d)	**15.**	(a)	**16.**	(a)
17.	(c)	**18.**	(a)	**19.**	(b)	**20.**	(a)
21.	(a)	**22.**	(a)	**23.**	(a)	**24.**	(b)
25.	(a)	**26.**	(b)	**27.**	(a)	**28.**	(b)
29.	(c)	**30.**	(b)	**31.**	(a)	**32.**	(c)
33.	(a)	**34.**	(a)	**35.**	(b)	**36.**	(b)
37.	(b)	**38.**	(a)	**39.**	(c)	**40.**	(b)
41.	(c)	**42.**	(a)	**43.**	(b)	**44.**	(d)
45.	(c)	**46.**	(a)	**47.**	(a)	**48.**	(a)
49.	(b)	**50.**	(d)	**51.**	(d)	**52.**	(c)
53.	(c)	**54.**	(d)	**55.**	(b)	**56.**	(a)
57.	(a)	**58.**	(b)	**59.**	(b)	**60.**	(a)
61.	(c)	**62.**	(d)	**63.**	(b)	**64.**	(d)
65.	(c)	**66.**	(d)	**67.**	(a)	**68.**	(b)
69.	(a)	**70.**	(a)	**71.**	(b)	**72.**	(a)
73.	(a)	**74.**	(c)	**75.**	(c)	**76.**	(b)
77.	(a)	**78.**	(d)	**79.**	(a)	**80.**	(b)
81.	(d)	**82.**	(a)	**83.**	(a)	**84.**	(c)
85.	(d)	**86.**	(c)	**87.**	(d)	**88.**	(a)
89.	(b)	**90.**	(c)	**91.**	(d)	**92.**	(d)
93.	(c)	**94.**	(b)	**95.**	(a)	**96.**	(c)
97.	(b)	**98.**	(a)	**99.**	(c)	**100.**	(a)
101.	(b)	**102.**	(a)	**103.**	(a)	**104.**	(c)
105.	(a)	**106.**	(c)	**107.**	(d)	**108.**	(d)
109.	(d)	**110.**	(a)	**111.**	(d)	**112.**	(a)
113.	(c)	**114.**	(b)	**115.**	(c)	**116.**	(b)
117.	(a)	**118.**	(c)	**119.**	(c)	**120.**	(c)
121.	(d)	**122.**	(a)	**123.**	(b)	**124.**	(d)

SHORT QUESTIONS

10.1 What do you understand by linear magnification and angular magnification? Explain how a convex lens is used as a magnifier?

Ans. **Linear Magnification:** It is defined as the ratio of the size of image to the size of object. Mathematically

$$M = \frac{I}{O} = \frac{q}{p}$$

Angular Magnification: It is the ratio of the angle subtended by the image as seen through the optical instrument to the angle subtended by the object at the unaided eye.

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

Both linear and angular magnification has no unit.

A Convex lens as a Magnifier: A convex lens of short focal length can be used as magnifying glass because when an object is placed between lens and focus then the image formed is erect, virtual and very much magnified.

10.2 Explain the difference between angular magnification and resolving power of an optical instrument. What limits the magnification of an optical instrument?

Ans. Angular magnification means how large or magnified image is formed by the instrument but resolving power is its ability to provide the minor details of an object under examination. The magnification of an optical instrument is limited due to defects in the lenses. Such as chromatic and spherical aberrations.

10.3 Why would it be advantageous to use blue light with a compound microscope?

Ans. We know that the expression for resolving power is:

$$R \propto \frac{1}{\alpha_{min.}}$$

Here, $$\alpha_{min.} = 1.22\frac{\lambda}{D}$$

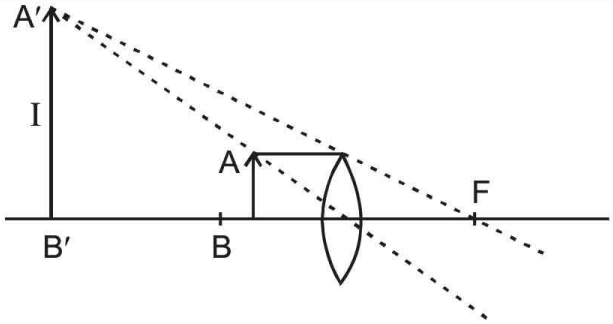
From this equation we see that resolving power is inversely proportional to $\alpha_{min.}$ and $\alpha_{min.}$ depends upon wavelength and diameter of lens. As blue light has short wavelength therefore it will produce less diffraction and resolving power of compound microscope will increase.

10.4 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?

Ans. It is due to the defect of lenses known as chromatic aberrations. This is because of the prism like formation of the lens in which all rays of white light cannot meet at a single point therefore image is not sharp and has coloured edges.

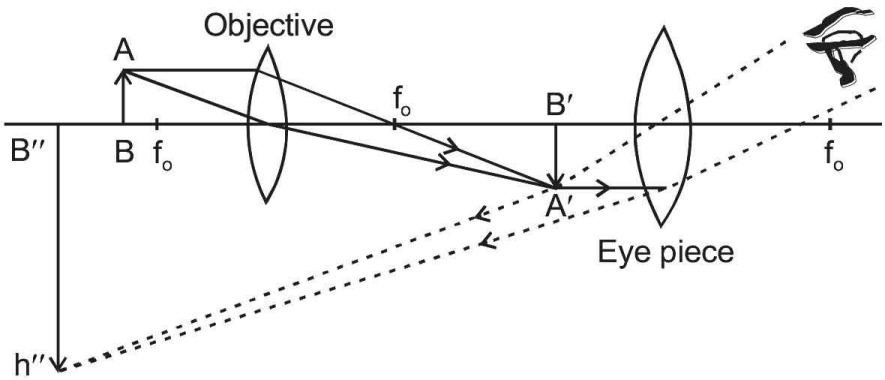
10.5 Describe with the help of diagram, how (a) a single biconvex lens can be used as a magnifying glass. (b) biconvex lenses can be arranged to form a microscope.

Ans. (a) Ray diagram of a biconvex lens used as magnifying glass:



Simple microscope or magnifying glass

(b) Ray diagram of two biconvex lens arranged to make microscope.

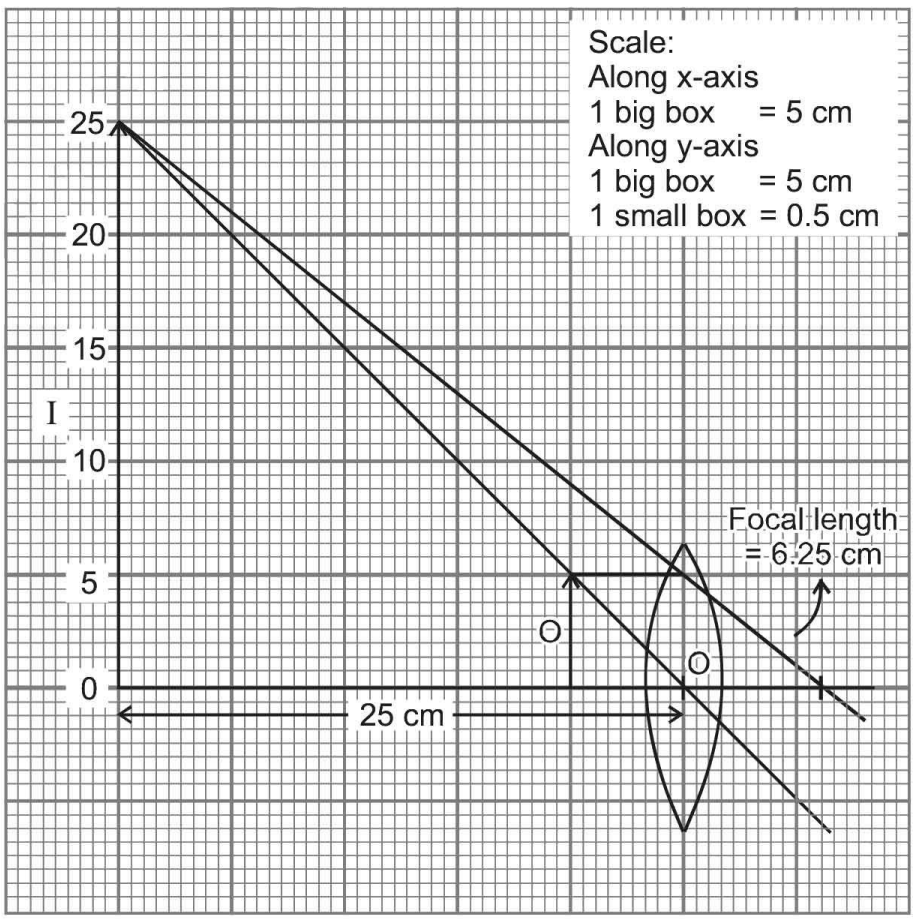


Compound microscope

10.6 If a person were looking through a telescope at the full moon, how would the appearance of the moon be changed by covering half of the objective lens?

Ans. The person will see the full image of the moon if half of the objective lens of a telescope is covered but its brightness is reduced because less light is transmitted through the 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.



Data

Magnification = M = 5

Image distance = q = 25 cm

Focal length of lens = f = ?

Solution

By formula

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

$$5 = 1 + \frac{25}{f}$$

$$5 - 1 = \frac{25}{f}$$

$$4f = 25$$

$$f = \frac{25}{4}$$

$$f = 6.2 \text{ cm}$$

10.8 Identify the correct answer:

(i) The resolving power of a compound microscope depends on;

(a) The refrective index of the medium in which the object is placed.

(b) The diameter of the objective lens.

(c) The angle subtended by the objective lens at the object.

(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.

Ans. (i) The formula for the resolving power of a lens of diameter D is given by

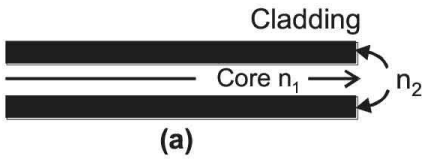
$$R = \frac{D}{1.22\lambda}$$

Hence the resolving power of a lens depends upon the diameter of objective so (b) is correct.

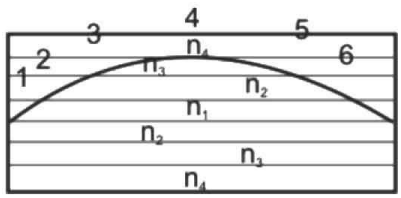
(ii) As we know that the resolving power of an astronomical telescope depends upon the diameter of objective lens so (d) is correct.

10.9 Draw sketches showing the different light paths through a single-mode and a multimode fibre. Why is the single-mode fibre preferred in telecommunications?

Ans.



(a)



(b)

It has a very thin core of about 5 μm diameter and has a relatively larger cladding. It can carry more than 14 TV channels or 14000 phone calls so it is preferred in telecommunication.

10.10 How the light signal is transmitted through the optical fibre?

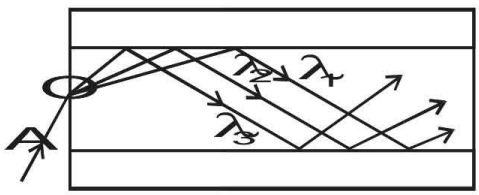
Ans. The light signals are transmitted through the optical fibre on the principle of:

(i) Total internal reflection.

(ii) Continuous refraction.

10.11 How the power is lost in optical fibre through dispersion? Explain.

Ans. If the source of light signals is not monochromatic then the light will disperse while propagating through the core of the optical fibre into different wavelength so the light of different wavelengths reaches the other end of the fibre at different times and the signal received is distorted. So the power is lost in optical fibre through dispersion.



PROBLEMS WITH SOLUTIONS

PROBLEM 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?

Data

Focal length of the lens = f = 5.0 cm

Distance of near point = q = d = 25 cm

To Find

(i) Distance of object from lens = p = ?

(ii) Angular magnification = M = ?

Angular magnification when the image is at infinity = M′ = ?

SOLUTION

(i) By lens formula

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

As q = –d, the image is virtual so

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

$$\frac{1}{5} = \frac{1}{p} - \frac{1}{25}$$

$$\frac{1}{p} = \frac{1}{5} + \frac{1}{25}$$

$$= \frac{5+1}{25}$$

$$\frac{1}{p} = \frac{6}{25}$$

$$p = \frac{25}{6} = 4.16 \text{ cm}$$

(ii) As we know that

$$\text{Angular magnification} = M = 1 + \frac{d}{f}$$

$$= 1 + \frac{25}{5}$$

$$= 1 + 5$$

$$M = 6$$

For angular magnification when the image is at infinity then the object must be at focus. So

$$M' = \frac{d}{f} \quad \text{Since} \quad p = f$$

$$M' = \frac{d}{f} = \frac{25}{5}$$

$$M' = 5$$

Result

(i) Distance of object from the lens = p = 4.16 cm

(ii) Angular magnification = M = 6

Angular magnification when the image is at infinity = M′ = 5

PROBLEM 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.

Data

Focal length of objective = f_o = 96 cm

Diameter of objective = d_o = 12 cm

Linear magnification = M = 24

To Find

Focal length of eye-piece = f_e = ?

Diameter of eye-piece = d_e = ?

SOLUTION

By using the formula for linear magnification in case of telescope

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

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

$$f_e = \frac{96}{24}$$

$$f_e = 4 \text{ cm}$$

For the diameter of eye-piece

$$\boxed{\frac{f_o}{f_e} = \frac{d_o}{d_e}}$$

CONCORDIA

$$d_e = \frac{f_e \times d_o}{f_o}$$

$$= \frac{4 \times 12}{96}$$

$$d_e = 0.5 \text{ cm}$$

Result

Focal length of eye-piece = f_e = 4 cm

Diameter of eye-piece = d_e = 0.5 cm

PROBLEM 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.

Data

Focal length of objective = f_o = 20 cm

Focal length of eye-piece = f_e = 5.0 cm

To Find

Angular magnification = M = ?

SOLUTION

By formula

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

$$M = \frac{20}{5.0}$$

$$M = 4$$

Result

Angular magnification = M = 4

PROBLEM 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.

Data

Focal length of objective = f_o = 100 cm

Focal length of eye-piece = f_e = 5.0 cm

To Find

(i) Distance of final image = q = ?

(ii) Angular magnification = M = ?

SOLUTION

(i) For distance of final image

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

The final image is virtual so

$$\frac{1}{f_e} = \frac{1}{p} - \frac{1}{q} \qquad \text{Since} \quad p = f_e = 5.0 \text{ cm}$$

So $$\frac{1}{5.0} = \frac{1}{5.0} - \frac{1}{q}$$

$$\frac{1}{q} = \frac{0}{5.0}$$

$$q = \frac{5.0}{0}$$

$$q = \infty \text{ (infinity)}$$

(ii) For angular magnification

$$M = \frac{f_o}{f_e} = \frac{100}{5.0}$$

$$M = 20$$

Result

(i) Distance of final image = q = ∞

(ii) Angular magnification = M = 20

PROBLEM 10.5

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 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.

Data

Distance of object = p_1 = 3.6 cm

Distance between lenses = L = 26 cm

Focal length of 1st lens = f_1 = 3.0 cm

Focal length of 2nd lens = f_2 = 16.0 cm

To Find

Position of the final image = q_2 = ?

SOLUTION

For 1st law

$$\frac{1}{f_1} = \frac{1}{p_1} + \frac{1}{q_1}$$

$$\frac{1}{3.0} = \frac{1}{3.6} + \frac{1}{q_1}$$

$$\frac{1}{3} - \frac{1}{3.6} = \frac{1}{q_1}$$

$$\frac{1}{3} - \frac{10}{36} = \frac{1}{q_1}$$

$$\frac{12 - 10}{36} = \frac{1}{q_1}$$

$$q_1 = \frac{36}{2}$$

$$q_1 = 18 \text{ cm}$$

Distance of object from the 2nd lens $= p_2 = L - q_1$

$$= 26 - 18$$

$$p_2 = 8 \text{ cm}$$

So for 2nd lens

$$\frac{1}{f_2} = \frac{1}{p_2} + \frac{1}{q_2}$$

So

$$\frac{1}{16} = \frac{1}{8} + \frac{1}{q_2}$$

$$\frac{1}{q_2} = \frac{1}{10} - \frac{1}{8}$$

$$= \frac{1 - 2}{16}$$

$$\frac{1}{q_2} = -\frac{1}{16}$$

$$q_2 = -16 \text{ cm}$$

Result

Position of final image $= q_2 = -16$ cm

PROBLEM 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.

Data

Focal length of objective = f_o = 1.0 cm

Focal length of eye-piece = f_e = 3.0 cm

Distance of object from objective = p_1 = 1.2 cm

Distance of final image = q_2 = 25 cm

To Find

Separation between the lenses = L = ?

Magnification of the instrument = M = ?

SOLUTION

For objective

$$\frac{1}{f_o} = \frac{1}{p_1} + \frac{1}{q_1}$$

$$\frac{1}{10} = \frac{1}{1.2} + \frac{1}{q_1}$$

$$\frac{1}{1} - \frac{1}{1.2} = \frac{1}{q_1}$$

$$1 - \frac{10}{12} = \frac{1}{q_1}$$

$$\frac{12 - 10}{12} = \frac{1}{q_1}$$

$$\frac{2}{12} = \frac{1}{q_1}$$

$$q_1 = \frac{12}{2}$$

$$q_1 = 6 \text{ cm}$$

For eye-piece of the compound microscope

$$\frac{1}{f_e} = \frac{1}{p_2} + \frac{1}{q_2}$$

Since the final image is virtual

So $$\frac{1}{f_e} = \frac{1}{p_2} - \frac{1}{q_2}$$

$$\frac{1}{3.0} = \frac{1}{p_2} - \frac{1}{25}$$

$$\frac{1}{3} + \frac{1}{25} = \frac{1}{p_2}$$

$$\frac{25 + 3}{75} = \frac{1}{p_2}$$

$$p_2 = \frac{75}{28}$$

$$p_2 = 2.67 \text{ cm}$$

So the separation between the lens $= L = q_1 + p_2$

$$= 6 + 2.67$$

$$= 8.67 \text{ cm}$$

For magnification of the instrument

$$M = \frac{q_1}{p_1}\left(1 + \frac{d}{f_e}\right)$$

$$= \frac{6}{1.2}\left(1 + \frac{25}{3.0}\right)$$

$$= 5(1 + 8.33)$$

$$= 46.7$$

$$M = 47$$

Result

Separation between the lenses $= L = 8.67$ cm

Magnification of the instrument $= M = 47$

PROBLEM 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.

Data

Wavelength of sodium light $= \lambda = 589$ nm

$$= 589 \times 10^{-9} \text{ m}$$

Aperture of lens $= D = 0.90$ cm

$$= 0.90 \times 10^{-2} \text{ m}$$

To Find

(i) Limiting angle of resolution $= \alpha_{min} = ?$

(ii) For any visible light, limiting angle of resolution $= \alpha'_{min} = ?$

SOLUTION

(i) By formula, for the limiting angle of resolution

$$\alpha_{min} = \frac{1.22\lambda}{D}$$

$$= \frac{1.22 \times 589 \times 10^{-9}}{6.90 \times 10^{-2}}$$

$$= 794.3 \times 10^{-9+2}$$

$$= 794.3 \times 10^{-7}$$

$$= 7.9 \times 10^{-5} \text{ rad.}$$

(ii) For any visible light

Wavelength of violet light $= \lambda = 400$ nm

$$= 400 \times 10^{-9} \text{ m}$$

Therefore;

$$\boxed{\alpha'_{min} = \frac{1.22\lambda}{D}}$$

$$\alpha'_{min} = \frac{1.22 \times 400 \times 10^{-9}}{0.90 \times 10^{-2}}$$

$$= 542.22 \times 10^{-9+2}$$

$$= 542.2 \times 10^{-7}$$

$$= 5.4 \times 10^{-5} \text{ rad.}$$

Result

(i) Limiting angle of resolution $= \alpha_{min} = 7.9 \times 10^{-5}$ rad.

(ii) For any visible light, limiting angle of resolution $= \alpha'_{min} = 5.4 \times 10^{-5}$ rad.

PROBLEM 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.

Data

Magnification of the lenses $= M = 5$

Distance between lenses $= L = 24$ cm

To Find

Focal length of objective $= f_o = ?$

Focal length of eye-piece $= f_e = ?$

SOLUTION

As we know that the magnification of the astronomical telescope is

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

$$5 = \frac{f_o}{f_e}$$

$$\boxed{f_o = 5f_e}$$

and the length of telescope is

$$L = f_o + f_e$$

$$f_o + f_e = 24$$

$$f_e + 5f_e = 24$$

$$6f_e = 24$$

$$f_e = \frac{24}{6}$$

$$f_e = 4 \text{ cm}$$

and $$f_o = 5f_e$$

$$f_o = 5(4)$$

$$= 20 \text{ cm}$$

Result

Focal length of objective $= f_o = 20$ cm

Focal length of eye-piece $= f_e = 4$ cm

PROBLEM 10.9

Glass light pipe in air will totally internally reflect a light ray if its angle of incidence is atleast 39°. What is the minimum angle for total internal reflection if pipe is in water? (Refractive Index of water = 1.33).

Data

Angle of incidence $= \theta_c = 39°$

Refractive index for water $= n_2 = 1.33$

To Find

Minimum angle for total internal reflection for water $= \theta_1 = ?$

SOLUTION

According to Snell's law

$$n_1 \sin \angle i = n_2 \sin \angle r$$

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

$$\boxed{\sin \theta_1 = \frac{n_2 \sin \theta_2}{n_1}} \quad \ldots\ldots \text{(i)}$$

But $$n_1 = \frac{1}{\sin \theta_c}$$

$$= \frac{1}{\sin 39°}$$

$$n_1 = 1.59$$

and the length of telescope is

$$L = f_o + f_e$$

$$f_o + f_e = 24$$

$$f_e + 5f_e = 24$$

$$6f_e = 24$$

$$f_e = \frac{24}{6}$$

$$f_e = 4 \text{ cm}$$

and $$f_o = 5f_e$$

$$f_o = 5(4)$$

$$= 20 \text{ cm}$$

Result

Focal length of objective $= f_o = 20$ cm

Focal length of eye-piece $= f_e = 4$ cm

PROBLEM 10.9

Glass light pipe in air will totally internally reflect a light ray if its angle of incidence is atleast 39°. What is the minimum angle for total internal reflection if pipe is in water? (Refractive Index of water = 1.33).

Data

Angle of incidence $= \theta_c = 39°$

Refractive index for water $= n_2 = 1.33$

To Find

Minimum angle for total internal reflection for water $= \theta_1 = ?$

SOLUTION

According to Snell's law

$$n_1 \sin \angle i = n_2 \sin \angle r$$

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

$$\boxed{\sin \theta_1 = \frac{n_2 \sin \theta_2}{n_1}} \quad \ldots\ldots \text{(i)}$$

But $$n_1 = \frac{1}{\sin \theta_c}$$

$$= \frac{1}{\sin 39°}$$

$$n_1 = 1.59$$

Putting in eq. (i)

$$\text{So} \quad \sin\theta_1 = \frac{1.33 \sin 90°}{1.59}$$

$$\sin\theta_1 = 0.83$$

$$\theta_1 = \sin^{-1}(0.83)$$

$$\theta_1 = 57°$$

Result

Minimum angle for total internal reflection for water $= \theta_1 = 57°$

PROBLEM 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.

Data

Refractive index of core $= n_1 = 1.6$

Refractive index of cladding $= n_2 = 1.4$

To Find

(i) Critical angle $= \theta_c = ?$

(ii) Maximum angle of incidence for air $= \theta_1' = ?$

SOLUTION

(i) By using Snell's law

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

But $\theta_1 = \theta_c$

$\theta_2 = 90°$

So $n_1 \sin\theta_c = n_2 \sin 90°$

$$\sin\theta_c = \frac{n_2}{n_1}$$

$$\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$$

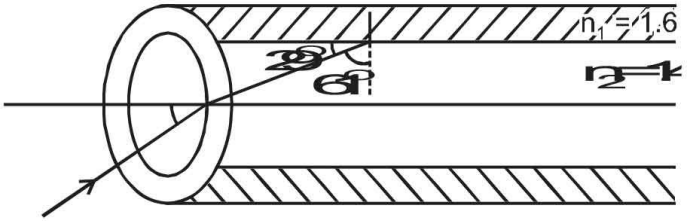
$$= \sin^{-1}\left(\frac{1.4}{1.6}\right)$$

$$\theta_c = 61°$$

(ii) For maximum angle of incidence $\theta_c = 61°$ and the angle of refraction is

$$\theta'_c = 90° - 61°$$

$$\theta'_c = 29°$$



Therefore;

$$n_1 \sin \theta'_1 = n_2 \sin \theta'_2$$

For air $n_1 = 1$

For core $n_2 = 1.6$

So $1 \times \sin \theta'_1 = 1.6 \times \sin 29°$

$$\sin \theta'_1 = 0.77$$

$$\theta'_1 = \sin^{-1}(0.77)$$

$$\theta'_1 = 50°.8$$

$$= 51°$$

Result

(i) Critical angle $= \theta_c = 61°$

(ii) Maximum angle of incidence for air $= \theta'_1 = 51°$