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

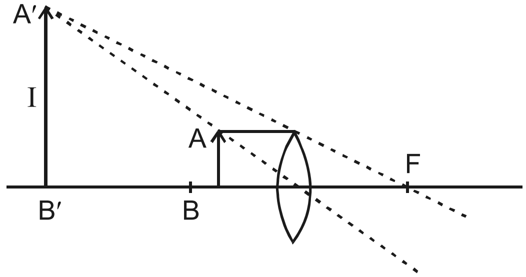
From this equation we see that resolving power is inversely proportional to $\alpha_{min.}$ and $\alpha_{min.}$ depends upon wavelength and diameter of lens. As blue light has short wavelength therefore it will produce less diffraction and resolving power of compound microscope will increase.

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.

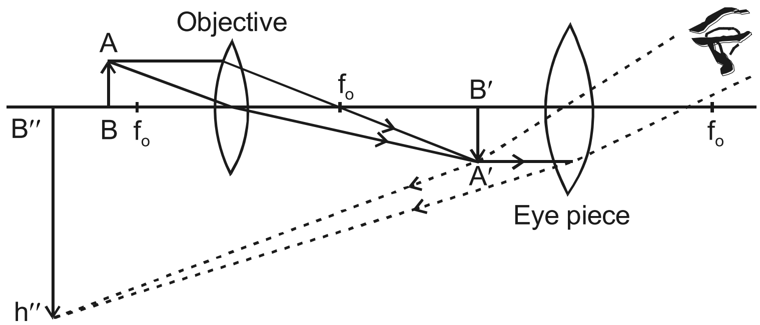
10.5 Describe with the help of diagram, how (a) a single biconvex lens can be used as a magnifying glass. (b) biconvex lenses can be arranged to form a microscope.

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.

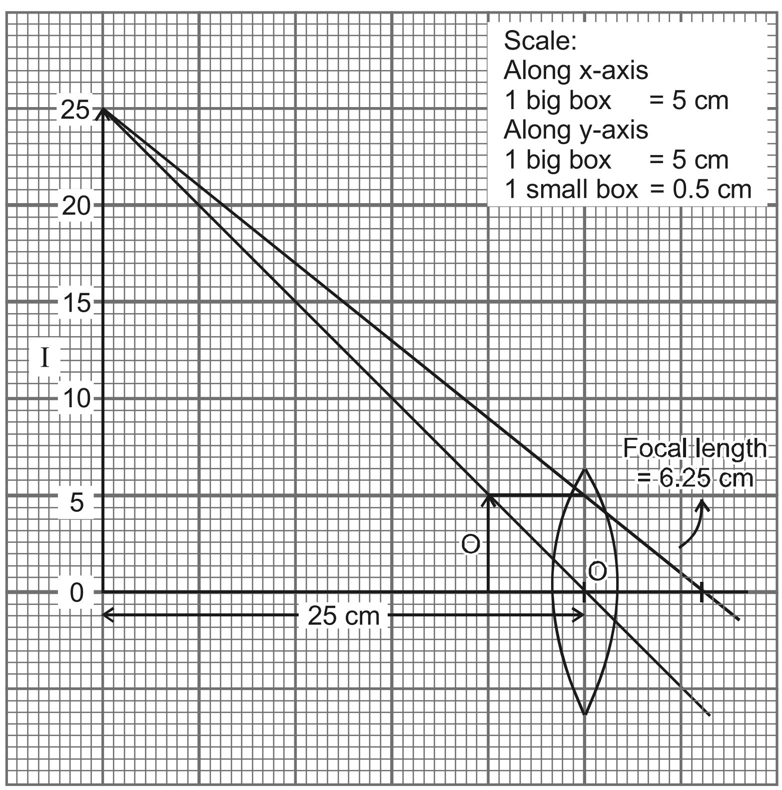


Compound microscope

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

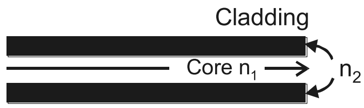
$$R = \frac{D}{1.22\lambda}$$

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

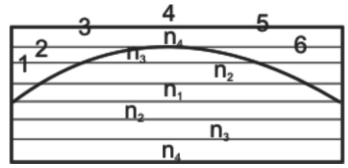
(ii) As we know that the resolving power of an astronomical telescope depends upon the diameter of objective lens so (d) is correct.

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?

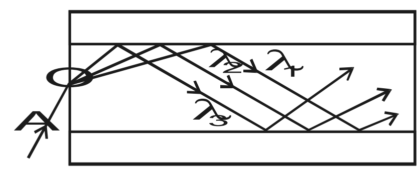
Ans. The light signals are transmitted through the optical fibre on the principle of:

(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

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

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

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

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

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

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 $= q = \infty$

(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

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

Aperture of lens $= D = 0.90$ cm

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

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

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

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

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

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

(ii) For any visible light

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

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

Therefore;

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

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

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

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

$= 5.4 \times 10^{-5}$ 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 = θ_c = 39°

Refractive index for water = n_2 = 1.33

To Find

Minimum angle for total internal reflection for water = θ_1 = ?

SOLUTION

According to Snell's law

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

But
$$n_1 = \frac{1}{\sin \theta_c}$$
$$= \frac{1}{\sin 39°}$$
$$n_1 = 1.59$$

Putting in eq. (i)

So $\sin\theta_1 = \dfrac{1.33 \sin 90°}{1.59}$

$\sin\theta_1 = 0.83$

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

$\theta_1 = 57°$

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 $n_1 \sin\theta_c = n_2 \sin 90°$

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

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

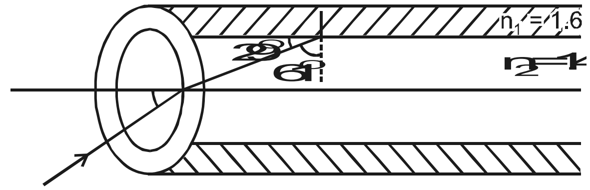
$= \sin^{-1}\left(\dfrac{1.4}{1.6}\right)$

$\theta_c = 61°$

(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 $= \theta'_1 = 51°$