Question 9.18:

Answer the following questions:

(a) You have learnt that plane and convex mirrors produce virtual images of objects.
Can they produce real images under some circumstances? Explain.

(b) A virtual image, we always say, cannot be caught on a screen.
Yet when we 'see' a virtual image, we are obviously bringing it on to the 'screen' (i.e., the retina) of our eye. Is there a contradiction?

(c) A diver under water, looks obliquely at a fisherman standing on the bank of a lake. Would the fisherman look taller or shorter to the diver than what he actually is?

(d) Does the apparent depth of a tank of water change if viewed obliquely? If so, does the apparent depth increase or decrease?

(e) The refractive index of diamond is much greater than that of ordinary glass. Is this fact of some use to a diamond cutter?

Answer 9.18:

(a) Yes

Plane and convex mirrors can produce real images as well. If the object is virtual,
i.e., if the light rays converging at a point behind a plane mirror (or a convex mirror) are reflected to a point on a screen placed in front of the mirror, then a real image will be formed.

(b) No

A virtual image is formed when light rays diverge. The convex lens of the eye causes these divergent rays to converge at the retina. In this case, the virtual image serves as an object for the lens to produce a real image.

(c) The diver is in the water and the fisherman is on land (i.e., in air). Water is a denser medium than air. It is given that the diver is viewing the fisherman. This indicates that the light rays are travelling from a denser medium to a rarer medium. Hence, the refracted rays will move away from the normal. As a result, the fisherman will appear to be taller.

(d) Yes; Decrease

The apparent depth of a tank of water changes when viewed obliquely. This is because light bends on travelling from one medium to another. The apparent depth of the tank when viewed obliquely is less than the near-normal viewing.

(e) Yes

The refractive index of diamond (2.42) is more than that of ordinary glass (1.5). The critical angle for diamond is less than that for glass. A diamond cutter uses a large angle of incidence to ensure that the light entering the diamond is totally reflected from its faces. This is the reason for the sparkling effect of a diamond.

Question 9.19:

The image of a small electric bulb fixed on the wall of a room is to be obtained on the opposite wall 3 m away by means of a large convex lens. What is the maximum possible focal length of the lens required for the purpose?

Answer 9.19:

Distance between the object and the image, d = 3 m

Maximum focal length of the convex lens = f_{max}

For real images, the maximum focal length is given as:

$$f_{\max} = \frac{d}{4}$$

$$= \frac{3}{4} = 0.75 \text{ m}$$

Hence, for the required purpose, the maximum possible focal length of the convex lens is 0.75 m.

Question 9.20:

A screen is placed 90 cm from an object. The image of the object on the screen is formed by a convex lens at two different locations separated by 20 cm. Determine the focal length of the lens.

Answer 9.20:

Distance between the image (screen) and the object, D = 90 cm

Distance between two locations of the convex lens, d = 20 cm

Focal length of the lens = f

Focal length is related to d and D as:

$$f = \frac{D^2 - d^2}{4D}$$

$$= \frac{(90)^2 - (20)^2}{4 \times 90} = \frac{770}{36} = 21.39 \text{ cm}$$

Therefore, the focal length of the convex lens is 21.39 cm.

Question 9.21:

(a) Determine the 'effective focal length' of the combination of the two lenses in Exercise 9.10, if they are placed 8.0 cm apart with their principal axes coincident. Does the answer depend on which side of the combination a beam of parallel light is incident? Is the notion of effective focal length of this system useful at all?

(b) An object 1.5 cm in size is placed on the side of the convex lens in the arrangement (a) above. The distance between the object and the convex lens is 40 cm. Determine the magnification produced by the two-lens system, and the size of the image.

Answer 9.21:

Focal length of the convex lens, f_1 = 30 cm
Focal length of the concave lens, f_2 = −20 cm
Distance between the two lenses, d = 8.0 cm

(a) When the parallel beam of light is incident on the convex lens first:
According to the lens formula, we have:

$$\frac{1}{v_1} - \frac{1}{u_1} = \frac{1}{f_1}$$

Where, u_1 = Object distance = ∞ and v_1 = Image distance

$$\frac{1}{v_1} = \frac{1}{30} - \frac{1}{\infty} = \frac{1}{30}$$

$$\therefore v_1 = 30 \text{ cm}$$

The image will act as a virtual object for the concave lens.
Applying lens formula to the concave lens, we have:

$$\frac{1}{v_2} - \frac{1}{u_2} = \frac{1}{f_2}$$

Where, u_1 = Object distance
= (30 − d) = 30 − 8 = 22 cm
v_2 = Image distance

$$\frac{1}{v_2} = \frac{1}{22} - \frac{1}{20} = \frac{10 - 11}{220} = \frac{-1}{220}$$

$$\therefore v_2 = -220 \text{ cm}$$

The parallel incident beam appears to diverge from a point that is $\left(220 - \frac{d}{2} = 220 - 4\right)$ 216 cm from the centre of the combination of the two lenses.

(ii) When the parallel beam of light is incident, from the left, on the concave lens first:
According to the lens formula,
We have:

$$\frac{1}{v_2} - \frac{1}{u_2} = \frac{1}{f_2}$$

$$\frac{1}{v_2} = \frac{1}{f_2} + \frac{1}{u_2}$$

Where, u_2 = Object distance = −∞

v_2 = Image distance

$$\frac{1}{v_2} = \frac{1}{-20} + \frac{1}{-\infty} = -\frac{1}{20}$$

$$\therefore v_2 = -20 \text{ cm}$$

The image will act as a real object for the convex lens.
Applying lens formula to the convex lens, we have:

$$\frac{1}{v_1} - \frac{1}{u_1} = \frac{1}{f_1}$$

Where, u_1 = Object distance = − (20 + d) = − (20 + 8) = −28 cm

v_1 = Image distance

$$\frac{1}{v_1} = \frac{1}{30} + \frac{1}{-28} = \frac{14-15}{420} = \frac{-1}{420}$$

$$\therefore v_2 = -420 \text{ cm}$$

Hence, the parallel incident beam appear to diverge from a point that is (420 − 4) 416 cm from the left of the centre of the combination of the two lenses.
The answer does depend on the side of the combination at which the parallel beam of light is incident. The notion of effective focal length does not seem to be useful for this combination.

(b) Height of the image, h_1 = 1.5 cm
Object distance from the side of the convex lens, $u_1 = -40$ cm

$$|u_1| = 40 \text{ cm}$$

According to the lens formula:

$$\frac{1}{v_1} - \frac{1}{u_1} = \frac{1}{f_1}$$

Where,

v_1 = Image distance

$$\frac{1}{v_1} = \frac{1}{30} + \frac{1}{-40} = \frac{4-3}{120} = \frac{1}{120}$$

$$\therefore v_1 = 120 \text{ cm}$$

Magnification, $m = \frac{v_1}{|u_1|}$

$$= \frac{120}{40} = 3$$

Hence, the magnification due to the convex lens is 3.
The image formed by the convex lens acts as an object for the concave lens.
According to the lens formula:

$$\frac{1}{v_2} - \frac{1}{u_2} = \frac{1}{f_2}$$

Where, u_2 = Object distance = + (120 − 8) = 112 cm
v_2 = image distance

$$\frac{1}{v_2} = \frac{1}{-20} + \frac{1}{112} = \frac{-112+20}{2240} = \frac{-92}{2240}$$

$$\therefore v_2 = \frac{-2240}{92} \text{ cm}$$

Magnification $m' = \left|\frac{v_2}{u_2}\right| = \frac{2240}{92} \times \frac{1}{112} = \frac{20}{92}$

Hence, the magnification due to the concave lens is $\frac{20}{92}$.

The magnification produced by the combination of the two lenses is calculated as:

$m \times m'$

$= 3 \times \frac{20}{92} = \frac{60}{92} = 0.652$

The magnification of the combination is given as:

$\frac{h_2}{h_1} = 0.652$

$h_2 = 0.652 \times h_1$

Where, h_1 = Object size = 1.5 cm

h_2 = Size of the image

$\therefore h_2 = 0.652 \times 1.5 = 0.98$ cm

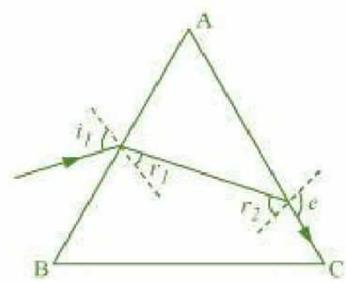
Hence, the height of the image is 0.98 cm.

Question 9.22:

At what angle should a ray of light be incident on the face of a prism of refracting angle 60° so that it just suffers total internal reflection at the other face? The refractive index of the material of the prism is 1.524.

Answer 9.22:

The incident, refracted, and emergent rays associated with a glass prism ABC are shown in the given figure.



Angle of prism, ∴A = 60°

Refractive index of the prism, μ = 1.524

i_1 = Incident angle

r_1 = Refracted angle

r_2 = Angle of incidence at the face AC

e = Emergent angle = 90°

According to Snell's law, for face AC, we can have:

$$\frac{\sin e}{\sin r_2} = \mu$$

$$\sin r_2 = \frac{1}{\mu} \times \sin 90°$$

$$= \frac{1}{1.524} = 0.6562$$

$$\therefore r_2 = \sin^{-1} 0.6562 \approx 41°$$

It is clear from the figure that angle $A = r_1 + r_2$

$\therefore r_1 = A - r_2 = 60 - 41 = 19°$

According to Snell's law, we have the relation:

$$\mu = \frac{\sin i_1}{\sin r_1}$$

$$\sin i_1 = \mu \sin r_1$$

$$= 1.524 \times \sin 19° = 0.496$$

$$\therefore i_1 = 29.75°$$

Hence, the angle of incidence is 29.75°.

Question 9.23:
You are given prisms made of crown glass and flint glass with a wide variety of angles. Suggest a combination of prisms which will
(a) deviate a pencil of white light without much dispersion,
(b) disperse (and displace) a pencil of white light without much deviation.

Answer 9.23:
(a) Place the two prisms beside each other. Make sure that their bases are on the opposite sides of the incident white light, with their faces touching each other. When the white light is incident on the first prism, it will get dispersed. When this dispersed light is incident on the second prism, it will recombine and white light will emerge from the combination of the two prisms.
(b) Take the system of the two prisms as suggested in answer (a). Adjust (increase) the angle of the flint-glass-prism so that the deviations due to the combination of the prisms become equal. This combination will disperse the pencil of white light without much deviation.

Question 9.24:
For a normal eye, the far point is at infinity and the near point of distinct vision is about 25cm in front of the eye. The cornea of the eye provides a converging power of about 40 dioptres, and the least converging power of the eye-lens behind the cornea is about 20 dioptres. From this rough data estimate the range of accommodation (i.e., the range of converging power of the eye-lens) of a normal eye.

Answer 9.24:
Least distance of distinct vision, d = 25 cm
Far point of a normal eye, $d' = \infty$
Converging power of the cornea, $P_c = 40\ D$
Least converging power of the eye-lens, $P_e = 20\ D$
To see the objects at infinity, the eye uses its least converging power.
Power of the eye-lens, $P = P_c + P_e = 40 + 20 = 60$ D Power of the eye-lens is given as:

$$P = \frac{1}{\text{Focal length of the eye lens}(f)}$$

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

$$= \frac{1}{60\text{D}}$$

$$= \frac{100}{60} = \frac{5}{3}\text{ cm}$$

To focus an object at the near point, object distance (u) = −d = −25 cm
Focal length of the eye-lens = Distance between the cornea and the retina = Image distance
Hence, image distance, $v = \frac{5}{3}$ cm
According to the lens formula, we can write:

$$\frac{1}{f'} = \frac{1}{v} - \frac{1}{u}$$

Where, f'= focal length

$$\frac{1}{f'} = \frac{3}{5} + \frac{1}{25} = \frac{15+1}{25} = \frac{16}{25}\ \text{cm}^{-1}$$

$$\text{Power, } P' = \frac{1}{f'} \times 100$$

$$= \frac{16}{25} \times 100 = 64\text{ D}$$

∴ Power of the eye-lens = 64 − 40 = 24 D
Hence, the range of accommodation of the eye-lens is from 20 D to 24 D.

Question 9.25:
Does short-sightedness (myopia) or long-sightedness (hypermetropia) imply necessarily that the eye has partially lost its ability of accommodation? If not, what might cause these defects of vision?

Answer 9.25:
A myopic or hypermetropic person can also possess the normal ability of accommodation of the eye-lens. Myopia occurs when the eye-balls get elongated from front to back. Hypermetropia occurs when the eye-balls get shortened. When the eye-lens loses its ability of accommodation, the defect is called presbyopia.

Question 9.26:
A myopic person has been using spectacles of power −1.0 dioptre for distant vision.
During old age he also needs to use separate reading glass of power + 2.0 dioptres.
Explain what may have happened.

Answer 9.26:
The power of the spectacles used by the myopic person, P = −1.0 D
Focal length of the spectacles, $f = \frac{1}{P} = \frac{1}{-1\times10^{-2}} = -100$ cm
Hence, the far point of the person is 100 cm. He might have a normal near point of 25 cm. When he uses the spectacles, the objects placed at infinity produce virtual images at 100 cm. He uses the ability of accommodation of the eye-lens to see the objects placed between 100 cm and 25 cm.
During old age, the person uses reading glasses of power, $P' = +2$ D
The ability of accommodation is lost in old age. This defect is called presbyopia. As a result, he is unable to see clearly the objects placed at 25 cm.

Question 9.27:
A person looking at a person wearing a shirt with a pattern comprising vertical and horizontal lines is able to see the vertical lines more distinctly than the horizontal ones. What is this defect due to? How is such a defect of vision corrected?

Answer 9.27:
In the given case, the person is able to see vertical lines more distinctly than horizontal lines. This means that the refracting system (cornea and eye-lens) of the eye is not working in the same way in different planes. This defect is called astigmatism. The person's eye has enough curvature in the vertical plane. However, the curvature in the horizontal plane is insufficient. Hence, sharp images of the vertical lines are formed on the retina, but horizontal lines appear blurred. This defect can be corrected by using cylindrical lenses.

Question 9.28:
A man with normal near point (25 cm) reads a book with small print using a magnifying glass: a thin convex lens of focal length 5 cm.
(a) What is the closest and the farthest distance at which he should keep the lens from the page so that he can read the book when viewing through the magnifying glass?
(b) What is the maximum and the minimum angular magnification (magnifying power) possible using the above simple microscope?

Answer 9.28:
(a) Focal length of the magnifying glass, f = 5 cm
Least distance of distance vision, d = 25 cm, closest object distance = u and image distance, v = −d = −25 cm
According to the lens formula, we have:

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$$

$$\frac{1}{u} = \frac{1}{v} - \frac{1}{f}$$

$$= \frac{1}{-25} - \frac{1}{5} = \frac{-5-1}{25} = \frac{-6}{25}$$

$$\therefore u = -\frac{25}{6} = -4.167 \text{ cm}$$

Hence, the closest distance at which the person can read the book is 4.167 cm.

For the object at the farthest distant (u'), the image distance $(v') = \infty$.

According to the lens formula, we have:

$$\frac{1}{f} = \frac{1}{v'} - \frac{1}{u'}$$

$$\frac{1}{u'} = \frac{1}{\infty} - \frac{1}{5} = -\frac{1}{5}$$

$$\therefore u' = -5 \text{ cm}$$

Hence, the farthest distance at which the person can read the book is 5 cm.

(b) Maximum angular magnification is given by the relation:

$$\alpha_{\max} = \frac{d}{|u|}$$

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

Minimum angular magnification is given by the relation:

$$\alpha_{\min} = \frac{d}{|u'|}$$

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

Question 9.29:

A card sheet divided into squares each of size 1 mm2 is being viewed at a distance of 9 cm through a magnifying glass (a converging lens of focal length 9 cm) held close to the eye.

(a) What is the magnification produced by the lens? How much is the area of each square in the virtual image?

(b) What is the angular magnification (magnifying power) of the lens?

(c) Is the magnification in (a) equal to the magnifying power in (b)?

Explain.

Answer 9.29:

(a) Area of each square, A = 1 mm^2

Object distance, u = −9 cm

Focal length of a converging lens, f = 10 cm

For image distance v, the lens formula can be written as:

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$$

$$\frac{1}{10} = \frac{1}{v} + \frac{1}{9}$$

$$\frac{1}{v} = -\frac{1}{90}$$

$$\therefore v = -90 \text{ cm}$$

Magnification, $m = \frac{v}{u}$

$$= \frac{-90}{-9} = 10$$

∴ Area of each square in the virtual image = $(10)^2$ A

= $10^2 \times 1 = 100$ mm^2

= 1 cm^2

(b) Magnifying power of the lens $= \frac{d}{|u|} = \frac{25}{9} = 2.8$

(c) The magnification in (a) is not the same as the magnifying power in (b).

The magnification magnitude is $\left(\left|\frac{v}{u}\right|\right)$and the magnifying power is $\left(\frac{d}{|u|}\right)$.

The two quantities will be equal when the image is formed at the near point (25 cm).

Question 9.30:

(a) At what distance should the lens be held from the figure in
Exercise 9.29 in order to view the squares distinctly with the maximum possible magnifying power?

(b) What is the magnification in this case?

(c) Is the magnification equal to the magnifying power in this case?
Explain.

Answer 9.30:

(a) The maximum possible magnification is obtained when the image is formed at the near point (d = 25 cm).

Image distance, v = −d = −25 cm

Focal length, f = 10 cm

Object distance = u

According to the lens formula, we have:

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$$

$$\frac{1}{u} = \frac{1}{v} - \frac{1}{f}$$

$$= \frac{1}{-25} - \frac{1}{10} = \frac{-2-5}{50} = -\frac{7}{50}$$

$$\therefore u = -\frac{50}{7} = -7.14 \text{ cm}$$

Hence, to view the squares distinctly, the lens should be kept 7.14 cm away from them.

(b) Magnification $= \left|\frac{v}{u}\right| = \frac{25}{\frac{50}{7}} = 3.5$

(c) Magnifying power $\frac{d}{u} = \frac{25}{\frac{50}{7}} = 3.5$

Since the image is formed at the near point (25 cm), the magnifying power is equal to the magnitude of magnification.

Question 9.31:

What should be the distance between the object in Exercise 9.30 and the magnifying glass if the virtual image of each square in the figure is to have an area of 6.25 mm²? Would you be able to see the squares distinctly with your eyes very close to the magnifier?

[Note: Exercises 9.29 to 9.31 will help you clearly understand the difference between magnification in absolute size and the angular magnification (or magnifying power) of an instrument.]

Answer 9.31:

Area of the virtual image of each square, A = 6.25 mm^2

Area of each square, A_0 = 1 mm^2

Hence, the linear magnification of the object can be calculated as:

$$m = \sqrt{\frac{A}{A_0}}$$

$$= \sqrt{\frac{6.25}{1}} = 2.5$$

But $m = \frac{\text{Image distance } (v)}{\text{Object distance } (u)}$

$\therefore v = mu$

$= 2.5u \quad \ldots (1)$

Focal length of the magnifying glass, f = 10 cm. According to the lens formula, we have the relation:

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$$

$$\frac{1}{10} = \frac{1}{2.5u} - \frac{1}{u} = \frac{1}{u}\left(\frac{1}{2.5} - \frac{1}{1}\right) = \frac{1}{u}\left(\frac{1-2.5}{2.5}\right)$$

$$\therefore u = -\frac{1.5 \times 10}{2.5} = -6 \text{ cm}$$

And $v = 2.5u$

$= 2.5 \times 6 = -15$ cm

The virtual image is formed at a distance of 15 cm, which is less than the near point (i.e., 25 cm) of a normal eye. Hence, it cannot be seen by the eyes distinctly.

Question 9.32:

Answer the following questions:

(a) The angle subtended at the eye by an object is equal to the angle subtended at the eye by the virtual image produced by a magnifying glass. In what sense then does a magnifying glass provide angular magnification?

(b) In viewing through a magnifying glass, one usually positions one's eyes very close to the lens. Does angular magnification change if the eye is moved back?

(c) Magnifying power of a simple microscope is inversely proportional to the focal length of the lens. What then stops us from using a convex lens of smaller and smaller focal length and achieving greater and greater magnifying power?

(d) Why must both the objective and the eyepiece of a compound microscope have short focal lengths?

(e) When viewing through a compound microscope, our eyes should be positioned not on the eyepiece but a short distance away from it for best viewing. Why? How much should be that short distance between the eye and eyepiece?

Answer 9.32:

(a) Though the image size is bigger than the object, the angular size of the image is equal to the angular size of the object. A magnifying glass helps one see the objects placed closer than the least distance of distinct vision (i.e., 25 cm). A closer object causes a larger angular size. A magnifying glass provides angular magnification. Without magnification, the object cannot be placed closer to the eye. With magnification, the object can be placed much closer to the eye.

(b) Yes, the angular magnification changes. When the distance between the eye and a magnifying glass is increased, the angular magnification decreases a little. This is because the angle subtended at the eye is slightly less than the angle subtended at the lens. Image distance does not have any effect on angular magnification.

(c) The focal length of a convex lens cannot be decreased by a greater amount. This is because making lenses having very small focal lengths is not easy. Spherical and chromatic aberrations are produced by a convex lens having a very small focal length.

(d) The angular magnification produced by the eyepiece of a compound microscope is $\left[\left(\frac{25}{f_e}\right) + 1\right]$

Where, fe = Focal length of the eyepiece

It can be inferred that if fe is small, then angular magnification of the eyepiece will be large.

The angular magnification of the objective lens of a compound microscope is given as $\frac{1}{(|u_0|f_0)}$

Where, u_0 = Object distance for the objective lens and f_0 = Focal length of the objective

The magnification is large when $u_0 > f_0$. In the case of a microscope, the object is kept close to the objective lens. Hence, the object distance is very little. Since u_0 is small, f_0 will be even smaller. Therefore, f_e and f_0 are both small in the given condition.

(e) When we place our eyes too close to the eyepiece of a compound microscope, we are unable to collect much refracted light. As a result, the field of view decreases substantially. Hence, the clarity of the image gets blurred.
The best position of the eye for viewing through a compound microscope is at the eye-ring attached to the eyepiece. The precise location of the eye depends on the separation between the objective lens and the eyepiece.

Question 9.33:
An angular magnification (magnifying power) of 30X is desired using an objective of focal length 1.25 cm and an eyepiece of focal length 5 cm. How will you set up the compound microscope?

Answer 9.33:
Focal length of the objective lens, f_0 = 1.25 cm
Focal length of the eyepiece, f_e = 5 cm
Least distance of distinct vision, d = 25 cm
Angular magnification of the compound microscope = 30X
Total magnifying power of the compound microscope, m = 30
The angular magnification of the eyepiece is given by the relation:

$$m_e = \left(1 + \frac{d}{f_e}\right)$$
$$= \left(1 + \frac{25}{5}\right) = 6$$

The angular magnification of the objective lens (m_o) is related to me as: $m_0 m_e = m$

$$m_o = \frac{m}{m_e}$$
$$= \frac{30}{6} = 5$$

We also have the relation:

$$m_o = \frac{\text{Image distance for the objective lens}(v_o)}{\text{Object distance for the objective lens}(-u_o)}$$

$$5 = \frac{v_o}{-u_o}$$

$$\therefore v_o = -5u_o \qquad \ldots(1)$$

Applying the lens formula for the objective lens:

$$\frac{1}{f_o} = \frac{1}{v_o} - \frac{1}{u_o}$$

$$\frac{1}{1.25} = \frac{1}{-5u_o} - \frac{1}{u_o} = \frac{-6}{5u_o}$$

$$\therefore u_o = \frac{-6}{5} \times 1.25 = -1.5 \text{ cm}$$

And $v_o = -5u_o$

$$= -5 \times (-1.5) = 7.5 \text{ cm}$$

The object should be placed 1.5 cm away from the objective lens to obtain the desired magnification.

Applying the lens formula for the eyepiece:

$$\frac{1}{v_e} - \frac{1}{u_e} = \frac{1}{f_e}$$

Where, v_e = Image distance for the eyepiece = – d = – 25 cm
u_e = Object distance for the eyepiece

$$\frac{1}{u_e} = \frac{1}{v_e} - \frac{1}{f_e}$$
$$= \frac{-1}{25} - \frac{1}{5} = -\frac{6}{25}$$
$$\therefore u_e = -4.17 \text{ cm}$$

Separation between the objective lens and the eyepiece $= |u_e| + |v_0| = 4.17 + 7.5 = 11.67$ cm
Therefore, the separation between the objective lens and the eyepiece should be 11.67 cm.

Question 9.34:
A small telescope has an objective lens of focal length 140 cm and an eyepiece of focal length 5.0 cm. What is the magnifying power of the telescope for viewing distant objects when
(a) the telescope is in normal adjustment (i.e., when the final image is at infinity)?
(b) the final image is formed at the least distance of distinct vision (25 cm)?

Answer 9.34:
Focal length of the objective lens, f_0 = 140 cm
Focal length of the eyepiece, f_e = 5 cm
Least distance of distinct vision, d = 25 cm
(a) When the telescope is in normal adjustment, its magnifying power is given as:

$$m = \frac{f_o}{f_e}$$
$$= \frac{140}{5} = 28$$

(b) When the final image is formed at d, the magnifying power of the telescope is given as:

$$\frac{f_o}{f_e}\left[1 + \frac{f_e}{d}\right]$$
$$= \frac{140}{5}\left[1 + \frac{5}{25}\right]$$
$$= 28[1 + 0.2]$$
$$= 28 \times 1.2 = 33.6$$

Question 9.35:
(a) For the telescope described in Exercise 9.34 (a), what is the separation between the objective lens and the eyepiece?
(b) If this telescope is used to view a 100 m tall tower 3 km away, what is the height of the image of the tower formed by the objective lens?
(c) What is the height of the final image of the tower if it is formed at 25 cm?

Answer 9.35:
Focal length of the objective lens, f_0 = 140 cm
Focal length of the eyepiece, f_e = 5 cm
(a) In normal adjustment, the separation between the objective lens and the eyepiece $= f_0 + f_e = 140 + 5 = 145$ cm
(b) Height of the tower, h_1 = 100 m

Distance of the tower (object) from the telescope, u = 3 km = 3000 m

The angle subtended by the tower at the telescope is given as:

$$\theta = \frac{h_1}{u}$$

$$= \frac{100}{3000} = \frac{1}{30} \text{ rad}$$

The angle subtended by the image produced by the objective lens is given as: $\theta = \frac{h_2}{f_o} = \frac{h_2}{140}$ rad

Where, h_2 = Height of the image of the tower formed by the objective lens

$$\frac{1}{30} = \frac{h_2}{140}$$

$$\therefore h_2 = \frac{140}{30} = 4.7 \text{ cm}$$

Therefore, the objective lens forms a 4.7 cm tall image of the tower.

(c) Image is formed at a distance, d = 25 cm

The magnification of the eyepiece is given by the relation:

$$m = 1 + \frac{d}{f_e}$$

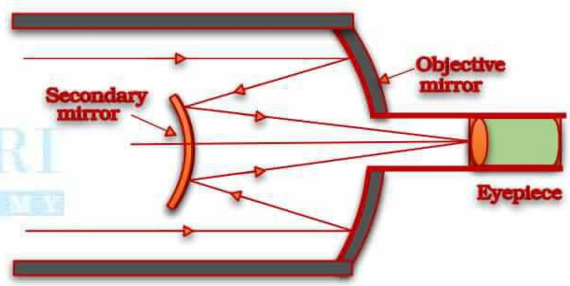
$$= 1 + \frac{25}{5} = 1 + 5 = 6$$

Height of the final image = $mh_2 = 6 \times 4.7 = 28.2$ cm

Hence, the height of the final image of the tower is 28.2 cm.

Question 9.36:

A Cassegrain telescope uses two mirrors as shown in Figure. Such a telescope is built with the mirrors 20 mm apart. If the radius of curvature of the large mirror is 220 mm and the small mirror is 140 mm, where will the final image of an object at infinity be?



Answer 9.36:

The following figure shows a Cassegrain telescope consisting of a concave mirror and a convex mirror.

Distance between the objective mirror and the secondary mirror, d = 20 mm

Radius of curvature of the objective mirror, R1 = 220 mm

Hence, focal length of the objective mirror, $f_1 = \frac{R_1}{2} = 110$ mm

Radius of curvature of the secondary mirror, R_1 = 140 mm

Hence, focal length of the secondary mirror, $f_2 = \frac{R_2}{2} = \frac{140}{2} = 70$ mm

The image of an object placed at infinity, formed by the objective mirror, will act as a virtual object for the secondary mirror.

Hence, the virtual object distance for the secondary mirror, $u = f_1 - d = 110 - 20 = 90$ mm

Applying the mirror formula for the secondary mirror, we can calculate image distance (v) as:

$$\frac{1}{v} + \frac{1}{u} = \frac{1}{f_2}$$

$$\frac{1}{v} = \frac{1}{f_2} - \frac{1}{u}$$

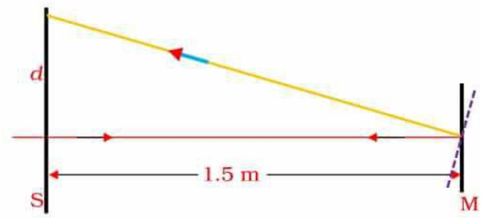
$$= \frac{1}{70} - \frac{1}{90} = \frac{9-7}{630} = \frac{2}{630}$$

$$\therefore v = \frac{630}{2} = 315 \text{ mm}$$

Hence, the final image will be formed 315 mm away from the secondary mirror.

Question 9.37:

Light incident normally on a plane mirror attached to a galvanometer coil retraces backwards as shown in Figure. A current in the coil produces a deflection of 3.5° of the mirror. What is the displacement of the reflected spot of light on a screen placed 1.5 m away?



Answer 9.37:

Angle of deflection, θ = 3.5°

Distance of the screen from the mirror, D = 1.5 m

The reflected rays get deflected by an amount twice the angle of deflection i.e., 2θ = 7.0°

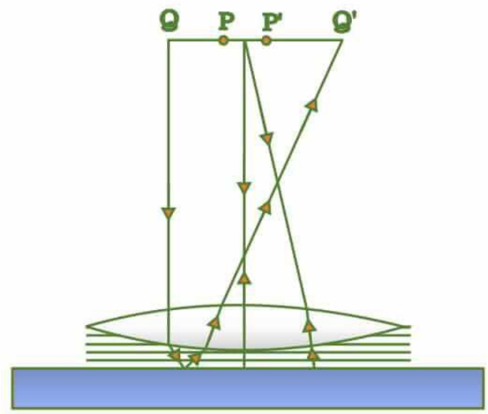
The displacement (d) of the reflected spot of light on the screen is given as:

$$\tan 2\theta = \frac{d}{1.5} \Rightarrow d = 1.5 \times \tan 7° = 0.184\, m = 18.4\, cm$$

Hence, the displacement of the reflected spot of light is 18.4 cm.

Question 9.38:

Figure shows an equiconvex lens (of refractive index 1.50) in contact with a liquid layer on top of a plane mirror. A small needle with its tip on the principal axis is moved along the axis until its inverted image is found at the position of the needle. The distance of the needle from the lens is measured to be 45.0 cm. The liquid is removed and the experiment is repeated. The new distance is measured to be 30.0 cm. What is the refractive index of the liquid?



Answer 9.38:

Focal length of the convex lens, f_1 = 30 cm

The liquid acts as a mirror. Focal length of the liquid = f_2

Focal length of the system (convex lens + liquid), f = 45 cm

For a pair of optical systems placed in contact, the equivalent focal length is given as:

$$\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2}$$

$$\frac{1}{f_2} = \frac{1}{f} - \frac{1}{f_1}$$

$$= \frac{1}{45} - \frac{1}{30} = -\frac{1}{90}$$

$$\therefore f_2 = -90 \text{ cm}$$

Let the refractive index of the lens be μ_1 and the radius of curvature of one surface be R.

Hence, the radius of curvature of the other surface is −R.

R can be obtained using the relation: $\frac{1}{f_1} = (\mu_1 - 1)\left(\frac{1}{R} + \frac{1}{-R}\right) \quad \Rightarrow \frac{1}{30} = (1.5 - 1)\left(\frac{2}{R}\right) \quad \Rightarrow R = \frac{30}{0.5 \times 2} = 30$ cm

Let μ_2 be the refractive index of the liquid.

Radius of curvature of the liquid on the side of the plane mirror $= \infty$

Radius of curvature of the liquid on the side of the lens, R = −30 cm.

The value of μ_2 can be calculated using the relation:

$$\frac{1}{f_2} = (\mu_2 - 1)\left[\frac{1}{-R} - \frac{1}{\infty}\right]$$

$$\frac{-1}{90} = (\mu_2 - 1)\left[\frac{1}{+30} - 0\right]$$

$$\mu_2 - 1 = \frac{1}{3}$$

$$\therefore \mu_2 = \frac{4}{3} = 1.33$$

Hence, the refractive index of the liquid is 1.33.