Question 9.1:

A small candle, 2.5 cm in size is placed at 27 cm in front of a concave mirror of radius of curvature 36 cm. At what distance from the mirror should a screen be placed in order to obtain a sharp image? Describe the nature and size of the image. If the candle is moved closer to the mirror, how would the screen have to be moved?

Answer

Size of the candle, h = 2.5 cm

Image size = h'

Object distance, u = −27 cm

Radius of curvature of the concave mirror, R = −36 cm

Focal length of the concave mirror, $f = \frac{R}{2} = -18 \text{ cm}$

Image distance = v

The image distance can be obtained using the mirror formula:

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

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

$$= \frac{1}{-18} - \frac{1}{-27} = \frac{-3+2}{54} = -\frac{1}{54}$$

$$\therefore v = -54 \text{ cm}$$

Therefore, the screen should be placed 54 cm away from the mirror to obtain a sharp image.

The magnification of the image is given as:

$$m = \frac{h'}{h} = -\frac{v}{u}$$

$$\therefore h' = -\frac{v}{u} \times h$$

$$= -\left(\frac{-54}{-27}\right) \times 2.5 = -5 \text{ cm}$$

The height of the candle's image is 5 cm. The negative sign indicates that the image is inverted and virtual.

If the candle is moved closer to the mirror, then the screen will have to be moved away from the mirror in order to obtain the image.

Question 9.2:

A 4.5 cm needle is placed 12 cm away from a convex mirror of focal length 15 cm. Give the location of the image and the magnification. Describe what happens as the needle is moved farther from the mirror.

Answer

Height of the needle, h1 = 4.5 cm

Object distance, u = −12 cm

Focal length of the convex mirror, f = 15 cm

Image distance = v

The value of v can be obtained using the mirror formula:

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

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

$$= \frac{1}{15} + \frac{1}{12} = \frac{4+5}{60} = \frac{9}{60}$$

$$\therefore v = \frac{60}{9} = 6.7 \text{ cm}$$

Hence, the image of the needle is 6.7 cm away from the mirror. Also, it is on the other side of the mirror.

The image size is given by the magnification formula:

$$m = \frac{h_2}{h_1} = -\frac{v}{u}$$

$$\therefore h_2 = -\frac{v}{u} \times h_1$$

$$= \frac{-6.7}{-12} \times 4.5 = +2.5 \text{ cm}$$

Hence, magnification of the image, $m = \frac{h_2}{h_1} = \frac{2.5}{4.5} = 0.56$

The height of the image is 2.5 cm. The positive sign indicates that the image is erect, virtual, and diminished.

If the needle is moved farther from the mirror, the image will also move away from the mirror, and the size of the image will reduce gradually.

Question 9.3:

A tank is filled with water to a height of 12.5 cm. The apparent depth of a needle lying at the bottom of the tank is measured by a microscope to be 9.4 cm. What is the refractive index of water? If water is replaced by a liquid of refractive index 1.63 up to the same height, by what distance would the microscope have to be moved to focus on the needle again?

Answer

Actual depth of the needle in water, h1 = 12.5 cm

Apparent depth of the needle in water, h2 = 9.4 cm

Refractive index of water = μ

The value of μcan be obtained as follows:

$$\mu = \frac{h_1}{h_2}$$
$$= \frac{12.5}{9.4} \approx 1.33$$

Hence, the refractive index of water is about 1.33.

Water is replaced by a liquid of refractive index, $\mu' = 1.63$

The actual depth of the needle remains the same, but its apparent depth changes.

Let y be the new apparent depth of the needle. Hence, we can write the relation:

$$\mu' = \frac{h_1}{y}$$
$$\therefore y = \frac{h_1}{\mu'}$$
$$= \frac{12.5}{1.63} = 7.67 \text{ cm}$$

Hence, the new apparent depth of the needle is 7.67 cm. It is less than h2.

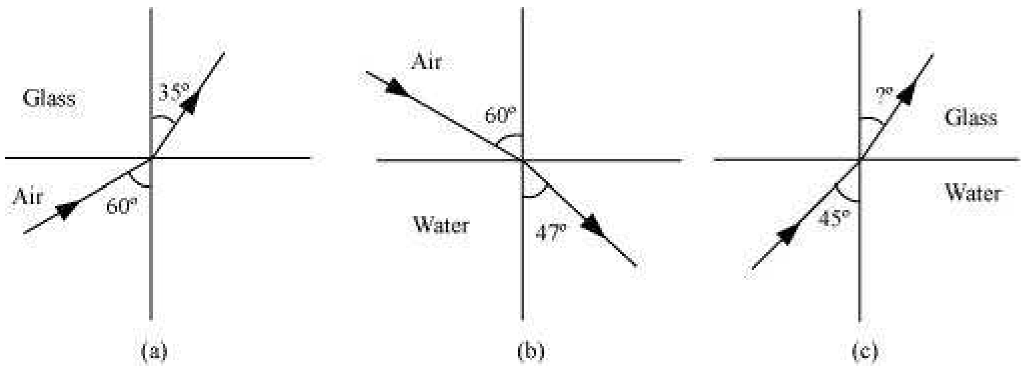
Therefore, to focus the needle again, the microscope should be moved up.

Distance by which the microscope should be moved up = 9.4 − 7.67

= 1.73 cm

Question 9.4:

Figures 9.34(a) and (b) show refraction of a ray in air incident at 60° with the normal to a glass-air and water-air interface, respectively. Predict the angle of refraction in glass when the angle of incidence in water is 45º with the normal to a water-glass interface [Fig. 9.34(c)].



Answer

As per the given figure, for the glass − air interface:

Angle of incidence, i = 60°

Angle of refraction, r = 35°

The relative refractive index of glass with respect to air is given by Snell's law as:

$$\mu_g^a = \frac{\sin i}{\sin r}$$

$$= \frac{\sin 60°}{\sin 35°} = \frac{0.8660}{0.5736} = 1.51 \qquad \dots(1)$$

As per the given figure, for the air − water interface:

Angle of incidence, i = 60°

Angle of refraction, r = 47°

The relative refractive index of water with respect to air is given by Snell's law as:

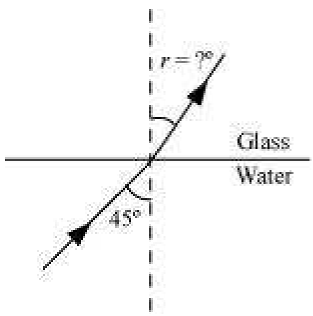
$$\mu_w^a = \frac{\sin i}{\sin r}$$

$$= \frac{\sin 60}{\sin 47} = \frac{0.8660}{0.7314} = 1.184 \qquad \dots(2)$$

Using (1) and (2), the relative refractive index of glass with respect to water can be obtained as:

$$\mu_g^w = \frac{\mu_g^a}{\mu_w^a}$$
$$= \frac{1.51}{1.184} = 1.275$$

The following figure shows the situation involving the glass − water interface.



Angle of incidence, i = 45°

Angle of refraction = r

From Snell's law, r can be calculated as:

$$\frac{\sin i}{\sin r} = \mu_g^w$$
$$\frac{\sin 45°}{\sin r} = 1.275$$
$$\sin r = \frac{\frac{1}{\sqrt{2}}}{1.275} = 0.5546$$
$$\therefore r = \sin^{-1}(0.5546) = 38.68°$$

Hence, the angle of refraction at the water − glass interface is 38.68°.

Question 9.5:

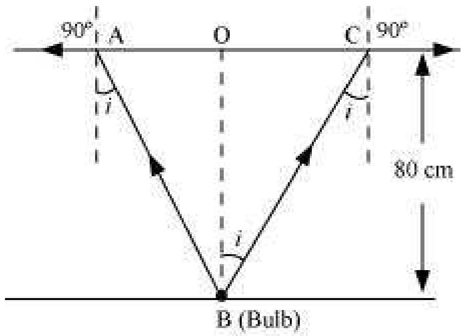
A small bulb is placed at the bottom of a tank containing water to a depth of 80 cm. What is the area of the surface of water through which light from the bulb can emerge out? Refractive index of water is 1.33. (Consider the bulb to be a point source.)

Answer

Actual depth of the bulb in water, d1 = 80 cm = 0.8 m

Refractive index of water, $\mu = 1.33$

The given situation is shown in the following figure:



Where,

i = Angle of incidence

r = Angle of refraction = 90°

Since the bulb is a point source, the emergent light can be considered as a circle of radius, $R = \frac{AC}{2} = AO = OB$

Using Snell' law, we can write the relation for the refractive index of water as:

$$\mu = \frac{\sin r}{\sin i}$$

$$1.33 = \frac{\sin 90°}{\sin i}$$

$$\therefore i = \sin^{-1}\left(\frac{1}{1.33}\right) = 48.75°$$

Using the given figure, we have the relation:

$$\tan i = \frac{OC}{OB} = \frac{R}{d_1}$$

R = tan 48.75° × 0.8 = 0.91 m

Area of the surface of water = πR2 = π (0.91)2 = 2.61 m2

Hence, the area of the surface of water through which the light from the bulb can emerge is approximately 2.61 m2.

Question 9.6:

A prism is made of glass of unknown refractive index. A parallel beam of light is incident on a face of the prism. The angle of minimum deviation is measured to be 40°. What is the refractive index of the material of the prism? The refracting angle of the prism is 60°. If the prism is placed in water (refractive index 1.33), predict the new angle of minimum deviation of a parallel beam of light.

Answer

Angle of minimum deviation, δ_m = 40°

Angle of the prism, A = 60°

Refractive index of water, μ = 1.33

Refractive index of the material of the prism = μ'

The angle of deviation is related to refractive index (μ') as:

$$\mu' = \frac{\sin\frac{(A+\delta_m)}{2}}{\sin\frac{A}{2}}$$

$$= \frac{\sin\frac{(60^\circ + 40^\circ)}{2}}{\sin\frac{60^\circ}{2}} = \frac{\sin 50^\circ}{\sin 30^\circ} = 1.532$$

Hence, the refractive index of the material of the prism is 1.532.

Since the prism is placed in water, let δ_m' be the new angle of minimum deviation for the same prism.

The refractive index of glass with respect to water is given by the relation:

$$\mu_g^w = \frac{\mu'}{\mu} = \frac{\sin\frac{\left(A+\delta_m'\right)}{2}}{\sin\frac{A}{2}}$$

$$\sin\frac{\left(A+\delta_m'\right)}{2} = \frac{\mu'}{\mu}\sin\frac{A}{2}$$

$$\sin\frac{\left(A+\delta_m'\right)}{2} = \frac{1.532}{1.33}\times\sin\frac{60°}{2} = 0.5759$$

$$\frac{\left(A+\delta_m'\right)}{2} = \sin^{-1}0.5759 = 35.16°$$

$$60° + \delta_m' = 70.32°$$

$$\therefore \delta_m' = 70.32° - 60° = 10.32°$$

Hence, the new minimum angle of deviation is 10.32°.

Question 9.7:

Double-convex lenses are to be manufactured from a glass of refractive index 1.55, with both faces of the same radius of curvature. What is the radius of curvature required if the focal length is to be 20 cm?

Answer

Refractive index of glass, $\mu = 1.55$

Focal length of the double-convex lens, f = 20 cm

Radius of curvature of one face of the lens = R1

Radius of curvature of the other face of the lens = R2

Radius of curvature of the double-convex lens = R

$\therefore R_1 = R$ and $R_2 = -R$

The value of R can be calculated as:

$$\frac{1}{f}=(\mu-1)\left[\frac{1}{R_1}-\frac{1}{R_2}\right]$$
$$\frac{1}{20}=(1.55-1)\left[\frac{1}{R}+\frac{1}{R}\right]$$
$$\frac{1}{20}=0.55\times\frac{2}{R}$$
$$\therefore R=0.55\times 2\times 20=22\text{ cm}$$

Hence, the radius of curvature of the double-convex lens is 22 cm.

Question 9.8:

A beam of light converges at a point P. Now a lens is placed in the path of the convergent beam 12 cm from P. At what point does the beam converge if the lens is (a) a convex lens of focal length 20 cm, and (b) a concave lens of focal length 16 cm?

Answer

In the given situation, the object is virtual and the image formed is real.

Object distance, u = +12 cm

(a) Focal length of the convex lens, f = 20 cm

Image distance = v

According to the lens formula, we have the relation:

$$\frac{1}{v}-\frac{1}{u}=\frac{1}{f}$$
$$\frac{1}{v}-\frac{1}{12}=\frac{1}{20}$$
$$\frac{1}{v}=\frac{1}{20}+\frac{1}{12}=\frac{3+5}{60}=\frac{8}{60}$$
$$\therefore v=\frac{60}{8}=7.5\text{ cm}$$

Hence, the image is formed 7.5 cm away from the lens, toward its right.

(b) Focal length of the concave lens, f = −16 cm

Image distance = v

According to the lens formula, we have the relation:

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

$$\frac{1}{v}=-\frac{1}{16}+\frac{1}{12}=\frac{-3+4}{48}=\frac{1}{48}$$

$$\therefore v=48 \text{ cm}$$

Hence, the image is formed 48 cm away from the lens, toward its right.

Question 9.9:

An object of size 3.0 cm is placed 14 cm in front of a concave lens of focal length 21 cm. Describe the image produced by the lens. What happens if the object is moved further away from the lens?

Answer

Size of the object, h1 = 3 cm

Object distance, u = −14 cm

Focal length of the concave lens, f = −21 cm

Image distance = v

According to the lens formula, we have the relation:

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

$$\frac{1}{v}=-\frac{1}{21}-\frac{1}{14}=\frac{-2-3}{42}=\frac{-5}{42}$$

$$\therefore v=-\frac{42}{5}=-8.4 \text{ cm}$$

Hence, the image is formed on the other side of the lens, 8.4 cm away from it. The negative sign shows that the image is erect and virtual.

The magnification of the image is given as:

$$m = \frac{\text{Image height}(h_2)}{\text{Object height}(h_1)} = \frac{v}{u}$$

$$\therefore h_2 = \frac{-8.4}{-14} \times 3 = 0.6 \times 3 = 1.8 \text{ cm}$$

Hence, the height of the image is 1.8 cm.

If the object is moved further away from the lens, then the virtual image will move toward the focus of the lens, but not beyond it. The size of the image will decrease with the increase in the object distance.

Question 9.10:

What is the focal length of a convex lens of focal length 30 cm in contact with a concave lens of focal length 20 cm? Is the system a converging or a diverging lens? Ignore thickness of the lenses.

Answer

Focal length of the convex lens, f1 = 30 cm

Focal length of the concave lens, f2 = −20 cm

Focal length of the system of lenses = f

The equivalent focal length of a system of two lenses in contact is given as:

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

$$\frac{1}{f} = \frac{1}{30} - \frac{1}{20} = \frac{2-3}{60} = -\frac{1}{60}$$

$$\therefore f = -60 \text{ cm}$$

Hence, the focal length of the combination of lenses is 60 cm. The negative sign indicates that the system of lenses acts as a diverging lens.

Question 9.11:

A compound microscope consists of an objective lens of focal length 2.0 cm and an eyepiece of focal length 6.25 cm separated by a distance of 15 cm. How far from the objective should an object be placed in order to obtain the final image at (a) the least distance of distinct vision (25 cm), and (b) at infinity? What is the magnifying power of the microscope in each case?

Answer

Focal length of the objective lens, f1 = 2.0 cm

Focal length of the eyepiece, f2 = 6.25 cm

Distance between the objective lens and the eyepiece, d = 15 cm

(a) Least distance of distinct vision, $d' = 25 \text{ cm}$

∴Image distance for the eyepiece, v2 = −25 cm

Object distance for the eyepiece = u2

According to the lens formula, we have the relation:

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

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

$$= \frac{1}{-25} - \frac{1}{6.25} = \frac{-1-4}{25} = \frac{-5}{25}$$

$$\therefore u_2 = -5 \text{ cm}$$

Image distance for the objective lens, $v_1 = d + u_2 = 15 - 5 = 10 \text{ cm}$

Object distance for the objective lens = u1

According to the lens formula, we have the relation:

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

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

$$= \frac{1}{10} - \frac{1}{2} = \frac{1-5}{10} = \frac{-4}{10}$$

$$\therefore u_1 = -2.5 \text{ cm}$$

Magnitude of the object distance, $|u_1|$ = 2.5 cm

The magnifying power of a compound microscope is given by the relation:

$$m = \frac{v_1}{|u_1|}\left(1 + \frac{d'}{f_2}\right)$$
$$= \frac{10}{2.5}\left(1 + \frac{25}{6.25}\right) = 4(1+4) = 20$$

Hence, the magnifying power of the microscope is 20.

(b) The final image is formed at infinity.

Image distance for the eyepiece, $v_2 = \infty$

Object distance for the eyepiece = u2

According to the lens formula, we have the relation:

$$\frac{1}{v_2} - \frac{1}{u_2} = \frac{1}{f_2}$$
$$\frac{1}{\infty} - \frac{1}{u_2} = \frac{1}{6.25}$$
$$\therefore u_2 = -6.25 \text{ cm}$$

Image distance for the objective lens, $v_1 = d + u_2 = 15 - 6.25 = 8.75$ cm

Object distance for the objective lens = u1

According to the lens formula, we have the relation:

$$\frac{1}{v_1} - \frac{1}{u_1} = \frac{1}{f_1}$$
$$\frac{1}{u_1} = \frac{1}{v_1} - \frac{1}{f_1}$$
$$= \frac{1}{8.75} - \frac{1}{2.0} = \frac{2 - 8.75}{17.5}$$
$$\therefore u_1 = -\frac{17.5}{6.75} = -2.59 \text{ cm}$$

Magnitude of the object distance, $|u_1|$ = 2.59 cm

The magnifying power of a compound microscope is given by the relation:

$$m = \frac{v_1}{|u_1|}\left(\frac{d'}{|u_2|}\right)$$
$$= \frac{8.75}{2.59} \times \frac{25}{6.25} = 13.51$$

Hence, the magnifying power of the microscope is 13.51.

Question 9.12:

A person with a normal near point (25 cm) using a compound microscope with objective of focal length 8.0 mm and an eyepiece of focal length 2.5 cm can bring an object placed at 9.0 mm from the objective in sharp focus. What is the separation between the two lenses? Calculate the magnifying power of the microscope,

Answer

Focal length of the objective lens, fo = 8 mm = 0.8 cm

Focal length of the eyepiece, fe = 2.5 cm

Object distance for the objective lens, uo = −9.0 mm = −0.9 cm

Least distance of distant vision, d = 25 cm

Image distance for the eyepiece, ve = −d = −25 cm

Object distance for the eyepiece = u_e

Using the lens formula, we can obtain the value of u_e as:

$$\frac{1}{v_e} - \frac{1}{u_e} = \frac{1}{f_e}$$
$$\frac{1}{u_e} = \frac{1}{v_e} - \frac{1}{f_e}$$
$$= \frac{1}{-25} - \frac{1}{2.5} = \frac{-1-10}{25} = \frac{-11}{25}$$
$$\therefore u_e = -\frac{25}{11} = -2.27 \text{ cm}$$

We can also obtain the value of the image distance for the objective lens (v_o) using the lens formula.

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

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

$$= \frac{1}{0.8} - \frac{1}{0.9} = \frac{0.9 - 0.8}{0.72} = \frac{0.1}{0.72}$$

$$\therefore v_o = 7.2 \text{ cm}$$

The distance between the objective lens and the eyepiece $= |u_e| + v_o$

$= 2.27 + 7.2$

$= 9.47 \text{ cm}$

The magnifying power of the microscope is calculated as:

$$\frac{v_o}{|u_o|}\left(1 + \frac{d}{f_e}\right)$$

$$= \frac{7.2}{0.9}\left(1 + \frac{25}{2.5}\right) = 8(1 + 10) = 88$$

Hence, the magnifying power of the microscope is 88.

Question 9.13:

A small telescope has an objective lens of focal length 144 cm and an eyepiece of focal length 6.0 cm. What is the magnifying power of the telescope? What is the separation between the objective and the eyepiece?

Answer

Focal length of the objective lens, fo = 144 cm

Focal length of the eyepiece, fe = 6.0 cm

The magnifying power of the telescope is given as:

$$m = \frac{f_o}{f_e}$$
$$= \frac{144}{6} = 24$$

The separation between the objective lens and the eyepiece is calculated as:

$$f_o + f_e$$
$$= 144 + 6 = 150 \text{ cm}$$

Hence, the magnifying power of the telescope is 24 and the separation between the objective lens and the eyepiece is 150 cm.

Question 9.14:

(a) A giant refracting telescope at an observatory has an objective lens of focal length 15 m. If an eyepiece of focal length 1.0 cm is used, what is the angular magnification of the telescope?

(b) If this telescope is used to view the moon, what is the diameter of the image of the moon formed by the objective lens? The diameter of the moon is 3.48 × 106 m, and the radius of lunar orbit is 3.8 × 108 m.

Answer

Focal length of the objective lens, fo = 15 m = 15 × 102 cm

Focal length of the eyepiece, fe = 1.0 cm

(a) The angular magnification of a telescope is given as:

$$\alpha = \frac{f_o}{f_e}$$
$$= \frac{15 \times 10^2}{1.0} = 1500$$

Hence, the angular magnification of the given refracting telescope is 1500.

(b) Diameter of the moon, d = 3.48 × 106 m

Radius of the lunar orbit, r0 = 3.8 × 108 m

Let d' be the diameter of the image of the moon formed by the objective lens.

The angle subtended by the diameter of the moon is equal to the angle subtended by the image.

$$\frac{d}{r_0} = \frac{d'}{f_o}$$

$$\frac{3.48 \times 10^6}{3.8 \times 10^8} = \frac{d'}{15}$$

$$\therefore d' = \frac{3.48}{3.8} \times 10^{-2} \times 15$$

$$= 13.74 \times 10^{-2} \text{ m} = 13.74 \text{ cm}$$

Hence, the diameter of the moon's image formed by the objective lens is 13.74 cm

Question 9.15:

Use the mirror equation to deduce that:

(a) an object placed between f and 2f of a concave mirror produces a real image beyond 2f.

(b) a convex mirror always produces a virtual image independent of the location of the object.

(c) the virtual image produced by a convex mirror is always diminished in size and is located between the focus and the pole.

(d) an object placed between the pole and focus of a concave mirror produces a virtual and enlarged image.

[Note: This exercise helps you deduce algebraically properties of images that one obtains from explicit ray diagrams.]

Answer

(a) For a concave mirror, the focal length (f) is negative.

$\therefore f < 0$

When the object is placed on the left side of the mirror, the object distance (u) is negative.

$\therefore u < 0$

For image distance v, we can write the lens formula as:

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

$$\frac{1}{v}=\frac{1}{f}-\frac{1}{u} \qquad \dots(1)$$

The object lies between f and 2f.

$$\therefore 2f < u < f \qquad (\because\ u \text{ and } f \text{ are negative})$$

$$\frac{1}{2f} > \frac{1}{u} > \frac{1}{f}$$

$$-\frac{1}{2f} < -\frac{1}{u} < -\frac{1}{f}$$

$$\frac{1}{f}-\frac{1}{2f} < \frac{1}{f}-\frac{1}{u} < 0 \qquad \dots(2)$$

Using equation (1), we get:

$$\frac{1}{2f} < \frac{1}{v} < 0$$

 $\frac{1}{v}$ is negative, i.e., v is negative.

$$\frac{1}{2f} < \frac{1}{v}$$

$$2f > v$$

$$-v > -2f$$

Therefore, the image lies beyond 2f.

(b) For a convex mirror, the focal length (f) is positive.

 f > 0

When the object is placed on the left side of the mirror, the object distance (u) is negative.

 u < 0

For image distance v, we have the mirror formula:

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

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

Using equation (2), we can conclude that:

$$\frac{1}{v}<0$$

$$v>0$$

Thus, the image is formed on the back side of the mirror.

Hence, a convex mirror always produces a virtual image, regardless of the object distance.

(c) For a convex mirror, the focal length (f) is positive.

$f > 0$

When the object is placed on the left side of the mirror, the object distance (u) is negative,

$u < 0$

For image distance v, we have the mirror formula:

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

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

But we have $u<0$

$$\therefore \frac{1}{v}>\frac{1}{f}$$

$$v<f$$

Hence, the image formed is diminished and is located between the focus (f) and the pole.

(d) For a concave mirror, the focal length (f) is negative.

$f < 0$

When the object is placed on the left side of the mirror, the object distance (u) is negative.

$\therefore u < 0$

It is placed between the focus (f) and the pole.

$\therefore f > u > 0$

$\frac{1}{f} < \frac{1}{u} < 0$

$\frac{1}{f} - \frac{1}{u} < 0$

For image distance v, we have the mirror formula:

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

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

$\therefore \frac{1}{v} < 0$

$v > 0$

The image is formed on the right side of the mirror. Hence, it is a virtual image.

For u < 0 and v > 0, we can write:

$\frac{1}{u} > \frac{1}{v}$

$v > u$

Magnification, m $= \frac{v}{u} > 1$

Hence, the formed image is enlarged.

Question 9.16:

A small pin fixed on a table top is viewed from above from a distance of 50 cm. By what distance would the pin appear to be raised if it is viewed from the same point through a 15 cm thick glass slab held parallel to the table? Refractive index of glass = 1.5. Does the answer depend on the location of the slab?

Answer

Actual depth of the pin, d = 15 cm

Apparent dept of the pin = d'

Refractive index of glass, $\mu = 1.5$

Ratio of actual depth to the apparent depth is equal to the refractive index of glass, i.e.

$$\mu = \frac{d}{d'}$$

$$\therefore d' = \frac{d}{\mu}$$

$$= \frac{15}{1.5} = 10 \text{ cm}$$

The distance at which the pin appears to be raised = $d' - d$

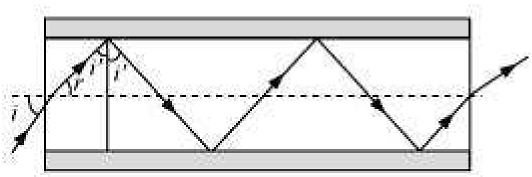
$= 15 - 10 = 5$ cm

For a small angle of incidence, this distance does not depend upon the location of the slab.

Question 9.17:

(a) Figure 9.35 shows a cross-section of a 'light pipe' made of a glass fibre of refractive index 1.68. The outer covering of the pipe is made of a material of refractive index 1.44. What is the range of the angles of the incident rays with the axis of the pipe for which total reflections inside the pipe take place, as shown in the figure.

(b) What is the answer if there is no outer covering of the pipe?



Answer

(a) Refractive index of the glass fibre, $\mu_1 = 1.68$

Refractive index of the outer covering of the pipe, μ_2 = 1.44

Angle of incidence = i

Angle of refraction = r

Angle of incidence at the interface = i'

The refractive index (μ) of the inner core − outer core interface is given as:

$$\mu = \frac{\mu_2}{\mu_1} = \frac{1}{\sin i'}$$

$$\sin i' = \frac{\mu_1}{\mu_2}$$

$$= \frac{1.44}{1.68} = 0.8571$$

$$\therefore i' = 59°$$

For the critical angle, total internal reflection (TIR) takes place only when $i > i'$, i.e., i > 59°

Maximum angle of reflection, $r_{\max} = 90° - i' = 90° - 59° = 31°$

Let, $i_{\max}$ be the maximum angle of incidence.

The refractive index at the air − glass interface, $\mu_1 = 1.68$

We have the relation for the maximum angles of incidence and reflection as:

$$\mu_1 = \frac{\sin i_{max}}{\sin r_{max}}$$

$$\begin{aligned}\sin i_{max} &= \mu_1 \sin r_{max}\\ &= 1.68 \sin 31°\\ &= 1.68 \times 0.5150\\ &= 0.8652\end{aligned}$$

$$\therefore i_{max} = \sin^{-1} 0.8652 \approx 60°$$

Thus, all the rays incident at angles lying in the range 0 < i < 60° will suffer total internal reflection.

(b) If the outer covering of the pipe is not present, then:

Refractive index of the outer pipe, $\mu_1 = \text{Refractive index of air} = 1$

For the angle of incidence i = 90°, we can write Snell's law at the air − pipe interface as:

$$\frac{\sin i}{\sin r} = \mu_2 = 1.68$$

$$\sin r = \frac{\sin 90°}{1.68} = \frac{1}{1.68}$$

$$\begin{aligned}r &= \sin^{-1}(0.5952)\\ &= 36.5°\end{aligned}$$

$$\therefore i' = 90° - 36.5° = 53.5°$$

Since $i' > r$, all incident rays will suffer total internal reflection.

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

(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

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

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

Focal length of the convex lens, f1 = 30 cm

Focal length of the concave lens, f2 = −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 = ∞

v1 = 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_2 = 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 $\left(220 - \frac{d}{2} = 220 - 4\right) 216 \text{ cm}$ 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, h1 = 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,

h1 = Object size = 1.5 cm

h2 = Size of the image

$$\therefore h_2 = 0.652 \times 1.5 = 0.98 \text{ cm}$$

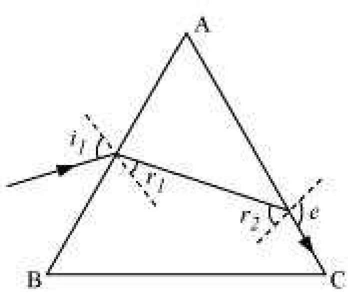
Hence, the height of the image is 0.98 cm.

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

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:

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

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

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

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

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

$$\therefore r_1 = A - r_2 = 60 - 41 = 19^\circ$$

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

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

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

$$= 1.524 \times \sin 19^\circ = 0.496$$

$$\therefore i_1 = 29.75^\circ$$

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

(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

Least distance of distinct vision, d = 25 cm

Far point of a normal eye, $d' = \infty$

Converging power of the cornea, $P_c = 40\,\mathrm{D}$

Least converging power of the eye-lens, $P_e = 20\,\mathrm{D}$

To see the objects at infinity, the eye uses its least converging power.

Power of the eye-lens, P = Pc + Pe = 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, $v = \frac{5}{3}\ \text{cm}$

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

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

The power of the spectacles used by the myopic person, P = −1.0 D

Focal length of the spectacles, $f = \frac{1}{P} = \frac{1}{-1 \times 10^{-2}} = -100 \text{ cm}$

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, $P' = +2 \text{ D}$

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

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

(a) Focal length of the magnifying glass, $f = 5$ cm

Least distance of distance vision, $d = 25$ cm

Closest object distance = u

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

(a) Area of each square, A = 1 mm2

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)2A

= 102 × 1 = 100 mm2

= 1 cm2

(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

(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

Area of the virtual image of each square, A = 6.25 mm2

Area of each square, A0 = 1 mm2

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

$$\therefore v = mu$$
$$= 2.5u \qquad \ldots(1)$$

Focal length of the magnifying glass, f = 10 cm

According to the lens formula, we have the relation:

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$$
$$\frac{1}{10} = \frac{1}{2.5u} - \frac{1}{u} = \frac{1}{u}\left(\frac{1}{2.5} - \frac{1}{1}\right) = \frac{1}{u}\left(\frac{1-2.5}{2.5}\right)$$
$$\therefore u = -\frac{1.5 \times 10}{2.5} = -6 \text{ cm}$$
$$\text{And } v = 2.5u$$
$$= 2.5 \times 6 = -15 \text{ cm}$$

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

(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.

Website: www.vidhyarjan.com Email: contact@vidhyarjan.com Mobile: 9999 249717

Head Office: 1/3-H-A-2, Street # 6, East Azad Nagar, Delhi-110051
(One Km from 'Welcome' Metro Station)

The angular magnification of the objective lens of a compound microscope is given as

$$\frac{1}{\left(|u_o|\, f_o\right)}$$

Where,

u_o = Object distance for the objective lens

f_o = Focal length of the objective

The magnification is large when $u_o > f_o$. In the case of a microscope, the object is kept close to the objective lens. Hence, the object distance is very little. Since u_o is small, f_o will be even smaller. Therefore, f_e and f_o 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

Focal length of the objective lens, f_o = 1.25 cm

Focal length of the eyepiece, fe = 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 (mo) is related to me as:

$m_o\ m_e$ = m

$$m_o = \frac{m}{m_e}$$

$$= \frac{30}{6} = 5$$

We also have the relation:

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

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

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

Applying the lens formula for the objective lens:

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

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

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

$$\text{And } v_o = -5u_o$$

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

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 $= |u_e| + |v_o|$

$= 4.17 + 7.5$

$= 11.67$ 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

Focal length of the objective lens, f_o = 140 cm

Focal length of the eyepiece, fe = 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

Focal length of the objective lens, fo = 140 cm

Focal length of the eyepiece, fe = 5 cm

(a) In normal adjustment, the separation between the objective lens and the eyepiece $= f_o + f_e = 140 + 5 = 145 \text{ cm}$

(b) Height of the tower, h1 = 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:

$$\theta = \frac{h_2}{f_o} = \frac{h_2}{140} \text{ rad}$$

Where,

h2 = 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

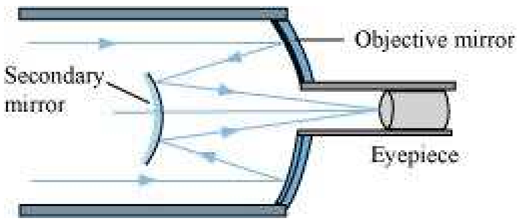
Hence, the height of the final image of the tower is 28.2 cm.

Question 9.36:

A Cassegrain telescope uses two mirrors as shown in Fig. 9.33. 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

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, $f_1 = \frac{R_1}{2} = 110 \text{ mm}$

Radius of curvature of the secondary mirror, R1 = 140 mm

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

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, $u = f_1 - d$

$= 110 - 20$

$= 90 \text{ mm}$

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

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

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

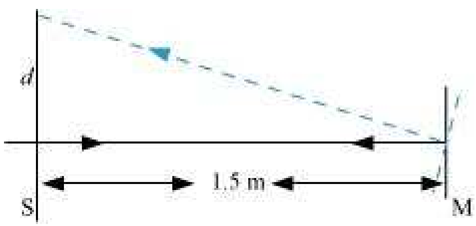
$$= \frac{1}{70} - \frac{1}{90} = \frac{9-7}{630} = \frac{2}{630}$$

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

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 Fig. 9.36. 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

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:

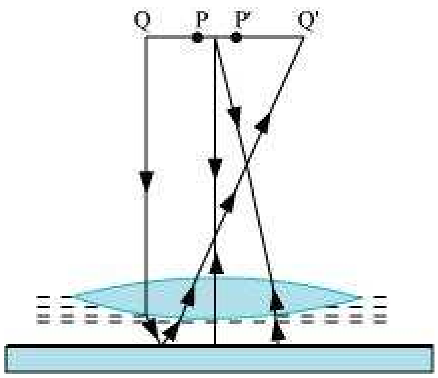
$$\tan 2\theta = \frac{d}{1.5}$$

$$\therefore d = 1.5 \times \tan 7^\circ = 0.184 \text{ m} = 18.4 \text{ cm}$$

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

Question 9.38:

Figure 9.37 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

Focal length of the convex lens, f1 = 30 cm

The liquid acts as a mirror. Focal length of the liquid = f2

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:

$$\frac{1}{f_1} = (\mu_1 - 1)\left(\frac{1}{R} + \frac{1}{-R}\right)$$
$$\frac{1}{30} = (1.5 - 1)\left(\frac{2}{R}\right)$$
$$\therefore R = \frac{30}{0.5 \times 2} = 30 \text{ cm}$$

Let μ_2 be the refractive index of the liquid.

Radius of curvature of the liquid on the side of the plane mirror = ∞

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.

Question 10.1:

Monochromatic light of wavelength 589 nm is incident from air on a water surface. What are the wavelength, frequency and speed of (a) reflected, and (b) refracted light? Refractive index of water is 1.33.

Answer

Wavelength of incident monochromatic light,

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

Speed of light in air, $c = 3 \times 10^8$ m/s

Refractive index of water, $\mu = 1.33$

(a) The ray will reflect back in the same medium as that of incident ray. Hence, the wavelength, speed, and frequency of the reflected ray will be the same as that of the incident ray.

Frequency of light is given by the relation,

$$\nu = \frac{c}{\lambda}$$

$$= \frac{3\times10^8}{589\times10^{-9}}$$

$$= 5.09\times10^{14}\,\text{Hz}$$

Hence, the speed, frequency, and wavelength of the reflected light are 3×10^8 m/s, 5.09×10^{14} Hz, and 589 nm respectively.

(b) Frequency of light does not depend on the property of the medium in which it is travelling. Hence, the frequency of the refracted ray in water will be equal to the frequency of the incident or reflected light in air.

$\therefore$ Refracted frequency, $\nu = 5.09 \times 10^{14}$ Hz

Speed of light in water is related to the refractive index of water as:

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

$$v = \frac{3\times10^8}{1.33} = 2.26\times10^8\,\text{m/s}$$

Wavelength of light in water is given by the relation,

$$\lambda = \frac{v}{\nu}$$
$$= \frac{2.26\times10^{8}}{5.09\times10^{14}}$$
$$= 444.007\times10^{-9}\,\text{m}$$
$$= 444.01\text{ nm}$$

Hence, the speed, frequency, and wavelength of refracted light are 2.26×10^8 m/s, 444.01nm, and 5.09×10^{14} Hz respectively.

Question 10.2:

What is the shape of the wavefront in each of the following cases:

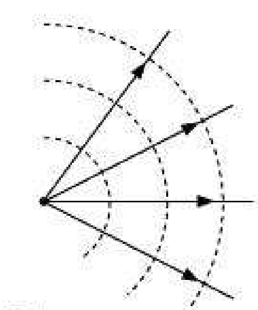
(a) Light diverging from a point source.

(b) Light emerging out of a convex lens when a point source is placed at its focus.

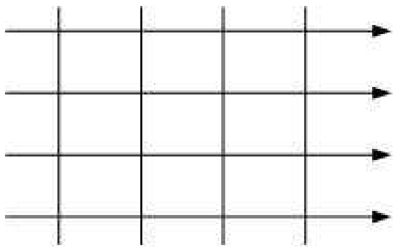
(c) The portion of the wavefront of light from a distant star intercepted by the Earth.

Answer

(a) The shape of the wavefront in case of a light diverging from a point source is spherical. The wavefront emanating from a point source is shown in the given figure.



(b) The shape of the wavefront in case of a light emerging out of a convex lens when a point source is placed at its focus is a parallel grid. This is shown in the given figure.



Wavefront

(c) The portion of the wavefront of light from a distant star intercepted by the Earth is a plane.

Question 10.3:

(a) The refractive index of glass is 1.5. What is the speed of light in glass? Speed of light in vacuum is 3.0×10^8 m s^{-1})

(b) Is the speed of light in glass independent of the colour of light? If not, which of the two colours red and violet travels slower in a glass prism?

Answer

(a) Refractive index of glass, $\mu = 1.5$

Speed of light, c = 3×10^8 m/s

Speed of light in glass is given by the relation,

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

$$= \frac{3\times10^8}{1.5} = 2\times10^8 \text{ m/s}$$

Hence, the speed of light in glass is 2×10^8 m/s.

(b) The speed of light in glass is not independent of the colour of light.

The refractive index of a violet component of white light is greater than the refractive index of a red component. Hence, the speed of violet light is less than the speed of red light in glass. Hence, violet light travels slower than red light in a glass prism.

Question 10.4:

In a Young's double-slit experiment, the slits are separated by 0.28 mm and the screen is placed 1.4 m away. The distance between the central bright fringe and the fourth bright fringe is measured to be 1.2 cm. Determine the wavelength of light used in the experiment.

Answer

Distance between the slits, d = 0.28 mm = 0.28×10^{-3} m

Distance between the slits and the screen, D = 1.4 m

Distance between the central fringe and the fourth (n = 4) fringe,

u = 1.2 cm = 1.2×10^{-2} m

In case of a constructive interference, we have the relation for the distance between the two fringes as:

$$u = n\lambda \frac{D}{d}$$

Where,

n = Order of fringes = 4

λ = Wavelength of light used

$$\therefore \lambda = \frac{ud}{nD}$$

$$= \frac{1.2\times10^{-2}\times0.28\times10^{-3}}{4\times1.4}$$

$$= 6\times10^{-7}$$

$$= 600 \text{ nm}$$

Hence, the wavelength of the light is 600 nm.

Question 10.5:

In Young's double-slit experiment using monochromatic light of wavelengthλ, the intensity of light at a point on the screen where path difference is λ, is K units. What is the intensity of light at a point where path difference is λ /3?

Answer

Let I_1 and I_2 be the intensity of the two light waves. Their resultant intensities can be obtained as:

$I' = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\phi$

Where,

ϕ = Phase difference between the two waves

For monochromatic light waves,

$I_1 = I_2$

$\therefore I' = I_1 + I_1 + 2\sqrt{I_1 I_1}\cos\phi$

$= 2I_1 + 2I_1\cos\phi$

Phase difference = $\frac{2\pi}{\lambda} \times \text{Path difference}$

Since path difference = λ,

Phase difference, $\phi = 2\pi$

$\therefore I' = 2I_1 + 2I_1 = 4I_1$

Given,

$I' = K$

$\therefore I_1 = \frac{K}{4}$ ... (1)

When path difference $= \frac{\lambda}{3}$,

Phase difference, $\phi = \frac{2\pi}{3}$

Hence, resultant intensity, $I'_R = I_1 + I_1 + 2\sqrt{I_1 I_1}\cos\frac{2\pi}{3}$

$= 2I_1 + 2I_1\left(-\frac{1}{2}\right) = I_1$

Using equation (1), we can write:

$I_R = I_1 = \frac{K}{4}$

Hence, the intensity of light at a point where the path difference is $\frac{\lambda}{3}$ is $\frac{K}{4}$ units.

Question 10.6:

A beam of light consisting of two wavelengths, 650 nm and 520 nm, is used to obtain interference fringes in a Young's double-slit experiment.

(a) Find the distance of the third bright fringe on the screen from the central maximum for wavelength 650 nm.

(b) What is the least distance from the central maximum where the bright fringes due to both the wavelengths coincide?

Answer

Wavelength of the light beam, $\lambda_1 = 650 \text{ nm}$

Wavelength of another light beam, $\lambda_2 = 520 \text{ nm}$

Distance of the slits from the screen = D

Distance between the two slits = d

(a) Distance of the n^{th} bright fringe on the screen from the central maximum is given by the relation,

$$x = n\lambda_1 \left(\frac{D}{d}\right)$$

For third bright fringe, $n = 3$

$$\therefore x = 3 \times 650 \frac{D}{d} = 1950 \left(\frac{D}{d}\right) \text{ nm}$$

(b) Let the n^{th} bright fringe due to wavelength λ_2 and $(n - 1)^{th}$ bright fringe due to wavelength λ_1 coincide on the screen. We can equate the conditions for bright fringes as:

$$n\lambda_2 = (n-1)\lambda_1$$

$$520n = 650n - 650$$

$$650 = 130n$$

$$\therefore n = 5$$

Hence, the least distance from the central maximum can be obtained by the relation:

$$x = n\lambda_2 \frac{D}{d}$$

$$= 5 \times 520 \frac{D}{d} = 2600 \frac{D}{d} \text{ nm}$$

Note: The value of *d* and *D* are not given in the question.

Question 10.7:

In a double-slit experiment the angular width of a fringe is found to be 0.2° on a screen placed 1 m away. The wavelength of light used is 600 nm. What will be the angular width of the fringe if the entire experimental apparatus is immersed in water? Take refractive index of water to be 4/3.

Answer

Distance of the screen from the slits, *D* = 1 m

Wavelength of light used, $\lambda_1 = 600 \text{ nm}$

Angular width of the fringe in air, $\theta_1 = 0.2°$

Angular width of the fringe in water = θ_2

Refractive index of water, $\mu = \frac{4}{3}$

Refractive index is related to angular width as:

$$\mu = \frac{\theta_1}{\theta_2}$$

$$\theta_2 = \frac{3}{4}\theta_1$$

$$= \frac{3}{4} \times 0.2 = 0.15$$

Therefore, the angular width of the fringe in water will reduce to 0.15°.

uestion 10.8:

What is the Brewster angle for air to glass transition? (Refractive index of glass = 1.5.)

Answer

Refractive index of glass, $\mu = 1.5$

Brewster angle = θ

Brewster angle is related to refractive index as:

$$\tan\theta = \mu$$

$$\theta = \tan^{-1}(1.5) = 56.31°$$

Therefore, the Brewster angle for air to glass transition is 56.31°.

Question 10.9:

Light of wavelength 5000 Å falls on a plane reflecting surface. What are the wavelength and frequency of the reflected light? For what angle of incidence is the reflected ray normal to the incident ray?

Answer

Wavelength of incident light, λ = 5000 Å = 5000 × 10^{-10} m

Speed of light, c = 3 × 10^8 m

Frequency of incident light is given by the relation,

$$\nu = \frac{c}{\lambda}$$

$$= \frac{3\times10^{8}}{5000\times10^{-10}} = 6\times10^{14}\ \text{Hz}$$

The wavelength and frequency of incident light is the same as that of reflected ray. Hence, the wavelength of reflected light is 5000 Å and its frequency is 6 × 10^{14} Hz.

When reflected ray is normal to incident ray, the sum of the angle of incidence, $\angle i$ and angle of reflection, $\angle r$ is 90°.

According to the law of reflection, the angle of incidence is always equal to the angle of reflection. Hence, we can write the sum as:

$$\angle i + \angle r = 90$$

$$\angle i + \angle i = 90$$

$$\angle i = \frac{90}{2} = 45°$$

Therefore, the angle of incidence for the given condition is 45°.

Question 10.10:

Estimate the distance for which ray optics is good approximation for an aperture of 4 mm and wavelength 400 nm.

Answer

Fresnel's distance (Z_F) is the distance for which the ray optics is a good approximation. It is given by the relation,

$$Z_F = \frac{a^2}{\lambda}$$

Where,

Aperture width, a = 4 mm = 4 $\times 10^{-3}$ m

Wavelength of light, λ = 400 nm = 400 $\times$ 10^{-9} m

$$Z_F = \frac{\left(4\times10^{-3}\right)^2}{400\times10^{-9}} = 40 \text{ m}$$

Therefore, the distance for which the ray optics is a good approximation is 40 m.

Question 10.11:

The 6563 Å H_α line emitted by hydrogen in a star is found to be red shifted by 15 Å. Estimate the speed with which the star is receding from the Earth.

Answer

Wavelength of H_α line emitted by hydrogen,

λ = 6563 Å

= 6563 × 10^{-10} m.

Star's red-shift, $(\lambda' - \lambda) = 15 \text{ Å} = 15\times10^{-10} \text{ m}$

Speed of light, $c = 3\times10^8$ m/s

Let the velocity of the star receding away from the Earth be v.

The red shift is related with velocity as:

$$\lambda' - \lambda = \frac{v}{c}\lambda$$

$$v = \frac{c}{\lambda}\times(\lambda' - \lambda)$$

$$= \frac{3\times10^8\times15\times10^{-10}}{6563\times10^{-10}} = 6.87\times10^5 \text{ m/s}$$

Therefore, the speed with which the star is receding away from the Earth is 6.87 × 10^5 m/s.

Question 10.12:

Explain how Corpuscular theory predicts the speed of light in a medium, say, water, to be greater than the speed of light in vacuum. Is the prediction confirmed by experimental determination of the speed of light in water? If not, which alternative picture of light is consistent with experiment?

Answer

No; Wave theory

Newton's corpuscular theory of light states that when light corpuscles strike the interface of two media from a rarer (air) to a denser (water) medium, the particles experience forces of attraction normal to the surface. Hence, the normal component of velocity increases while the component along the surface remains unchanged.

Hence, we can write the expression:

$c \sin i = v \sin r$ ... (i)

Where,

i = Angle of incidence

r = Angle of reflection

c = Velocity of light in air

v = Velocity of light in water

We have the relation for relative refractive index of water with respect to air as:

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

Hence, equation (i) reduces to

$$\frac{v}{c} = \frac{\sin i}{\sin r} = \mu \qquad \text{... (ii)}$$

But, $\mu > 1$

Hence, it can be inferred from equation (ii) that $v > c$. This is not possible since this prediction is opposite to the experimental results of $c > v$.

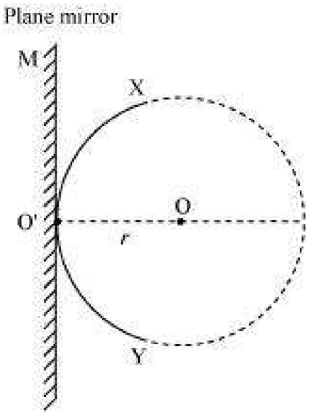
The wave picture of light is consistent with the experimental results.

Question 10.13:

You have learnt in the text how Huygens' principle leads to the laws of reflection and refraction. Use the same principle to deduce directly that a point object placed in front of a plane mirror produces a virtual image whose distance from the mirror is equal to the object distance from the mirror.

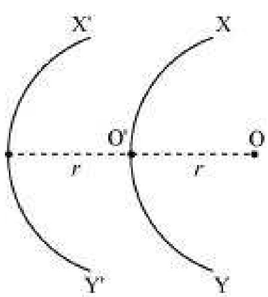
Answer

Let an object at O be placed in front of a plane mirror MO' at a distance *r* (as shown in the given figure).



A circle is drawn from the centre (O) such that it just touches the plane mirror at point O'. According to Huygens' Principle, XY is the wavefront of incident light.

If the mirror is absent, then a similar wavefront X'Y' (as XY) would form behind O' at distance *r* (as shown in the given figure).



$X'Y'$ can be considered as a virtual reflected ray for the plane mirror. Hence, a point object placed in front of the plane mirror produces a virtual image whose distance from the mirror is equal to the object distance (*r*).

Question 10.14:

Let us list some of the factors, which could possibly influence the speed of wave propagation:

(i) Nature of the source.

(ii) Direction of propagation.

(iii) Motion of the source and/or observer.

(iv) Wave length.

(v) Intensity of the wave.

On which of these factors, if any, does

(a) The speed of light in vacuum,

(b) The speed of light in a medium (say, glass or water), depend?

Answer

(a) Thespeed of light in a vacuum i.e., 3×10^8 m/s (approximately) is a universal constant. It is not affected by the motion of the source, the observer, or both. Hence, the given factor does not affect the speed of light in a vacuum.

(b) Out of the listed factors, the speed of light in a medium depends on the wavelength of light in that medium.

Question 10.15:

For sound waves, the Doppler formula for frequency shift differs slightly between the two situations: (i) source at rest; observer moving, and (ii) source moving; observer at rest. The exact Doppler formulas for the case of light waves in vacuum are, however, strictly identical for these situations. Explain why this should be so. Would you expect the formulas to be strictly identical for the two situations in case of light travelling in a medium?

Answer

No

Sound waves can propagate only through a medium. The two given situations are not scientifically identical because the motion of an observer relative to a medium is different in the two situations. Hence, the Doppler formulas for the two situations cannot be the same.

In case of light waves, sound can travel in a vacuum. In a vacuum, the above two cases are identical because the speed of light is independent of the motion of the observer and the motion of the source. When light travels in a medium, the above two cases are not identical because the speed of light depends on the wavelength of the medium.

Question 10.16:

In double-slit experiment using light of wavelength 600 nm, the angular width of a fringe formed on a distant screen is 0.1º. What is the spacing between the two slits?

Answer

Wavelength of light used, λ = 6000 nm = 600 × 10^{-9} m

Angular width of fringe, $\theta = 0.1° = 0.1 \times \frac{\pi}{180} = \frac{3.14}{1800}$ rad

Angular width of a fringe is related to slit spacing (*d*) as:

$$\theta = \frac{\lambda}{d}$$

$$d = \frac{\lambda}{\theta}$$

$$= \frac{600 \times 10^{-9}}{\frac{3.14}{1800}} = 3.44 \times 10^{-4} \text{ m}$$

Therefore, the spacing between the slits is 3.44×10^{-4} m.

Question 10.17:

Answer the following questions:

(a) In a single slit diffraction experiment, the width of the slit is made double the original width. How does this affect the size and intensity of the central diffraction band?

(b) In what way is diffraction from each slit related to the interference pattern in a double-slit experiment?

(c) When a tiny circular obstacle is placed in the path of light from a distant source, a bright spot is seen at the centre of the shadow of the obstacle. Explain why?

(d) Two students are separated by a 7 m partition wall in a room 10 m high. If both light and sound waves can bend around obstacles, how is it that the students are unable to see each other even though they can converse easily.

(e) Ray optics is based on the assumption that light travels in a straight line. Diffraction effects (observed when light propagates through small apertures/slits or around small obstacles) disprove this assumption. Yet the ray optics assumption is so commonly used in understanding location and several other properties of images in optical instruments. What is the justification?

Answer

(a) In a single slit diffraction experiment, if the width of the slit is made double the original width, then the size of the central diffraction band reduces to half and the intensity of the central diffraction band increases up to four times.

(b) The interference pattern in a double-slit experiment is modulated by diffraction from each slit. The pattern is the result of the interference of the diffracted wave from each slit.

(c) When a tiny circular obstacle is placed in the path of light from a distant source, a bright spot is seen at the centre of the shadow of the obstacle. This is because light waves are diffracted from the edge of the circular obstacle, which interferes constructively at the centre of the shadow. This constructive interference produces a bright spot.

(d) Bending of waves by obstacles by a large angle is possible when the size of the obstacle is comparable to the wavelength of the waves.

On the one hand, the wavelength of the light waves is too small in comparison to the size of the obstacle. Thus, the diffraction angle will be very small. Hence, the students are unable to see each other. On the other hand, the size of the wall is comparable to the wavelength of the sound waves. Thus, the bending of the waves takes place at a large angle. Hence, the students are able to hear each other.

(e) The justification is that in ordinary optical instruments, the size of the aperture involved is much larger than the wavelength of the light used.

Question 10.18:

Two towers on top of two hills are 40 km apart. The line joining them passes 50 m above a hill halfway between the towers. What is the longest wavelength of radio waves, which can be sent between the towers without appreciable diffraction effects?

Answer

Distance between the towers, d = 40 km

Height of the line joining the hills, d = 50 m.

Thus, the radial spread of the radio waves should not exceed 50 km.

Since the hill is located halfway between the towers, Fresnel's distance can be obtained as:

Z_P = 20 km = 2 × 10^4 m

Aperture can be taken as:

$a = d$ = 50 m

Fresnel's distance is given by the relation,

$$Z_P = \frac{a^2}{\lambda}$$

Where,

λ = Wavelength of radio waves

$$\therefore \lambda = \frac{a^2}{Z_P}$$

$$= \frac{(50)^2}{2\times10^4} = 1250\times10^{-4} = 0.1250 \text{ m} = 12.5 \text{ cm}$$

Therefore, the wavelength of the radio waves is 12.5 cm.

Question 10.19:

A parallel beam of light of wavelength 500 nm falls on a narrow slit and the resulting diffraction pattern is observed on a screen 1 m away. It is observed that the first minimum is at a distance of 2.5 mm from the centre of the screen. Find the width of the slit.

Answer

Wavelength of light beam, λ = 500 nm = 500 × 10^{-9} m

Distance of the screen from the slit, D = 1 m

For first minima, n = 1

Distance between the slits = d

Distance of the first minimum from the centre of the screen can be obtained as:

x = 2.5 mm = 2.5 × 10^{-3} m

It is related to the order of minima as:

$$n\lambda = x\frac{d}{D}$$

$$d = \frac{n\lambda D}{x}$$

$$= \frac{1 \times 500 \times 10^{-9} \times 1}{2.5 \times 10^{-3}} = 2 \times 10^{-4} \text{ m} = 0.2 \text{ mm}$$

Therefore, the width of the slits is 0.2 mm.

Question 10.20:

Answer the following questions:

(a) When a low flying aircraft passes overhead, we sometimes notice a slight shaking of the picture on our TV screen. Suggest a possible explanation.

(b) As you have learnt in the text, the principle of linear superposition of wave displacement is basic to understanding intensity distributions in diffraction and interference patterns. What is the justification of this principle?

Answer

(a) Weak radar signals sent by a low flying aircraft can interfere with the TV signals received by the antenna. As a result, the TV signals may get distorted. Hence, when a low flying aircraft passes overhead, we sometimes notice a slight shaking of the picture on our TV screen.

(b) The principle of linear superposition of wave displacement is essential to our understanding of intensity distributions and interference patterns. This is because superposition follows from the linear character of a differential equation that governs wave motion. If y_1 and y_2 are the solutions of the second order wave equation, then any linear combination of y_1 and y_2 will also be the solution of the wave equation.

Question 10.21:

In deriving the single slit diffraction pattern, it was stated that the intensity is zero at angles of $n\lambda/a$. Justify this by suitably dividing the slit to bring out the cancellation.

Answer

Consider that a single slit of width d is divided into n smaller slits.

$\therefore$ Width of each slit, $d' = \frac{d}{n}$

Angle of diffraction is given by the relation,

$$\theta = \frac{\frac{d}{d'}\lambda}{d} = \frac{\lambda}{d'}$$

Now, each of these infinitesimally small slit sends zero intensity in directionθ. Hence, the combination of these slits will give zero intensity.

6. OPTICS
RAY OPTICS

GIST

1 **REFLECTION BY CONVEX AND CONCAVE MIRRORS.**

a. Mirror formula $\frac{1}{v}+\frac{1}{u}=\frac{1}{f}$, where u is the object distance, v is the image distance and f is the focal length.

b. Magnification $m=-\frac{v}{u}=\frac{f-v}{f}=\frac{f}{f-u}$.

m is **-ve** for **real images** and **+ve** for **virtual images**.

2 **REFRACTION**

c. Ray of light bends when it enters from one medium to the other, having different optical densities.

d. Sun can be seen before actual sunrise and after actual sunset due to Atmospheric refraction

e. An object under water (any medium) appears to be raised due to refraction when observed inclined

$n=\frac{\text{Real depth}}{\text{apparent depth}}$ and

Shift in the position (apparent) of object is

X = t { 1 – 1/n) where t is the actual depth of the medium

f. Snell's law states that for a given colour of light, the ratio of sine of the angle of incidence to sine of angle of refraction is a constant, when light travels from rarer to denser,

$$\frac{Sin i}{\sin r}=\frac{n_2}{n_1}$$

g. Absolute refractive index is the ratio between the velocities of light in vacuum to the velocity of light in medium. For air n=1.

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

3 h. When a ray of light travels from denser to rarer medium and if the angle of incidence is greater than critical angle, the ray of light is reflected back to the denser medium. This phenomenon is called Total internal reflection.

$$SinC=\frac{n_R}{n_D}$$

i. Diamond has a high refractive index, resulting with a low critical angle ($C=24.4^0$). This promotes a multiple total internal reflection causing its brilliance and luster. Some examples of total internal reflection are formation of mirage and working of an optical fibre.

4 When light falls on a convex refracting surface, it bends and the relation between U, V and R is given by $\frac{n_2}{V}-\frac{n_1}{u}=\frac{n_2-n_1}{R}$

5 Lens maker's formula or thin lens formula is given by

$$\frac{1}{f}=\left(\frac{n_2-n_1}{n_1}\right)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)$$

For Convex Lens R_1 +ve ;R_2 –ve Concave lens R_1-ve; R_2 +ve

The way in which a lens behaves as converging or diverging depends upon the values of n_L and n_m.

6 When two lenses are kept in contact the equivalent focal length is given by

$$\frac{1}{F}=\frac{1}{f_1}+\frac{1}{f_2} \qquad \& \qquad P=P_1+P_2$$

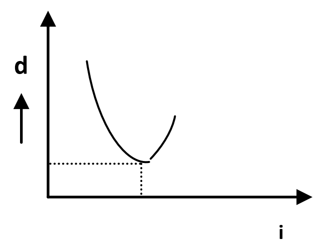
7 The lens formula is given by $\frac{1}{v}-\frac{1}{u}=\frac{1}{f}$

8 When light passes through a glass prism it undergoes refraction.

The expression for refractive index is $n=\dfrac{Sin\left(\dfrac{A+D_m}{2}\right)}{Sin\left(\dfrac{A}{2}\right)}$

As the angle of incidence increases, the angle of deviation decreases, reaches a minimum value and then increases. This minimum value is called angle of minimum deviation "D_m".

9



where d is minimum, i=e, refracted ray lies parallel to the base. For a small angled prism d=(n-1)A

10 When white light (poly chromatic or composite) is passed through a glass prism, It splits up into its component colours (Monochromatic). This phenomenon is called Dispersion.

11 Rainbow is formed due to a combined effect of dispersion, refraction and reflection of sunlight by spherical water droplets of rain.

12 Scattering of light takes place when size of the particle is very small when compared to the wavelength of light

Intensity of scattered light is $I\alpha\frac{1}{\lambda^4}$

The following properties or phenomena can be explained by scattering.

(i) Sky is blue.
(ii) Sky is reddish at the time of sunrise and sunset
(iii) Infra-red photography used in foggy days.
(iv) Orange colour of black Box
(v) Yellow light used in vehicles on foggy days.
(vi) Red light used in signals.

QUESTIONS: REFLECTION:

1 One half of the reflecting surface of a concave mirror is coated with black paint. How will the image be affected?

Brightness decreases

2 Why a concave mirror is preferred for shaving?

Enlarged VIRTUAL

3 Mirrors in search lights are parabolic and not spherical. Why?

Produce intense parallel beam) eliminating spherical aberration

4 Using the mirror formula show that a virtual image is obtained when an object is placed in between the principal focus and pole of the concave mirror.

$$\frac{1}{v}=\frac{1}{u}-\frac{1}{f} \quad \text{u<f} \Rightarrow \frac{1}{u} > \frac{1}{f} \Rightarrow v \ \text{ is } \ \text{+ve})$$

5 Using the mirror formula show that for a concave mirror, when the object is placed at the centre of curvature, the image is formed at the centre of curvature.

6 Find the position of an object, which when placed in front of a concave mirror of focal length 20cm, produces a virtual image which is twice the size of the object.

Ans. 10cm

7 Plot a graph between 1/u and 1/v for a concave mirror. What does the slope of the graph yield?

Ans. Straight line, slope =u/v=1/m

8 **<u>REFRACTION AND LENSES</u>**

Which of the following properties of light: Velocity, wavelength and frequency, changes during the phenomenon (i) reflection (ii) refraction

Ans. (i) No change (ii) velocity, wavelength change)

9 A convex lens is combined with a concave lens. Draw a ray diagram to show the image formed by the combination, for an object placed in between f and 2f of the convex lens. Compare the Power of the convex and concave lenses so that the image formed is real.

Ans: f of convex lens must be less than f of concave lens to produce real image. So power of Convex greater than that of concave)

10 Derive a relation between the focal length and radius of curvature of a Plano convex lens made of glass. Compare the relation with that of a concave mirror. What can you conclude? Justify your answer.

Ans. (f=2R) both are same. But applicable always in mirrors, but for lenses only in specific cases, the relation can be applied.)

11 In the given figure an object is placed at O in a medium (n_2>n_1). Draw a ray diagram for the image formation and hence deduce a relation between u, v and R

$$\frac{n_1}{v}-\frac{n_2}{u}=\frac{n_1-n_2}{R}$$

12 Show that a concave lens always produces a virtual image, irrespective of the position of the object.

Ans. $v = \dfrac{uf}{u+f}$ *But u is –ve and f is –ve for concave lens*

Hence v is always -ve. that is virtual

13 Sun glasses are made up of curved surfaces. But the power of the sun glass is zero. Why?

Ans. It is convex concave combination of same powers. So net power zero

14 A convex lens is differentiated to n regions with different refractive indices. How many images will be formed by the lens?

Ans. n images but less sharp

15 A convex lens has focal length f in air. What happens to the focal length of the lens, if it is immersed in (i) water (n=4/3) (ii) a medium whose refractive index is twice that of glass.

Ans. 4f, -f

16 Calculate the critical angle for glass air surface, if a ray falling on the surface from air, suffers a deviation of 15^0 when the angle of incidence is 40^0.

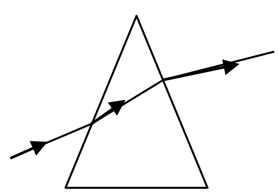
Find n by Snell's law and then find c=41.14^0

17 Two thin lenses when in contact produce a net power of +10D. If they are at 0.25m apart, the net power falls to +6 D. Find the focal lengths of the two lenses

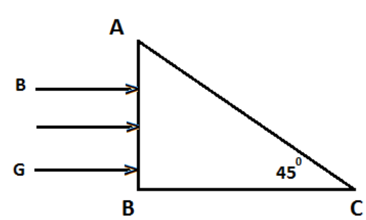
Ans. 0.125m, 0.5m)

18 A glass prism has an angle of minimum deviation D in air. What happens to the value of D if the prism is immersed in water? Ans. Decreases

19 Draw a ray diagram for the pat followed by the ray of light passing through a glass prism immersed in a liquid with refractive index greater than glass.



Three rays of light red (R) green (G) and blue (B) are incident on the surface of a right angled prism as shown in figure. The refractive indices for the material of the prism for red green and blue are 1.39, 1.43 and 1.47 respectively. Trace the path of the rays through the prism. How will the situation change if the rays were falling normally on one of the faces of an equilateral prism?

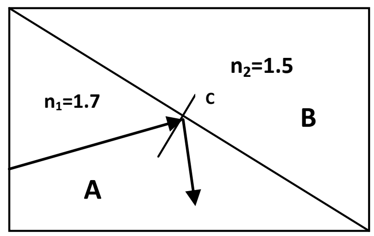


(Hint Calculate the critical angle for each and if the angle of incidence on the surface AC is greater, then TIR will take place.)

20 Show that the angle of deviation for a small angled prism is directly proportional to the refractive index of the material of the prism. One of the glass Prisms used in Fresnel's biprism experiment has refractive index 1.5. Find the angle of minimum deviation if the angle of the prism is 3^0. (3)

(D= (n-1) A, 1.5^0)

21 In the given diagram, a ray of light undergoes total internal reflection at the point C which is on the interface of two different media A and B with refractive indices1.7 and 1.5 respectively. What is the minimum value of angle of incidence? Can you expect the ray of light to undergo total internal reflection when it falls at C at the same angle of incidence while entering from B to A. Justify your answer?

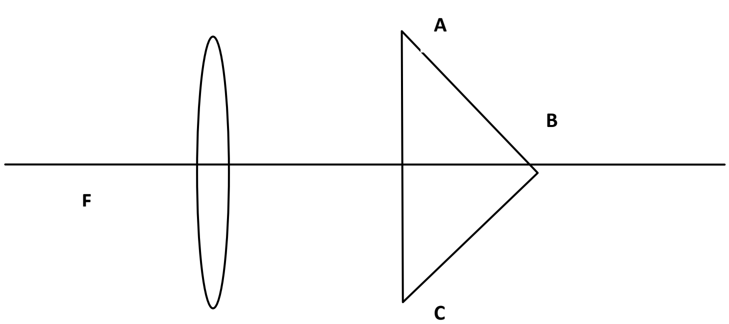


Ans. Use $SinC = \frac{n_r}{n_d} = 0.88$ *and* C=61.7^0 so i=61.8^0 no for TIR ray of light must travel from denser to rarer from B to A)

22 The velocity of light in flint glass for wavelengths 400nm and 700nm are 1.80×10^8m/s and 1.86×10^8 m/s respectively. Find the minimum angle of deviation of an equilateral prism made of flint glass for the given wavelengths.

(For 400nm D=52^0 and for 700nm D=48^0)

23 In the given diagram a point object is kept at the Focus F of the convex lens. The ray of light from the lens falls on the surfaces AB and BC of a right angled glass prism of refractive index 1.5 at an angle 42^0.Where will be the final image formed? Draw a ray diagram to show the position of the final image formed. What change do you expect in your answer if the prism is replaced by a plane mirror? Given C = 41-8˚



Ans- at F itself, no change

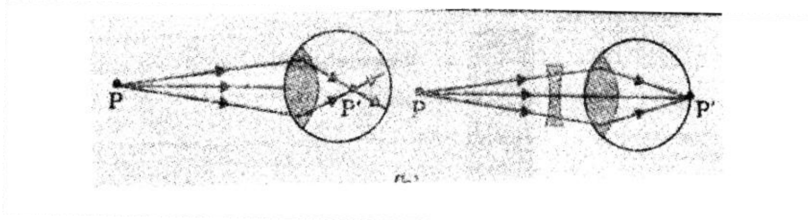
GIST

1 ➢ Human eye:

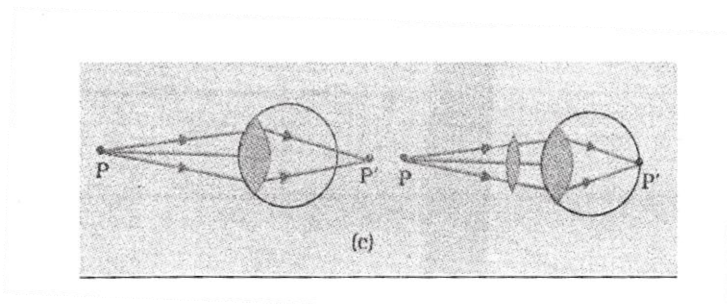
- Eye lens: crystalline
- Cilliary muscles: lens is held in position by these.
- Iris: Circular contractible diaphragm with an aperture near the centre.
- Pupil: the circular aperture is pupil. It adjusts controlling light entering the eye.
- Power of accommodation: ability of pupil for adjusting focal length.
- Far point: the maximum distant point that an eye can see clearly.
- Near point: closest distant that eye lens can focus on the retina.
- Range of vision: distant between near point and far point.

2 ➢ Defects of vision:

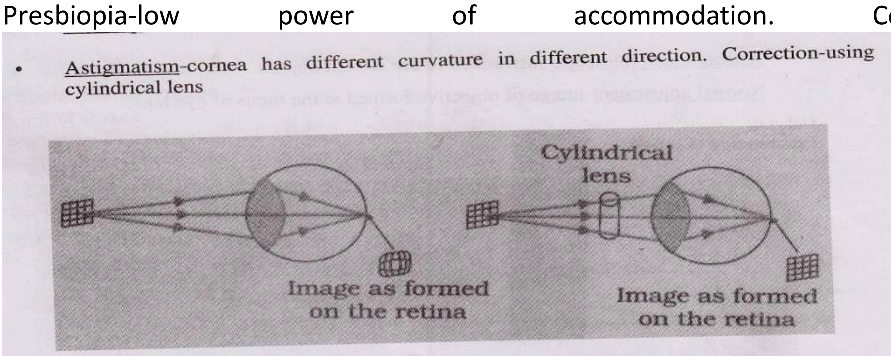
Myopia: image formed in front of the retina. Correction-using concave lens.



Hypermetropia- image behind the retina. Correction-using convex lens.



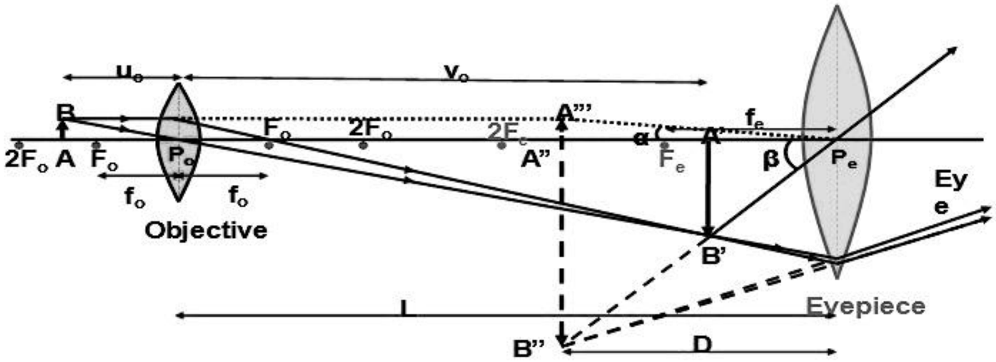
Presbiopia-low power of accommodation. Correction-bifocal lens.



Astigmatism-cornea has different curvature in different direction. Correction-using cylindrical Lens.

3

Compound Microscope:



Objective: The converging lens nearer to the object.
Eyepiece: The converging lens through which the final image is seen.
Both are of short focal length. Focal length of eyepiece is slightly greater than that of the objective.

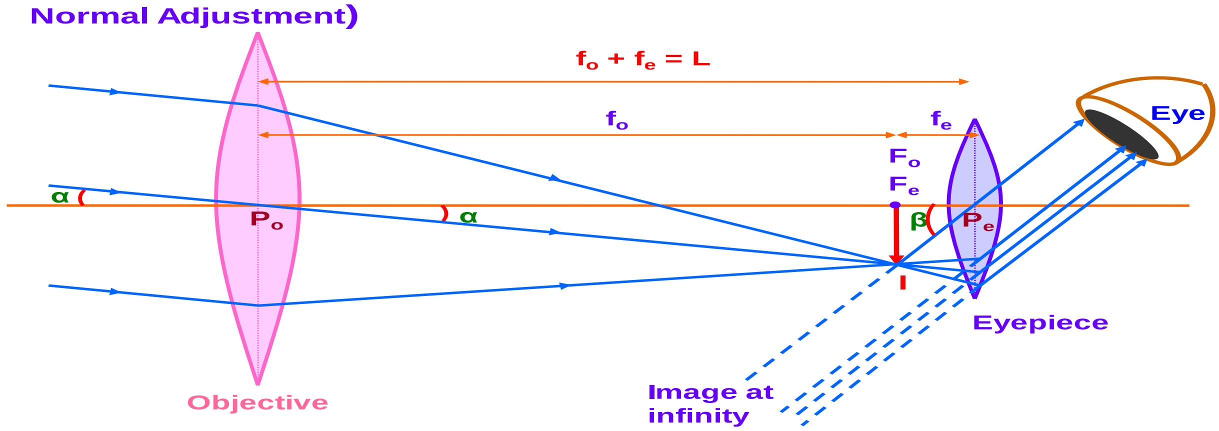
4 **Angular Magnification or Magnifying Power (M):**

$M = M_e \times M_o$

$$\boxed{M = \frac{v_o}{-u_o}\left(1 + \frac{D}{f_e}\right)} \quad \boxed{M = \frac{-L}{f_o}\left(1 + \frac{D}{f_e}\right)}$$

or $$\boxed{M \approx \frac{-L}{f_o} \times \frac{D}{f_e}}$$ (Normal adjustment i.e. image at infinity)

5 **Astronomical Telescope: (Image formed at infinity – Normal Adjustment)**



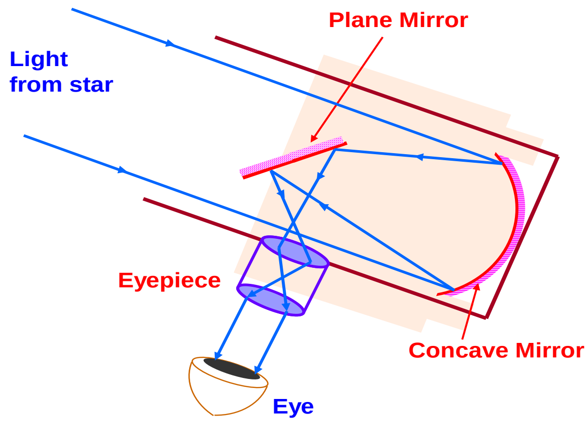
Focal length of the objective is much greater than that of the eyepiece.
Aperture of the objective is also large to allow more light to pass through it.

6 **Angular magnification or Magnifying power of a telescope in normal adjustment**

$$\boxed{M = \frac{\beta}{\alpha}} \quad \boxed{M = \frac{-f_o}{f_e}}$$

($f_o + f_e = L$ is called the length of the telescope in normal adjustment).

7 **Newtonian Telescope: (Reflecting Type)**



Magnifying Power:

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

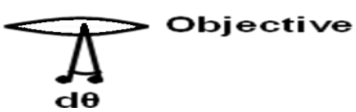
8 Cassegrain telescope refer from NCERT / refer Page no 83

$$\text{Resolving Power} = \frac{1}{\Delta d} = \boxed{\frac{2\,\mu \sin\theta}{\lambda}}$$

Resolving power depends on i) wavelength λ, ii) refractive index of the medium between the object and the objective and iii) half angle of the cone of light from one of the objects θ.

Resolving Power of a Telescope:

$$\text{Resolving Power} = \frac{1}{d\theta} = \boxed{\frac{a}{1.22\,\lambda}}$$



Resolving power depends on i) wavelength λ, ii) diameter of the objective a.

QUESTIONS

MICROSCOPE AND TELESCOPE

*1. You are given following three lenses. Which two lenses will you use as an eyepiece and as an objective to construct an astronomical telescope? 2

Lens	Power (P)	Aperture (A)
L1	3D	8 cm
L2	6D	1 cm
L3	10D	1 cm

Ans- The objective of an astronomical telescope should have the maximum diameter and its eyepiece should have maximum power. Hence, L1 could be used as an objective and L3 could be used as eyepiece.

2. Draw a ray diagram of a reflecting type telescope. State two advantages of this telescope over a refracting telescope. 2

3. Draw a ray diagram of an astronomical telescope in the normal adjustment position, state two drawbacks of this type of telescope. 2

4. Draw a ray diagram of a compound microscope. Write the expression for its magnifying power. 2

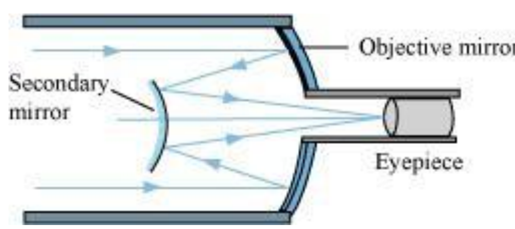
5. The magnifying power of an astronomical telescope in the normal adjustment position is 100. The distance between the objective and the eyepiece is 101 cm. Calculate the focal lengths of the objective and of the eye-piece. 2

6. How does the 'resolving power' of an astronomical telescope get affected on (i) Increasing the aperture of the objective lens? (ii) Increasing the wavelength of the light used? 2

7. What are the two ways of adjusting the position of the eyepiece while observing the Final image in a compound microscope? Which of these is usually preferred and why? 5
Obtain an expression for the magnifying power of a compound microscope. Hence explain why (i) we prefer both the 'objective' and the 'eye-piece' to have small focal length? and (ii) we regard the 'length' of the microscope tube to be nearly equal to be separation between the focal points of its objective and its eye-piece? Calculate the magnification obtained by a compound microscope having an objective of focal length 1.5cm and an eyepiece of focal length 2.5 cm and a tube length of 30.

8. What are the two main considerations that have to be kept in mind while designing the 'objective' of an astronomical telescope? 5
Obtain an expression for the angular magnifying power and the length of the tube of an astronomical telescope in its 'normal adjustment' position.
An astronomical telescope having an 'objective' of focal length 2m and an eyepiece of focal length 1cm is used to observe a pair of stars with an actual angular separation of 0.75. What would be their observed angular separation as seen through the telescope?
Hint- observed angular separation = 0.75' ×200 = 150'

*9. Cassegrain telescope uses two mirrors as shown inFig. 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 140mm,where will the final image of an object at infinity be? 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,R_1=220 mm

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

Radiusof curvature of the secondary mirror,R_1=140 mm

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

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, $u = f_1 - d$

$$=110-20$$
$$=90\text{ mm}$$
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 formed315 mm away from the secondary mirror. Light incident normally on a plane mirror attached to a galvanometer coil retraces backwards as shown in

*10. The best position of the eye for viewing through a compound microscope is at the eye-ring attached to the eye piece. The precise location of the eye depends on the separation between the objective lens and the eye piece. An angular magnification (magnifying power) of 30X is desired using an objective of focallength1.25 cm and an eyepiece of focal length 5 cm. How will you set up the compound microscope? 5

Ans - Separation between the objective lens and the eyepiece

$$=4.17+7.5$$
$$=11.67\text{ cm}$$

DEFECTS OF VISION

1. A myopic person has been using spectacles of power −1.0 dioptre for distant vision.During old age healso needs to use separate reading glass of power + 2.0 dioptres. Explain what may have happened.
   Ans -
   The power of the spectacles used by the myopic person,P = −1.0 D
   $$f=\frac{1}{P}=\frac{1}{-1\times10^{-2}}=-100\text{ cm}$$
   Focal lengthof the spectacles,
   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=100/50) $P'=+2\text{ D}$
   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.

2. 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 eye piece 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?

Ans -

(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.

$$\left[\left(\frac{25}{f_e}\right)+1\right]$$

(d) The angular magnification produced by the eye piece of a compound microscope is

Where,

f_e=Focal length of the eyepiece

It can be inferred that if $f_e$is small, then angular magnification of the eye piece will be large.

The angular magnification of the objective lens of a compound microscope is given as

Where,

u_o =Object distance for the objective lens

f_o =Focal length of the objective

In the case of a microscope, the object is kept close to the objective lens. Hence, the object distance is very little. Since u_o is small, f_o will be even smaller. Therefore, f_e and f_o 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.

3. 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?

Ans -

(a) Focal length of the magnifying glass, f = 5 cm Least distance of distance vision, d = 25 cm Closes to object distance= u

Image distance, v= −d = −25 cm

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

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

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

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

According to the lens formula,we have:

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 5cm.

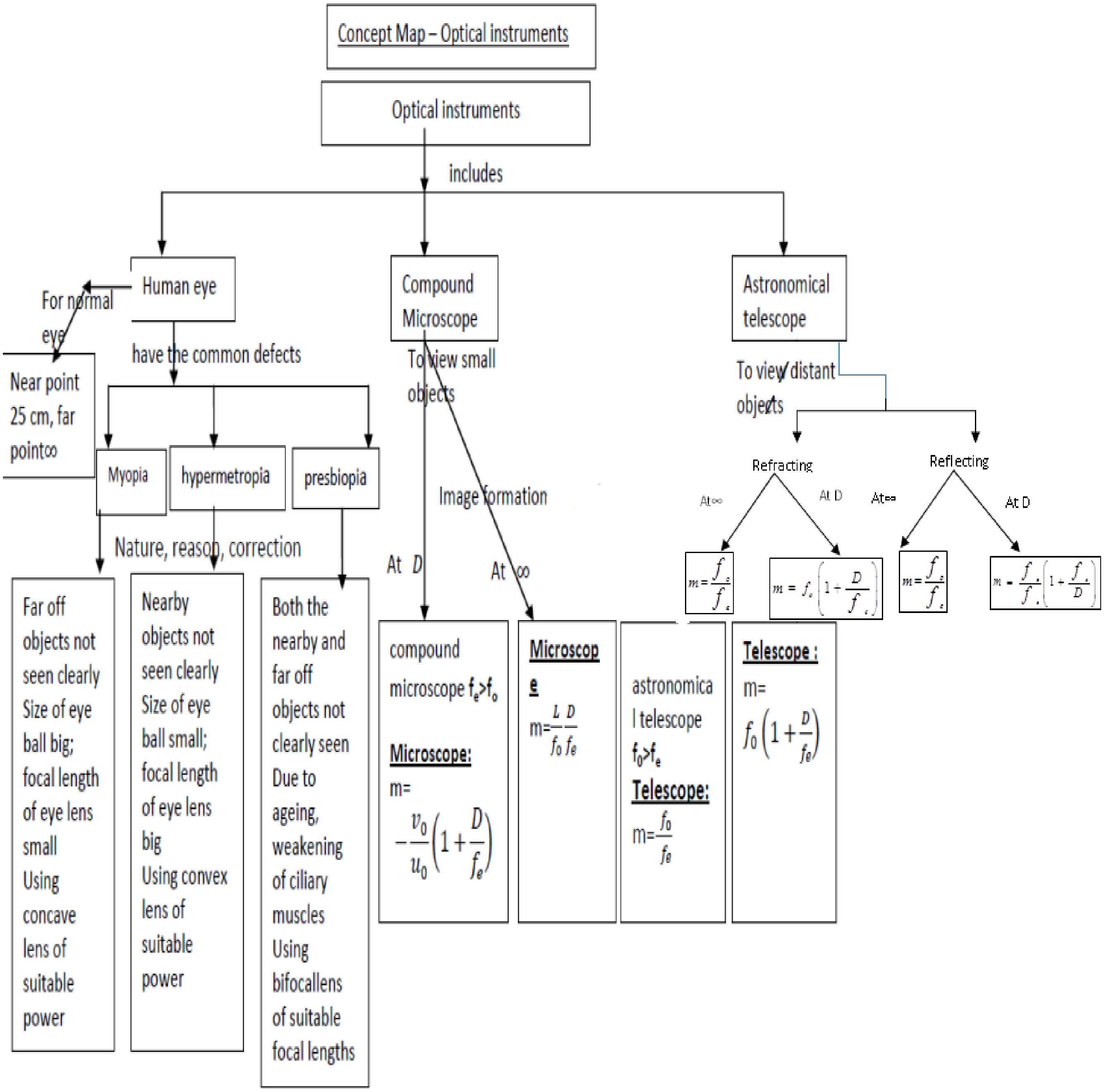
(b) Maximum angular magnification is given by the relation:

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

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

CONCEPT MAP

Optical Instruments



Wave Optics

GIST

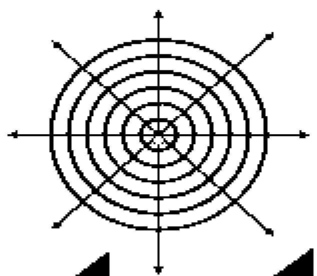
Wavefront:

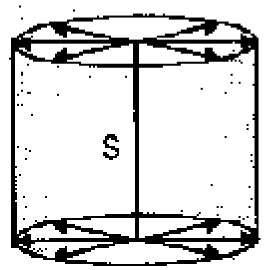
A wavelet is the point of disturbance due to propagation of light.

A wavefront is the locus of points (wavelets) having the same phase of oscillations.

A line perpendicular to a wavefront is called a 'ray'.

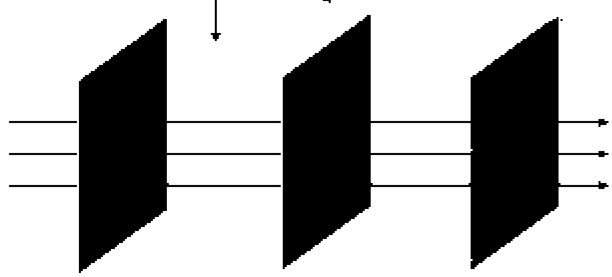
Spherical Wavefront from a



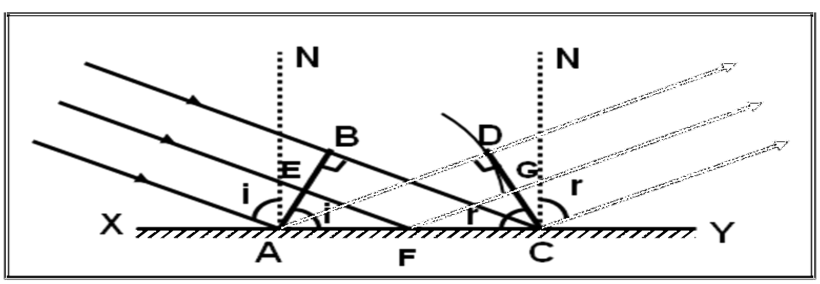


Cylindrical Wavefront from a linear source

Plane Wave front



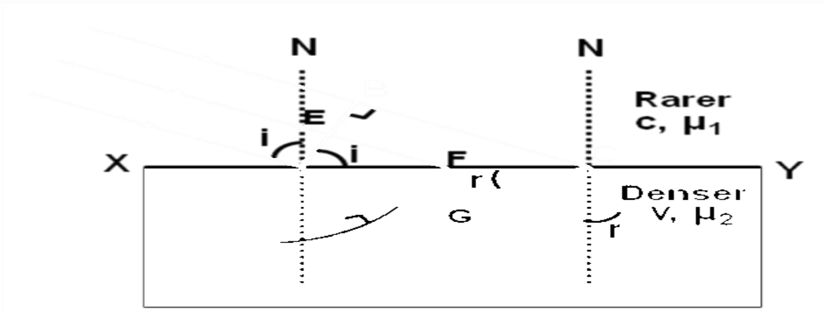
Laws of Reflection at a Plane Surface (On Huygens' Principle):



AB – Incident wavefront CD – Reflected wavefront XY – Reflecting surface

$\sin i - \sin r = 0$. i.e. $\sin i = \sin r$ or $i = r$

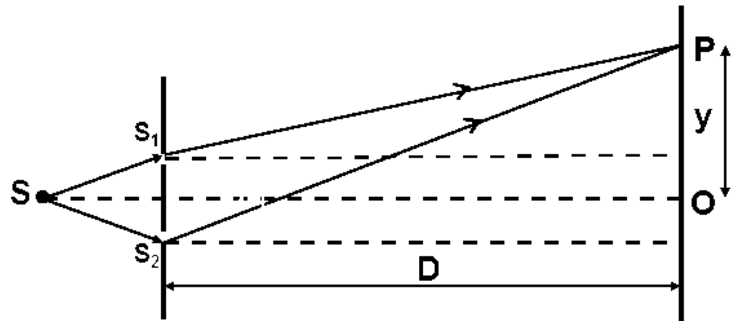
Laws of Refraction at a Plane Surface (On Huygens' Principle):



AB – Incident wavefront CD – Refracted wavefront XY – Refracting surface

$$\frac{\sin i}{c} - \frac{\sin r}{v} = 0 \quad \text{or} \quad \frac{\sin i}{c} = \frac{\sin r}{v} \quad \text{or} \quad \frac{\sin i}{\sin r} = \frac{c}{v} = \mu$$

INTERFERENCEOF WAVES



The waves from S_1 and S_2 reach the point P with some phase difference and hence path difference

$$\Delta = S_2P - S_1P$$

$$S_2P^2 - S_1P^2 = [D^2 + \{y + (d/2)\}^2] - [D^2 + \{y - (d/2)\}^2]$$

$$(S_2P - S_1P)(S_2P + S_1P) = 2\,yd \qquad \Delta\,(2D) = 2\,yd \qquad \Delta = yd / D$$

Comparison of intensities of maxima and minima:

$$\frac{I_{max}}{I_{min}} = \frac{(a+b)^2}{(a-b)^2} = \frac{(a/b+1)^2}{(a/b-1)^2}$$

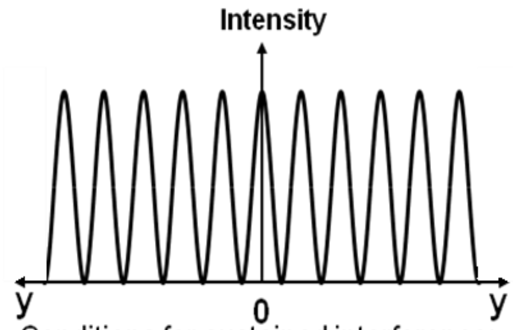
Relation between Intensity (I), Amplitude (a) of the wave and Width (w) of the slit:

$$I \propto a^2$$

$$a \propto \sqrt{w}$$

$$\boxed{\frac{I_1}{I_2} = \frac{(a_1)^2}{(a_2)^2} = \frac{w_1}{w_2}}$$

Distribution of Intensity:

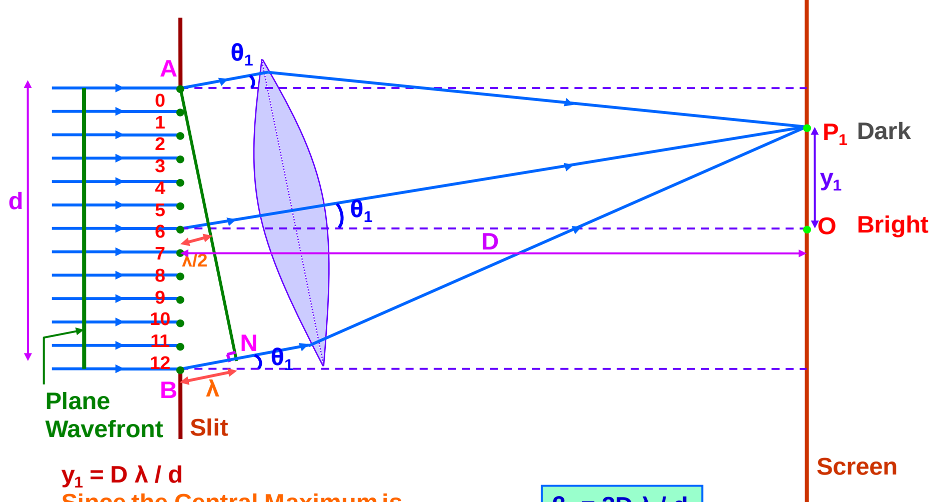


<u>Conditions for sustained interference:</u>

1. The two sources producing interference must be coherent.
2. The two interfering wave trains must have the same plane of polarisation.
3. The two sources must be very close to each other and the pattern must be observed at a larger distance to have sufficient width of the fringe. $(D \lambda / d)$
4. The sources must be monochromatic. Otherwise, the fringes of different colours will overlap.
5. The two waves must be having same amplitude for better contrast between bright and dark fringes.

<u>DIFFRACTION OF LIGHT AT A SINGLE SLIT ;</u>

Width of Central Maximum:



$y_1 = D \lambda / d$

Since the Central Maximum is spread on either side of O, the width is

$\beta_0 = 2D \lambda / d$

Fresnel's Distance:

$y_1 = D \lambda / d$

At Fresnel's distance, $y_1 = d$ and $D = D_F$

So, $D_F \lambda / d = d$ or $D_F = d^2 / \lambda$

POLARISATION OF LIGHT WAVES :

Malus' Law:

When a beam of plane polarised light is incident on an analyser, the intensity I of light transmitted from the analyser varies directly as the square of the cosine of the angle θ between the planes of transmission of analyser and polariser.

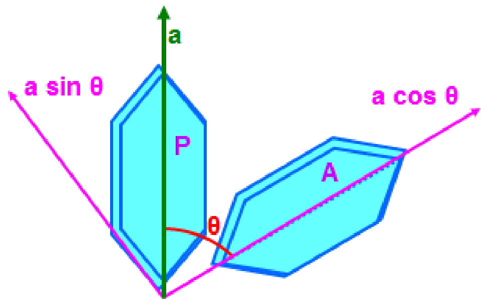
Intensity of transmitted light from the analyser is

$\boxed{I \propto \cos^2\theta}$

$I = k\,(a\cos\theta)^2$

or $I = k\,a^2\cos^2\theta$

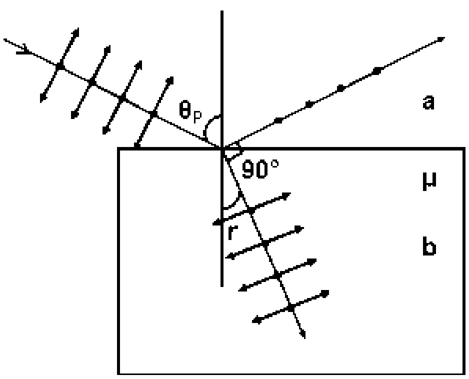
$\boxed{I = I_0\cos^2\theta}$



(where $I_0 = k\,a^2$ is the intensity of light transmitted from the polariser)

(2)

Polarisation by Reflection and Brewster's Law:



$\theta_P + r = 90°$ or $r = 90° - \theta_P$

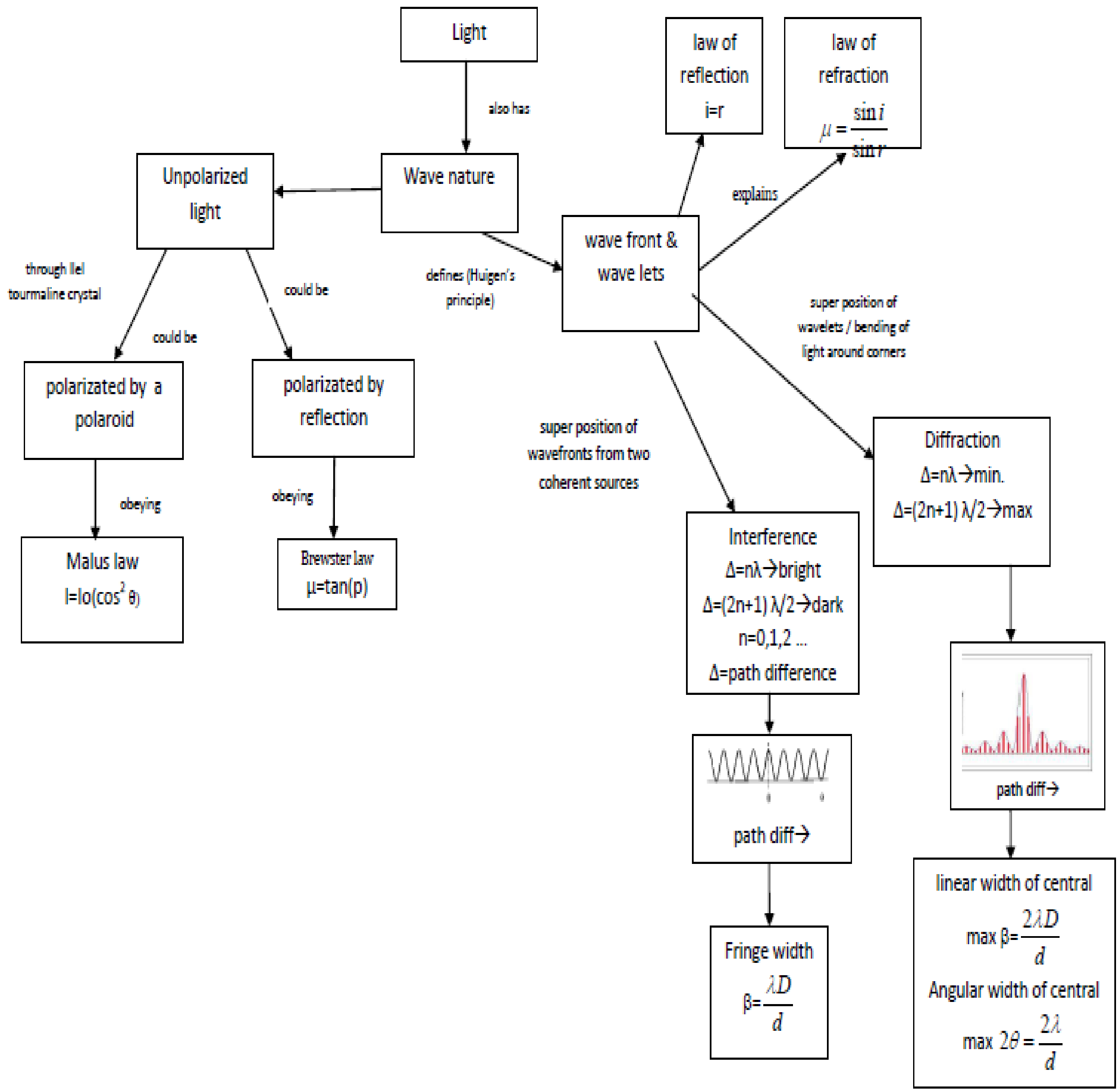
$${}_a\mu_b = \frac{\sin\theta_P}{\sin r}$$

$${}_a\mu_b = \frac{\sin\theta_P}{\sin 90° - \theta_P}$$

$$\boxed{{}_a\mu_b = \tan\theta_P}$$

CONCEPT MAP

WAVE NATURE OF LIGHT



Huygen's Principle

1. Draw a diagram to show the refraction of a plane wave front incident on a convex lens and hence draw the refracted wave front. 1

2. What type of wave front will emerge from a (i) point source, and (ii) distance light source? 1

3. Define the term wave front? Using Huygen's construction draw a figure showing the propagation of a plane wave reflecting at the interface of the two media. Show that the angle of incidence is equal to the angle of reflection. 3

4. Define the term 'wavefront'. Draw the wavefront and corresponding rays in the case of a (i) diverging spherical wave (ii) plane wave. Using Huygen's construction of a wavefront, explain the refraction of a plane wavefront at a plane surface and hence deduce Snell's law. 3

Interference

1. How does the angular separation of interference fringes change, in Young's experiment, when the distance between the slits is increased? 1
Ans-when separation between slits (d) is increased, fringe width β decreases.

2. How the angular separation of interference fringes in young would's double slit experiment change when the distance of separation between the slits and the screen is doubled? 1
Ans-No effect (or the angular separation remains the same)

*3. In double-slit experiment using light of wavelength 600 nm, the angular width of a fringe formed on adjacent screen is 0.1˚. What is the spacing between the two slits? 2
Ans- The spacing between the slits is 3.44×10^{-4} m

*4. If the path difference produced due to interference of light coming out of two slits for yellow colour of light at a point on the screen be 3λ/2, what will be the colour of the fringe at that point? Give reasons. 2
Ans. The given path difference satisfies the condition for the minimum of intensity for yellow light, Hence when yellow light is used, a dark fringe will be formed at the given point. If white light is used, all components of white light except the yellow one would be present at that point.

5. State two conditions to obtain sustained interference of light. In Young's double slit experiment, using light of wavelength 400 nm, interference fringes of width 'X' are obtained. The wavelength of light is increased to 600 nm and the separation between the slits is halved. In order to maintain same fringe with, by what distance the screen is to be moved? Find the ration of the distance of the screen in the above two cases. 3
Ans-Ratio-3:1

6. Two narrow slits are illuminated by a single monochromatic source. Name the pattern obtained on the screen. One of the slits is now completely covered. What is the name of the pattern now obtained on the screen? Draw intensity pattern obtained in the two cases. Also write two differences between the patterns obtained in the above two cases. 3

*7. In Young's double-slit experiment a monochromatic light of wavelength λ, is used. The intensity of light at a point on the screen where path difference is λ is estimated as K units. What is the intensity of light at a point where path difference is λ /3? 3
Ans-K/4

*8. A beam of light consisting of two wavelengths,650 nm and 520 nm, is used to obtain interference fringes in a Young's double-slit experiment.**(a)**Find the distance of the third bright fringe on the screen from the central maximum for wavelength 650 nm.**(b)**What is the least distance from the central maximum where the bright fringes due to both the wavelengths coincide? 3
Ans-a)

$$x = n\lambda_1\left(\frac{D}{d}\right)$$

For third bright fringe, $n = 3$

$$\therefore x = 3\times 650\frac{D}{d} = 1950\left(\frac{D}{d}\right) \text{ nm}$$

b)

$$x = n\lambda_2\frac{D}{d}$$

$$= 5\times 520\frac{D}{d} = 2600\frac{D}{d} \text{ nm}$$

*9. In a double-slit experiment the angular width of a fringe is found to be0.2° on a screen placed 1 m away. The wavelength of light used is 600 nm. What will be the angular width of the fringe if the entire experimental apparatus is immersed in water? Take refractive index of water to be 4/3. 3

Ans-

$$\mu = \frac{\theta_1}{\theta_2}$$

$$\theta_2 = \frac{3}{4}\theta_1$$

$$= \frac{3}{4}\times 0.2 = 0.15\ ^\circ$$

*10 A narrow monochromatic beam of light of intensity I is incident a glass plate. Another identical glass plate is kept close to the first one and parallel to it. Each plate reflects 25% of the incident light and transmits the reaming. Calculate the ratio of minimum and maximum intensity in the interference pattern formed by the two beams obtained after reflection from each plate. 3

Ans. Let I be the intensity of beam I incident on first glass plate. Each plate reflects 25% of light incident on it and transmits 75%.

Therefore,

I1 =I; and I2 = 25/100I = I/4;I3 =75/100 I = 3/4I;I4 = 25/100 I3 = 1⁄4 x 3⁄4 I = 3/16 I

I5= 7/100 I4= 3⁄4 x 3/16 I = 9/64 I

Amplitude ratio of beams 2 and 5 is R = √ I2/I5 = √I/4 x 64/91 = 4/3

Imin/ Imax = [r-1/r+1]2 = [4/3-1 / 4/3+1]2 = 1/49 = 1:49

*11 In a two slit experiment with monochromatic light, fringes are obtained on a screen placed at some distance D from the slits. If the screen is moved 5×10^{-2} m towards the slits, the charge in fringe width is 3×10^{-5} m. If the distance between the slit is 10^{-3} m. Calculate the wavelength of the light used.

Ans. The fringe width in the two cases will be β = Dλ/d;β ‘= D’λ/d

β - β’ = (D-D’)λ/d; or wavelength λ = (β - β’)d / (D-D’) But D-D’ = 5×10^{-2} m

β - β’ = 3×10^{-5} m , d= 10^{-3}m;λ = $3 \times 10^{-5} \times 10^{-3} / 5 \times 10^{-2} = 6 \times 10^{-7}$m= 6000A

12. Two Sources of Intensity I and 4I are used in an interference experiment. Find the intensity at points where the waves from two sources superimpose with a phase difference (i) zero (ii) π/2 (iii) π.

Ans-The resultant intensity at a point where phase difference is Φ is $I_R = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\Phi$

As I1 =I and I_2 = 4I therefore I_R = I +4I+2√1.4I Cos Φ = 5I +4I cos Φ

(i) when Φ =0 , I R = 5I +4I cos 0 = 9 I;(ii) when Φ =π/2 , I R = 5I +4I cos π/2 = 5 I

(iii) when Φ =π , I R = 5I +4I cos π = I

13. What are coherent sources of light? Two slits in Young’s double slit experiment are 5

illuminated by two different sodium lamps emitting light of the same wavelength. Why is no interference pattern observed?

(b) Obtain the condition for getting dark and bright fringes in Young's experiment. Hence write the expression for the fringe width.

(c) If S is the size of the source and its distance from the plane of the two slits, what should be the criterion for the interference fringes to be seen?

Ans-c) $\frac{S}{d} < \frac{\lambda}{a}$

14. What are coherent sources? Why are coherent sources required to produce interference of light? Give an example of interference of light in everyday life. In Young's double slit experiment, the two slits are 0.03 cm apart and the screen is placed at a distance of 1.5 m away from the slits. The distance between the central bright fringe and fourth bright fringe is 1 cm. Calculate the wavelength of light used. 5

Ans-(Numerical part)

$$\lambda = \frac{dx}{4D} = \frac{0.03\times10^{-2}\times1\times10^{-2}}{4\times1.5} = 5\times10^{-7}\text{ m}$$

15. What is interference of light? Write two essential conditions for sustained interference pattern to be produced on the screen. Draw a graph showing the variation of intensity versus the position on the screen in Young's experiment when (a) both the slits are opened and (b) one of the slit is closed. What is the effect on the interference pattern in Young's double slit experiment when: (i) Screen is moved closer to the plane of slits? (ii)Separation between two slits is increased. Explain your answer in each case. 5

Diffraction

*1. Why a coloured spectrum is seen, when we look through a muslin cloth and not in other clothes? **2**

Ans. Muslin cloth is made of very fine threads and as such fine slits are formed. White light passing through these silts gets diffracted giving rise to colored spectrum. The central maximum is white while the secondary maxima are coloured. This is because the positions of secondary maxima (except central maximum) depend on the wavelength of light. In a coarse cloth, the slits formed between the threads are wider and the diffraction is not so pronounced. Hence no such spectrum is seen.

2. A parallel beam of light of wavelength 600 nm is incident normally on a slit of width 'a'. If the distance between the slits and the screen is 0.8 m and the distance of 2nd order maximum from the centre of the screen is 15 mm, calculate the width of the slit. **2**

Ans-Difference between interference and diffraction: Interference is due to superposition of two distinct waves coming from two coherent sources. Diffraction is due to superposition of the secondary wavelets generated from different parts of the same wavefront.

Numerical: Here, λ = 600 nm = 600 × 10−19 = 6 × 10−7 m

D = 0.8 m, x = 15 mm = 1.5 × 10−3 m,n = 2, a = ?

$$\because a\frac{x}{D} = n\lambda$$

$$a = \frac{n\lambda D}{x} = \frac{2\times6\times10^{-7}\times0.8}{1.5\times10^{-3}}$$

$$= \frac{9.6\times10^{-4}}{1.5} = 6.4\times10^{-4}\text{ mm}$$

3. Answer the following questions: **2**

(a) How does the size and intensity of the central maxima changes when the width of the slit is double in a single slit diffraction experiment?

(b) In what way is diffraction from each slit related to the interference pattern in a double-slit experiment?

(c) When a tiny circular obstacle is placed in the path of light from a distant source,a bright spot is seen at the centre of the shadow of the obstacle. Explain why?

(d) Two students are separated by a 7 m partition wall ina room 10 mhigh. If both light and sound waves can bend around obstacles, how is it that the students are unable to see each other even though they can converse easily?

Ans-

(a) In a single slit diffraction experiment, if the width of the slit is made double the original width, then the size of the central diffraction band reduces to half and the intensity of the central diffraction band increases up to four times.

(b) The interference pattern in a double-slit experiment is modulated by diffraction from each slit. The pattern is the result of the interference of the diffracted wave from each slit.

(c) When a tiny circular obstacle is placed in the path of light from a distant source, a bright spot is seen at the centre of the shadow of the obstacle. This is because light waves are diffracted from the edge of the circular obstacle, which interferes constructively at the centre of the shadow. This constructive interference produces a bright spot.

(d) Bending of waves by obstacles by a large angle is possible when the size of the obstacle is comparable to the wavelength of the waves.

On the one hand, the wavelength of the light waves is too small in comparison to the size of the obstacle. Thus, the diffraction angle will be very small. Hence, the students are unable to see each other. On the other hand, the size of the wall is comparable to the wavelength of the sound waves. Thus, the bending of the waves takes place at a large angle. Hence, the students are able to hear each other.

4. Why light ways do not diffracted around buildings, while radio waves diffract easily? **2**

Ans- For diffraction to take place the wave length should be of the order of the size of the obstacle. The radio waves (particularly short radio waves) have wave length of the order of the size of the building and other obstacles coming in their way and hence they easily get diffracted. Since wavelength of the light waves is very small, they are not diffracted by the buildings.

5. Draw the diagram showing intensity distribution of light on the screen for diffraction of light at a single slit. How is the width of central maxima affected on increasing the (i) Wavelength of light used (ii) width of the slit? What happens to the width of the central maxima if the whole apparatus is immersed in water and why? **3**

6. State the condition under which the phenomenon of diffraction of light takes place. Derive an expression for the width of central maximum due to diffraction of light at a single slit. A slit of width ‘a’ is illuminated by a monochromatic light of wavelength 700 nm at normal incidence. Calculate the value of ‘a’ for position of **5**

* (i) first minimum at an angle of diffraction of 30°

(ii) first maximum at an angle of diffraction of 30°

Ans-i) $$a = \frac{\lambda}{\sin\theta} = \frac{700}{\sin 30} = 1400\,\text{nm}$$

ii) $$a = \frac{3\lambda}{2\sin\theta} = \frac{3\times 700}{2\times\sin 30} = 2100\,\text{nm}$$

Polarisation

1. At what angle of incidence should a light beam strike a glass slab of refractive index √3, such that the reflected and the refracted rays are perpendicular to each other? 1

Ans-i=60^0

*2. What does the statement, “natural light emitted from the sun is unpolarised” mean in terms of the direction of electric vector? Explain briefly how plane polarized light can be produced by reflection at the interface separating the two media. 2

Ans-The statement “natural light emitted from the sun is unpolarised” means that the natural light coming from sun is a mixture of waves, each having its electric vectors directed in random direction. When light falls on the interface separating two media, electrons start oscillating, which produces reflected ray in addition to refracted ray. As light is a transverse wave, therefore, oscillation in the transverse direction will produce a light wave. Parallel oscillations will not contribute to the light wave. When a light ray strikes an interface, the component of electric vector, which is parallel to the interface, gets reflected. Therefore, the reflected light wave is plane polarised light.

3. What is an unpolarized light? Explain with the help of suitable ray diagram how an unpolarized light can be polarized by reflection from a transparent medium. Write the expression for Brewster angle in terms of the refractive index of denser medium. 3

4. The critical angle between a given transparent medium and air is denoted by i_c, A ray of light in air medium enters this transparent medium at an angle of incidence equal to the polarizing angle(i_p). Deduce a relation for the angle of refraction (r_p) in terms of i_c. 3

5 What is meant by 'polarization' of a wave? How does this phenomenon help us to decide whether a given wave is transverse or longitudinal in nature? 5

QUESTIONS (HOTS)

VERY SHORT ANSWER QUESTIONS (1 MARK)

1. Air bubble is formed inside water. Does it act as converging lens or a diverging lens? 1
   Ans : [Diverging lens]
2. A water tank is 4 meter deep. A candle flame is kept 6 meter above the level. μ for water is $4/3$. Where will the image of the candle be formed?. Ans : [6m below the water level] 1

SHORTANSWER QUESTIONS (2 MARKS)

1. Water is poured into a concave mirror of radius of curvature 'R' up to a height h as shown in figure 1. What should be the value of x so that the image of object 'O' is formed on itself? 2

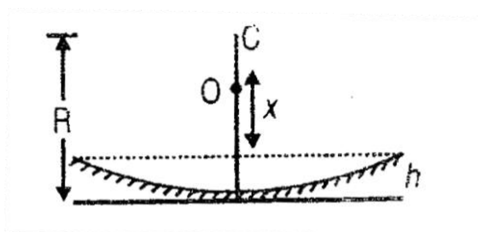
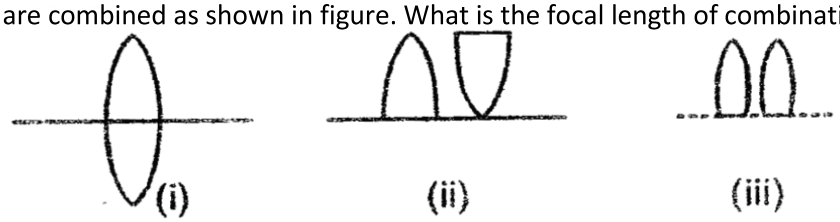


Fig 1

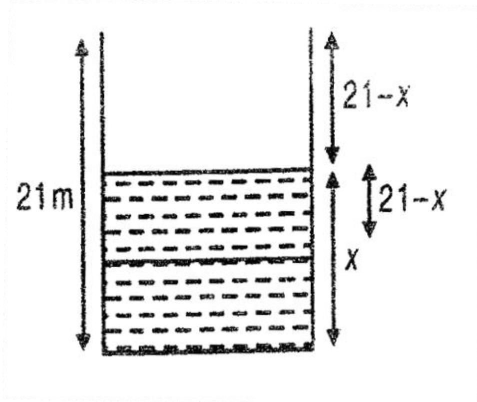
Fig 2

2. A point source S is placed midway between two concave mirrors having equal focal length f as shown in Figure 2. Find the value of d for which only one image is formed. 2

3. A thin double convex lens of focal length f is broken into two equals halves at the axis. The two halves are combined as shown in figure. What is the focal length of combination in (ii) and (iii).



2

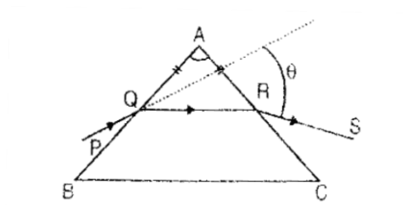


$$\frac{\text{Real depth}}{\text{Apparent depth}} = \mu$$

$$\frac{x}{21-x} = \frac{4}{3} \quad \Rightarrow \quad x = 12 \text{ cm.}$$

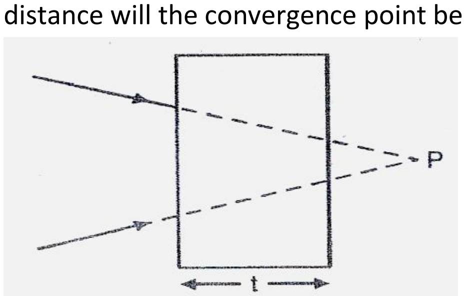
4. How much water should be filled in a container 21cm in height, so that it appears half filled when viewed from the top of the container $\left({}^{a}\mu_{\omega} = 4/3 \right)$? 2

5. A ray PQ incident on the refracting face BA is refracted in the prism BAC as shown in figure and emerges from the other refracting face AC as RS such that AQ= AR. If the angle, of prism A= $60°$ and μ of material of prism is $\sqrt{3}$ then find angle θ. 2
   Hint : This a case of min .deviation $\theta = 60°$



SHORT ANSWER QUESTIONS (3 MARKS)

1. A converging beam of light is intercepted by a slab of thickness t and refractive index μ. By what distance will the convergence point be shifted? Illustrate the answer. 3



$$X = \left(1 - \frac{1}{\mu}\right)t$$

2. In double slit experiment SS_2 is greater than SS_1 by 0.25λ. calculate the path difference between two interfering beam from S_1 and S_2 for maxima on the point P as shown in Figure. 3