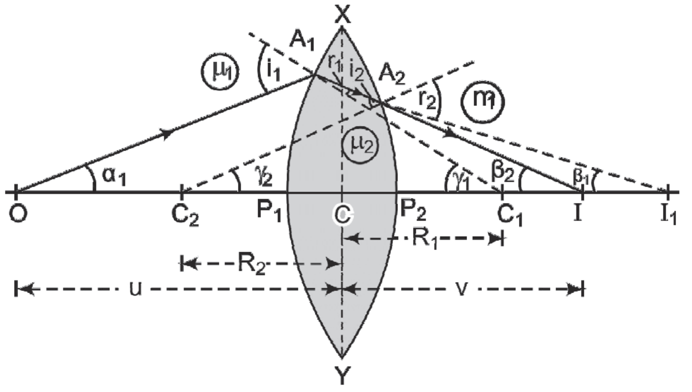
Ray Optics and Optical Instruments

Case Study Based Questions

Case Study 1

The lens maker's formula relates the focal length of a lens to the refractive index of its material and the radii of curvature of its two surfaces. This formula is used to manufacture a lens of particular focal length from the glass of a given refractive index. For this reason, it is called the lens maker's formula.



Read the given passage carefully and give the answer of the following questions:

Q1. For a plano-convex lens of radius of curvature 10 cm, the focal length is 30 cm, the refractive index of the material of the lens is:

a. 2.0 b. 1.33

c. 1.66 d. 1.5

Q2. A convex lens of focal length 20 cm is placed in contact with a diverging lens of unknown focal length. The lens combination acts as a converging lens and has a focal length of 30 cm. What is the focal length of diverging lens:

a. -90 cm b. -60 cm

c. -30 cm d. –10 cm

Q3. A biconvex lens has the same radius of curvature R for its faces. If the focal length of the lens in air is R/2, the refractive index of the material of the lens is:

a. 1.2 b. 1.33

c. $\sqrt{2}$ d. 2

Q4. Two thin lenses of focal length 60 cm and -20 cm in contact have a resultant focal length of:

a. -30 cm

b. +15 cm

c. -15 cm

d. +30 cm

Solutions

1. (b) 1.33

From formula, $\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$

Since, $R_2 \to \infty$

$$R_1 = 10 \text{ cm}, \; f = 30 \text{ cm}$$

$$\therefore \quad \frac{1}{30} = (\mu - 1)\left(\frac{1}{10} - \frac{1}{\infty}\right)$$

$$\Rightarrow \quad \mu = \frac{4}{3} = 1.33$$

2. (b) –60 cm

From formula,

$$\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2} \Rightarrow \frac{1}{30} = \frac{1}{20} + \frac{1}{f_2}$$

$$\Rightarrow \quad f_2 = -60 \text{ cm}$$

3. (d) 2

By the lens maker's formula,

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

For biconvex lens, R_1 is positive and R_2 is negative.

Now, $$\frac{1}{R/2} = (\mu - 1)\left(\frac{1}{R_1} + \frac{1}{R_1}\right) \qquad (\because R_1 = R_2 = R)$$

$$\Rightarrow \quad \frac{2}{R} = (\mu - 1)\left(\frac{1}{R} + \frac{1}{R}\right) \Rightarrow \mu = 2.$$

4. (a) -30 cm

From formula,

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

$$=\frac{1}{60}-\frac{1}{20}=\frac{-2}{60}\Rightarrow f=-30\,\text{cm}$$

Case Study 2

A convex or converging lens is thicker at the centre than at the edges. It converges a beam of light on refraction through it. It has a real focus. Convex lens is of three types: Double convex lens, Plano convex lens and Concavo-convex lens.

Concave lens is thinner at the centre than at the edges. It diverges a beam of light on refraction through it. It has a virtual focus. Concave lenses are of three types: Double concave lens, Plano concave lens and Convexo-concave lens.

When two thin lenses of focal lengths f_1 and f_2 are placed in contact with each other along their common principal axis, then the two lens system is regarded as a single lens of focal length f and

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

If several thin lenses of focal length f_1, f_2... f_n are placed in contact, then the effective focal length of the combination is given by

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

and in terms of power, we can write

$$P=P_1+P_2+\ldots.+P_n$$

The value of focal length and power of a lens must be used with proper sign consideration. (CBSE SQP 2023-24)

Read the given passage carefully and give the answer of the following questions:

Q1. Two thin lenses are kept coaxially in contact with each other and the focal length of the combination is 80 cm. If the focal length of one lens is 20 cm, the focal length of the other would be:

a. -26.7 cm
b. 60 cm
c. 80 cm
d. 30 cm

Q2. A spherical air bubble is embedded in a piece of glass. For a ray of light passing through the bubble, it behaves like a:

a. converging lens

b. diverging lens

c. mirror

d. thin plane sheet of glass

Q3. Lens generally used in magnifying glass is:

a. single concave lens

b. single convex lens

c. combination of convex lens of lower power and concave lens of lower focal length

d. planoconcave lens

Q4. The magnification of an image by a convex lens is positive only when the object is placed:

a. at its focus F

b. between F and 2 F

c. at 2 F

d. between F an optical centre

Or

A convex lens of 20 cm focal length forms a real image which is three times magnified. The distance of the object from the lens is:

a. 13.33 cm

b. 14 cm

c. 26.66 cm

d. 25 cm

Solutions

1. (a) We know that,

focal length of combination,

$$\frac{1}{f}=\frac{1}{f_1}+\frac{1}{f_2} \Rightarrow \frac{1}{80}=\frac{1}{20}+\frac{1}{f_2}$$

$$f_2=-\frac{80}{3}\text{cm}=-26.7\text{cm}$$

2. (b) diverging lens

3. (b) single convex lens

4. (d) between F and optical centre

Or

For real image

Given m = -3

$$\because\ m = -\frac{v}{u}$$

$$\therefore\ \frac{v}{u} = -3$$

by lens formula,

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

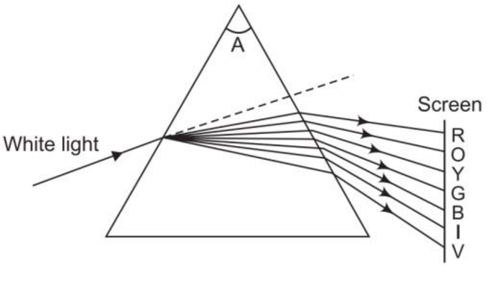
$$\frac{1}{20} = \frac{-1}{3u} - \frac{1}{u}$$

$$\frac{1}{20} = \frac{-4}{3u}$$

$$u = \frac{-4 \times 20}{3} = \frac{-80}{3} = 26.66\text{cm}$$

Case Study 3

If a beam of white light is made to fall on one face of prism, the light emerging from the other face of the prism consist of seven colours violet, indigo, blue, green, yellow, orange, red. The phenomena of splitting of white light into its constituent colours is called dispersion of light.



Read the given passage carefully and give the answer of the following questions:

Q1. Which one of the following colours will suffer greatest dispersion?

a. Violet　　b. Indigo

c. Blue　　d. Red

Q2. The critical angle between an equilateral prism and air is 45°. If the incident ray is perpendicular to refracting surface, then:

a. it is reflected totally from the second surface and emerges perpendicular from the third surface.

b. it gets reflected from second and third surface and emerges from the first surface.

c. it keeps reflecting from all the three side of the prism and never emerges out.

d. after deviation, it gets refracted from the second surface.

Q3. A prism with a refracting angle of 60° gives angle of minimum deviation 53°, 51°, 52° for blue, yellow, red light respectively. What is the dispersive power of the material of the prism?

a. 385 b. 0.385

c. 0.0385 d. 38.5

Q4. The refractive angle of a prism for a monochromatic light is 60° and refractive index is $\sqrt{2}$. For minimum deviation the angle of incidence will be:

a. 60° b. 45°

c. 30° d. 75°

Solutions

1. (a) Violet

Less is the wavelength; more is the dispersion.

2. (b) it gets reflected from second and third surface and emerges from the first surface.

3. (c) 0.0385,

$$\text{Dispersive power} = \frac{\delta_b - \delta_r}{\delta_y} = \frac{53-51}{52} = \frac{1}{26} = 0.0385$$

4. (b) 45°,
Given, $A = 60°$, $\mu = \sqrt{2}$

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

$$\Rightarrow \quad \sqrt{2} = \frac{\sin\left(\frac{60^\circ+\delta_m}{2}\right)}{\sin\frac{60^\circ}{2}}$$

$$\Rightarrow \quad \sin\left(\frac{60^\circ+\delta_m}{2}\right) = \frac{1}{\sqrt{2}}$$

$$\Rightarrow \quad \frac{60^\circ+\delta_m}{2} = 45^\circ$$

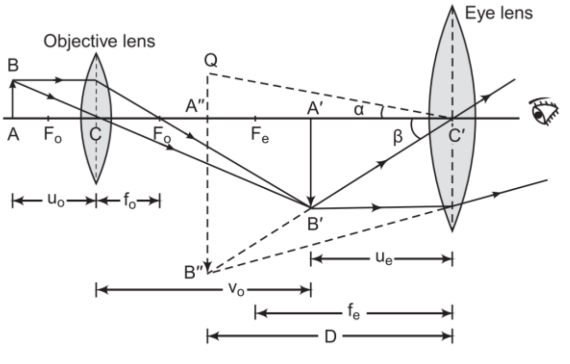
$$\delta_m = 90^\circ - 60^\circ = 30^\circ \quad \text{and} \quad \delta_m = 2i - A$$

$$30^\circ = 2i - 60^\circ$$

$$i = 45^\circ$$

Case Study 4

A compound microscope consists of two lenses. A lens of short aperture and short focal length facing the object is called the objective lens and another lens of short focal length but large aperture is called the eye lens. Magnifying power is defined as the ratio of angle subtended by the final image at the eye to the angle subtended by the object is seen directly, when both are placed at least distance of distinct vision.



Read the given passage carefully and give the answer of the following questions:

Q1. An objective lens consists of:

a. short aperture and short focal length

b. large aperture and large focal length

c. short aperture and large focal length

d. large aperture and short focal length

Q2. An eyepiece consists of:

a. short aperture and short focal length

b. large aperture and large focal length

c. short aperture and large focal length

d. large aperture and short focal length

Q3. A compound microscope with an objective of focal length 1.0 cm and eyepiece of focal length 2.0 cm. Focal length of a tube is 20 cm. Calculate the magnifying power of the microscope.

a. 270 b. 27

c. 140 d. 14

Q4. Final image formed by compound microscope is:

a. inverted b. erect

c. virtual d. highly diminished

Solutions

1. (a) short aperture and short focal length

2. (d) large aperture and short focal length

3. (a) 270,

Magnifying power, $m = \frac{L}{f_o}\left(1+\frac{D}{F_e}\right) = \frac{20}{1.0}\left(1+\frac{25}{2.0}\right) = 270$

4. (a) inverted,

A compound microscope form inverted image the object is within its focal length.

Case Study 5

Refraction of light is the change in the path of light as it passes obliquely from one transparent medium to another medium. According to law of refraction $\frac{\sin i}{\sin r} = {}_1\mu_2$, where ${}_1\mu_2$ is called refractive index of second medium with respect to first medium. From refraction at a convex spherical surface, we have $\frac{\mu_2}{v} - \frac{\mu_1}{u} = \frac{\mu_2 - \mu_1}{R}$.

Similarly, from refraction at a concave spherical surface when object lies in the rarer medium, we have $\frac{\mu_2}{v} - \frac{\mu_1}{u} = \frac{\mu_2 - \mu_1}{R}$ and when object lies in the denser medium, we have $\frac{\mu_1}{v} - \frac{\mu_2}{u} = \frac{\mu_1 - \mu_2}{R}$.

Read the given passage carefully and give the answer of the following questions:

Q1. Refractive index of a medium depend upon which factors?

Q2. A ray of light of frequency 5×10^{14} Hz is passed through a liquid. The wavelength of light measured inside the liquid is found to be 450×10^{-9} m. What is the refractive index of the liquid?

Q3. A ray of light is incident at an angle of 60° on one face of a rectangular glass slab of refractive index 1.5. What will be the angle of refraction?

Q4. When light is refracted into a medium, what will be change in its wavelength and frequency?

Solutions

1. Refractive index of a medium depends upon nature and temperature of the medium and wavelength of light.

2. Given, $\nu = 5 \times 10^{14}$ Hz; $\lambda = 450 \times 10^{-9}$ m,
$c = 3 \times 10^8$ ms^{-1}

Refractive index of the liquid,

$$\mu = \frac{c}{v} = \frac{c}{\nu\lambda} = \frac{3 \times 10^8}{5 \times 10^{14} \times 450 \times 10^{-9}} = 1.33$$

3. Given,

$i = 60°$, $\mu = 1.5$

By Snell's law,

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

$$\sin r = \frac{\sin i}{\mu} = \frac{\sin 60°}{1.5} = \frac{0.866}{1.5}$$

$\sin r = 0.5773$ or $r = \sin^{-1}(0.58)$

4. Its wavelength increases but frequency remains unchanged.

Case Study 6

A number of optical devices and instruments have been designed and developed such as periscope, binoculars, microscopes and telescopes utilising the reflecting and refracting properties of mirrors, lenses and prisms. Most of them are in common use. Our knowledge about the formation of images by the mirrors and lenses is the basic requirement for understanding the working of these devices. (CBSE SQP 2022-23)

Q1. Why the image formed at infinity is often considered most suitable for viewing? Explain.

Q2. In modern microscopes, multi-component lenses are used for both the objective and the eyepiece. Why?

Q3. Write two points of difference between a compound microscope and an astronomical telescope.

Or

Write two distinct advantages of a reflecting type telescope over a refracting type telescope.

Solutions

1. When the image is formed at infinity, we can see it with minimum strain in the ciliary muscles of the eye.

2. The multi-component lenses are used for both objective and the eyepiece to improve image quality by minimising various optical aberrations in lenses.

3. Difference between a compound microscope and astronomical telescope are given below:

(i) The compound microscope is used to observe minute nearby objects whereas the astronomical telescope is used to observe distant objects.

(ii) In compound microscope, the focal length of the objective is lesser than that of the eyepiece whereas in astronomical telescope, the focal length of the objective is larger than that of the eyepiece.

Or

Two advantages of a reflecting type telescope over a refracting type telescope are given below:

(i) The image formed by reflecting type telescope is brighter than that formed by refracting telescope.

(ii) The image formed by the reflecting type telescope is more magnified than that formed by the refracting type telescope.

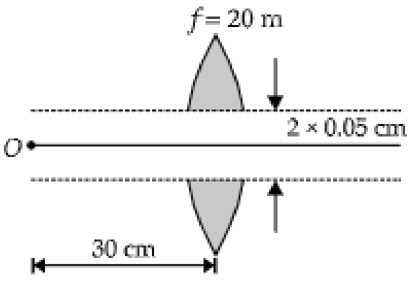
Solutions for Questions 7 to 16 are Given Below

Case Study 7

Refraction Through Lens

A convex or converging lens is thicker at the centre than at the edges. It converges a parallel beam of light on refraction through it. It has a real focus. Convex lens is of three types : (i) Double convex lens (ii) Plano-convex lens (iii) Concavo-convex lens. Concave lens is thinner at the centre than at the edges. It diverges a parallel beam of light on refraction through it. It has a virtual focus.

(i) A point object O is placed at a distance of 0.3 m from a convex lens (focal length 0.2 m) cut into two halves each of which is displaced by 0.0005 m as shown in figure.



What will be the location of the image?

(a) 30 cm right of lens
(b) 60 cm right of lens
(c) 70 cm left of lens
(d) 40 cm left of lens

(ii) Two thin lenses are in contact and the focal length of the combination is 80 cm. If the focal length of one lens is 20 cm, the focal length of the other would be.

(a) –26.7 cm
(b) 60 cm
(c) 80 cm
(d) 20 cm

(iii) A spherical air bubble is embedded in a piece of glass. For a ray of light passing through the bubble, it behaves like a

(a) converging lens
(b) diverging lens
(c) plano-converging lens
(d) plano-diverging lens

(iv) Lens used in magnifying glass is

(a) Concave lens (b) Convex lens (c) Both (a) and (b) (d) None of the above

(v) The magnification of an image by a convex lens is positive only when the object is placed

(a) at its focus F (b) between F and $2F$

(c) at $2F$ (d) between F and optical centre

Case Study 8

Power of a Lens

Power (P) of a lens is given by reciprocal of focal length (f) of the lens *i.e.*, $P = \frac{1}{f}$, where f is in metre and P is in dioptre. For a convex lens, power is positive and for a concave lens, power is negative. When a number of thin lenses of powers P_1, P_2, P_3, ... are held in contact with one another, the power of the combination is given by algebraic sum of the powers of all the lenses *i.e.*, $P = P_1 + P_2 + P_3 + \ldots$.

(i) A convex and a concave lens separated by distance d are then put in contact. The focal length of the combination

(a) becomes 0 (b) remains the same (c) decreases (d) increases.

(ii) If two lenses of power +1.5 D and +1.0 D are placed in contact, then the effective power of combination will be

(a) 2.5 D (b) 1.5 D (c) 0.5 D (d) 3.25 D

(iii) If the power of a lens is +5 dioptre, what is the focal length of the lens ?

(a) 10 cm (b) 20 cm (c) 15 cm (d) 5 cm

(iv) Two thin lenses of focal lengths +10 cm and –5 cm are kept in contact. The power of the combination is

(a) –10 D (b) –20 D (c) 10 D (d) 15 D

(v) A convex lens of focal length 25 cm is placed coaxially in contact with a concave lens of focal length 20 cm. The system will be

(a) converging in nature (b) diverging in nature

(c) can be converging or diverging (d) None of the above

Case Study 9

Total Internal Refraction

Total internal reflection is the phenomenon of reflection of light into denser medium at the interface of denser medium with a rarer medium. For this phenomenon to occur necessary condition is that light must travel from denser to rarer and angle of incidence in denser medium must be greater than critical angle (C) for the pair of media in contact. Critical angle depends on nature of medium and wavelength of light. We can show that $\mu = \frac{1}{\sin C}$.

(i) Critical angle for glass air interface, where μ of glass is $\frac{3}{2}$, is

(a) 41.8° (b) 60° (c) 30° (d) 15°

(ii) Critical angle for water air interface is 48.6°. What is the refractive index of water?

(a) 1 (b) $\frac{3}{2}$ (c) $\frac{4}{3}$ (d) $\frac{3}{4}$

(iii) Critical angle for air water interface for violet colour is 49°. Its value for red colour would be

(a) 49° (b) 50° (c) 48° (d) cannot say

(iv) Which of the following is not due to total internal reflection?

(a) Working of optical fibre.

(b) Difference between apparent and real depth of a pond.

(c) Mirage on hot summer days.

(d) Brilliance of diamond.

(v) Critical angle of glass is θ_1 and that of water is θ_2. The critical angle for water and glass surface would be ($\mu_g = 3/2$, $\mu_w = 4/3$).

(a) less than θ_2 (b) between θ_1 and θ_2 (c) greater than θ_2 (d) less than θ_1

Case Study 10

Variation in Focal Length

The lens maker's formula is a relation that connects focal length of a lens to radii of curvature of two surfaces of the lens and refractive index of the material of the lens. It is $\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$, where μ is refractive index of lens material w.r.t. the medium in which lens is held. As $\mu_v > \mu_r$, therefore, $f_r > f_v$. Mean focal length of lens for yellow colour is $f = \sqrt{f_r \times f_v}$.

(i) Focal length of a equiconvex lens of glass $\mu = \frac{3}{2}$ in air is 20 cm. The radius of curvature of each surface is

(a) 10 cm (b) –10 cm (c) 20 cm (d) –20 cm

(ii) A substance is behaving as convex lens in air and concave in water, then its refractive index is

(a) greater than air but less than water (b) greater than both air and water

(c) smaller than air (d) almost equal to water

(iii) For a thin lens with radii of curvatures R_1 and R_2, refractive index n and focal length f, the factor $\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$ is equal to

(a) $\frac{1}{f(n-1)}$ (b) $f(n-1)$ (c) $\frac{(n-1)}{f}$ (d) $\frac{n}{f(n-1)}$

(iv) A given convex lens of glass $\left(\mu = \frac{3}{2}\right)$ can behave as concave when it is held in a medium of μ equal to

(a) 1 (b) $\frac{3}{2}$ (c) $\frac{2}{3}$ (d) $\frac{7}{4}$

(v) The radii of curvature of the surfaces of a double convex lens are 20 cm and 40 cm respectively, and its focal length is 20 cm. What is the refractive index of the material of the lens?

(a) $\frac{5}{2}$ (b) $\frac{4}{3}$ (c) $\frac{5}{3}$ (d) $\frac{4}{5}$

Case Study 11

Astronomical Telescope

An astronomical telescope is an optical instrument which is used for observing distinct images of heavenly bodies libe stars, planets etc. It consists of two lenses. In normal adjustment of telescope, the final image is formed at infinity. Magnifying power of an astronomical telescope in normal adjustment is defined as the ratio of the angle subtended at the eye by the angle subtended at the eye by the final image to the angle subtended at the eye, by the object directly, when the final image and the object both lie at infinite distance from the eye. It is given by, $m = \frac{f_0}{f_e}$. To increase magnifying power of an astronomical telescope in normal adjustment, focal length of objective lens should be large and focal length of eye lens should be small.

(i) An astronomical telescope of magnifying power 7 consists of the two thin lenses 40 cm apart, in normal adjustment. The focal lengths of the lenses are

(a) 5 cm, 35 cm (b) 7 cm, 35 cm (c) 17 cm, 35 cm (d) 5 cm, 30 cm

(ii) An astronomical telescope has a magnifying power of 10. In normal adjustment, distance between the objective and eye piece is 22 cm. The focal length of objective lens is

(a) 25 cm (b) 10 cm (c) 15 cm (d) 20 cm

(iii) In astronomical telescope compare to eye piece, objective lens has

(a) negative focal length (b) zero focal length (c) small focal length (d) large focal length

(iv) To see stars, use

(a) simple microscope (b) compound microscope

(c) endoscope (d) astronomical telescope

(v) For large magnifying power of astronomical telescope

(a) $f_o << f_e$ (b) $f_o = f_e$ (c) $f_o >> f_e$ (d) none of these

Case Study 12

Refraction Through Spherical Surfaces

Refraction of light is the change in the path of light as it passes obliquely from one transparent medium to another medium. According to law of refraction $\frac{\sin i}{\sin r} = {}^1\mu_2$, where ${}^1\mu_2$ is called refractive index of second medium with respect to first medium. From refraction at a convex spherical surface, we have $\frac{\mu_2}{v} - \frac{\mu_1}{u} = \frac{\mu_2 - \mu_1}{R}$. Similarly from refraction at a concave spherical surface when object lies in the rarer medium, we have $\frac{\mu_2}{v} - \frac{\mu_1}{u} = \frac{\mu_2 - \mu_1}{R}$ and when object lies in the denser medium, we have $\frac{\mu_1}{v} - \frac{\mu_2}{u} = \frac{\mu_1 - \mu_2}{R}$.

(i) Refractive index of a medium depends upon

(a) nature of the medium (b) wavelength of the light used

(c) temperature (d) all of these

(ii) A ray of light of frequency 5×10^{14} Hz is passed through a liquid. The wavelength of light measured inside the liquid is found to be 450×10^{-9} m. The refractive index of the liquid is

(a) 1.33 (b) 2.52 (c) 2.22 (d) 0.75

(iii) A ray of light is incident at an angle of 60° on one face of a rectangular glass slab of refractive index 1.5. The angle of refraction is

(a) $\sin^{-1}(0.95)$ (b) $\sin^{-1}(0.58)$ (c) $\sin^{-1}(0.79)$ (d) $\sin^{-1}(0.86)$

(iv) A point object is placed at the centre of a glass sphere of radius 6 cm and refractive index 1.5. The distance of the virtual image from the surface of sphere is

(a) 2 cm (b) 4 cm (c) 6 cm (d) 12 cm

(v) In refraction, light waves are bent on passing from one medium to the second medium because in the second medium

(a) the frequency is different (b) the co-efficient of elasticity is different

(c) the speed is different (d) the amplitude is smaller.

Case Study 13

Compound Microscope

A compound microscope is an optical instrument used for observing highly magnified images of tiny objects. Magnifying power of a compound microscope is defined as the ratio of the angle subtended at the eye by the final image to the angle subtended at the eye by the object, when both the final image and the object are situated at the least distance of distinct vision from the eye. It can be given that : $m = m_e \times m_o$, where m_e is magnification produced by eye lens and m_o is magnification produced by objective lens.

Consider a compound microscope that 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.

(i) The object distance for eye-piece, so that final image is formed at the least distance of distinct vision, will be

(a) 3.45 cm (b) 5 cm (c) 1.29 cm (d) 2.59 cm

(ii) How far from the objective should an object be placed in order to obtain the condition described in part(i)?

(a) 4.5 cm (b) 2.5 cm (c) 1.5 cm (d) 3.0 cm

(iii) What is the magnifying power of the microscope in case of least distinct vision?

(a) 20 (b) 30 (c) 40 (d) 10

(iv) The intermediate image formed by the objective of a compound microscope is

(a) real, inverted and magnified (b) real, erect, and magnified

(c) virtual, erect and magnified (d) virtual, inverted and magnified

(v) The magnifying power of a compound microscope increases with

(a) the focal length of objective lens is increased and that of eye lens is decreased

(b) the focal length of eye lens is increased and that of objective lens is decreased

(c) focal lengths of both objects and eye-piece are increased

(d) focal lengths of both objects and eye-piece are decreased.

Case Study 14

Lens Maker's Formula

The lens maker's formula relates the focal length of a lens to the refractive index of the lens material and the radii of curvature of its two surfaces. This formula is called so because it is used by manufacturers to design lenses of required focal length from a glass of given refractive index.
If the object is placed at infinity, the image will be formed at focus for both double convex lens and double concave lens.

Therefore, lens maker's formula is, $\frac{1}{f}=\left[\frac{\mu_2-\mu_1}{\mu_1}\right]\left[\frac{1}{R_1}-\frac{1}{R_2}\right]$

When lens is placed in air, $\mu_1 = 1$ and $\mu_2 = \mu$. The lens maker formula takes the form, $\frac{1}{f}=(\mu-1)\left[\frac{1}{R_1}-\frac{1}{R_2}\right]$

(i) The radius of curvature of each face of biconcave lens with refractive index 1.5 is 30 cm. The focal length of the lens in air is

(a) 12 cm (b) 10 cm (c) 20 cm (d) 30 cm

(ii) The radii of curvature of the faces of a double convex lens are 10 cm and 15 cm. If focal length is 12 cm, then refractive index of glass is

(a) 1.5 (b) 1.78 (c) 2.0 (d) 2.52

(iii) An under-water swimmer cannot see very clearly even in absolutely clear water because of

(a) absorption of light in water (b) scattering of light in water
(c) reduction of speed of light in water (d) change in the focal length of eye-lens

(iv) A thin lens of glass ($\mu = 1.5$) of focal length 10 cm is immersed in water ($\mu = 1.33$). The new focal length is

(a) 20 cm (b) 40 cm (c) 48 cm (d) 12 cm

(v) An object is immersed in a fluid. In order that the object becomes invisible, it should

(a) behave as a perfect reflector
(b) absorb all light falling on it
(c) have refractive index one
(d) have refractive index exactly matching with that of the surrounding fluid.

Case Study 15

Refraction Through a Prism

A prism is a portion of a transparent medium bounded by two plane faces inclined to each other at a suitable angle. A ray of light suffers two refractions on passing through a prism and hence deviates through a certain angle from its original path. The angle of deviation of a prism is, $\delta = (\mu - 1) A$, through which a ray deviates on passing through a thin prism of small refracting angle A.

If μ is refractive index of the material of the prism, then prism formula is, $\mu=\frac{\sin(A+\delta_m)/2}{\sin A/2}$

(i) For which colour, angle of deviation is minimum?

(a) Red (b) Yellow (c) Violet (d) Blue

(ii) When white light moves through vacuum
(a) all colours have same speed
(b) different colours have different speeds
(c) violet has more speed than red
(d) red has more speed than violet.

(iii) The deviation through a prism is maximum when angle of incidence is
(a) 45°
(b) 70°
(c) 90°
(d) 60°

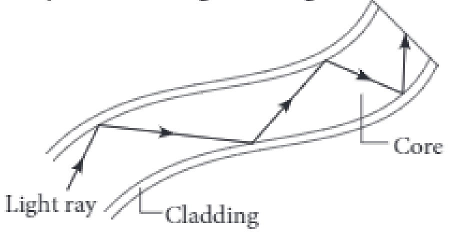
(iv) What is the deviation produced by a prism of angle 6°? (Refractive index of the material of the prism is 1.644).
(a) 3.864°
(b) 4.595°
(c) 7.259°
(d) 1.252°

(v) A ray of light falling at an angle of 50° is refracted through a prism and suffers minimum deviation. If the angle of prism is 60°, then the angle of minimum deviation is
(a) 45°
(b) 75°
(c) 50°
(d) 40°

Case Study 16

Optical Fibre

An optical fibre is a thin tube of transparent material that allows light to pass through, without being refracted into the air or another external medium. It make use of total internal reflection. These fibres are fabricated in such a way that light reflected at one side of the inner surface strikes the other at an angle larger than critical angle. Even, if fibre is bent, light can easily travel along the length.

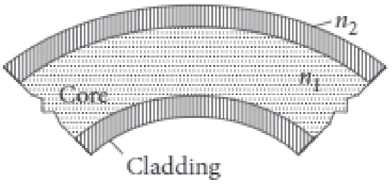


(i) Which of the following is based on the phenomenon of total internal reflection of light?
(a) Sparkling of diamond
(b) Optical fibre communication
(c) Instrument used by doctors for endoscopy
(d) All of these

(ii) A ray of light will undergo total internal reflection inside the optical fibre, if it
(a) goes from rarer medium to denser medium
(b) is incident at an angle less than the critical angle
(c) strikes the interface normally
(d) is incident at an angle greater than the critical angle

(iii) If in core, angle of incidence is equal to critical angle, then angle of refraction will be
(a) 0°
(b) 45°
(c) 90°
(d) 180°

(iv) In an optical fibre (shown), correct relation for refractive indices of core and cladding is



(a) $n_1 = n_2$
(b) $n_1 > n_2$
(c) $n_1 < n_2$
(d) $n_1 + n_2 = 2$

(v) If the value of critical angle is 30° for total internal reflection from given optical fibre, then speed of light in that fibre is
(a) 3×10^8 m s^{-1}
(b) 1.5×10^8 m s^{-1}
(c) 6×10^8 m s^{-1}
(d) 4.5×10^8 m s^{-1}

HINTS & EXPLANATIONS

7. **(i) (b):** Each half lens will form an image in the same plane. The optic axes of the lenses are displaced,

$\frac{1}{v} - \frac{1}{(-30)} = \frac{1}{20}$; $v = 60$ cm

(ii) (a): Here $f_1 = 20$ cm ; $f_2 = ?$

$F = 80$ cm

As $\frac{1}{f_1} + \frac{1}{f_2} = \frac{1}{F} \Rightarrow \frac{1}{f_2} = \frac{1}{F} - \frac{1}{f_1}$

$\frac{1}{f_2} = \frac{1}{80} - \frac{1}{20} = \frac{-3}{80}$

$f_2 = \frac{-80}{3} = -26.7\,\text{cm}$

(iii) (b): The bubble behaves libe a diverging lens.

(iv) (b): Convex lens is used in magnifying glass.

(v) (d)

8. **(i) (d)**

(ii) (a): $P = P_1 + P_2 = 1.5 + 1.0 = 2.5$ D

(iii) (b): $f = \frac{1}{P} = \frac{1}{5}\,\text{m} = +20\,\text{cm}$

(iv) (a): $P = P_1 + P_2 = \frac{1}{f_1} + \frac{1}{f_2}$

$= \frac{100}{10} + \frac{100}{-5} = -10\,\text{D}$

(v) (b): $P = P_1 + P_2 = \frac{100}{f_1} + \frac{100}{f_2}$

$P = \frac{100}{25} + \frac{100}{-20} = -1\,\text{D}$

As the power is negative, the system will be diverging.

9. **(i) (a):** $\sin C = \frac{1}{\mu} = \frac{1}{3/2} = \frac{2}{3} = 0.6667$

$C = \sin^{-1}(0.6667) = 41.8°$

(ii) (c): $\mu = \frac{1}{\sin C} = \frac{1}{\sin 48.6} = \frac{1}{0.75} = \frac{4}{3}$

(iii) (c): From $\mu = \frac{1}{\sin C}$, $\sin C = \frac{1}{\mu}$

As $\mu_v > \mu_r \;\therefore\; C_v < C_r$

The correct alternative may be (c).

(iv) (b): Difference between apparent and real depth of a pond is due to refraction. Other three are due to total internal reflection.

(v) (c): As ${}^{w}\mu_g < {}^{a}\mu_w < {}^{a}\mu_g$; $\therefore \theta > \theta_2 > \theta_1$

10. (i) (c) : $\frac{1}{f}=(\mu-1)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)$

For equiconvex lens, $R_1 = R$, $R_2 = -R$

$\frac{1}{20}=\left(\frac{3}{2}-1\right)\left(\frac{2}{R}\right)=\frac{1}{R}$

$R = 20$ cm

(ii) (a) : When a lens is immersed in a medium whose refractive index is greater than that of the lens, its nature changes. Here the lens changes its nature when immersed in water it means its refractive index is less than that of water.

(iii) (a) : According to lens maker's formula

$$\frac{1}{f}=(n-1)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)\therefore\left(\frac{1}{R_1}-\frac{1}{R_2}\right)=\frac{1}{f(n-1)}$$

(iv) (d): $\frac{1}{f_m}=\left(\frac{\mu_g}{\mu_m}-1\right)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)$

The given lens would behave as concave when f_m becomes negative, for which $\mu_m > \mu_g$.
Choice (d) is correct.

(v) (c) : Here, $R_1 = 20$ cm, $R_2 = -40$ cm, $f = 20$ cm
Using lens maker's formula we get,

$$\frac{1}{20}=(\mu-1)\left(\frac{1}{20}+\frac{1}{40}\right);\ \frac{1}{20}=(\mu-1)\frac{3}{40}\Rightarrow\mu=\frac{5}{3}$$

11. (i) (a) : $m=\frac{f_o}{f_e}=7$

$f_o = 7f_e$

In normal adjustment, distance between the lenses,

$f_o + f_e = 40$

$7f_e + f_e = 40 \Rightarrow f_e=\frac{40}{8}=5$ cm

$f_o = 7f_e = 7 \times 5 = 35$ cm

(ii) (d): $m = -10$; $L = 22$ cm

As $m=\frac{-f_o}{f_e}\Rightarrow -10=-\frac{f_o}{f_e}$

$f_o = 10f_e$

As $L = f_o + f_e$

$22 = 10f_e + f_e = 11f_e$

or $f_e=\frac{22}{11}=2$ cm

$f_o = 10f_e = 20$ cm

(iii) (d): Objective lens has larger focal length than eye-piece.

(iv) (d): Astronomial telescope is used to see stars, sun etc.

(v) (c) : $f_o >> f_e$

12. (i) (d): Refractive index of a medium depends upon nature and temperature of the medium, wavelength of light.

(ii) (a) : Here $\nu = 5 \times 10^{14}$ Hz; $\lambda = 450 \times 10^{-9}$m

$c = 3 \times 10^8$ m s^{-1}

Refractive index of the liquid,

$$\mu=\frac{c}{v}=\frac{c}{\nu\lambda}=\frac{3\times10^8}{5\times10^{14}\times450\times10^{-9}}$$

$\mu = 1.33$

(iii) (b): Here $i = 60°$; $\mu = 1.5$

By snell's law, $\mu=\frac{\sin i}{\sin r}$

$$\sin r=\frac{\sin i}{\mu}=\frac{\sin 60°}{1.5}=\frac{0.866}{1.5}$$

$\sin r = 0.5773$ or $r = \sin^{-1}(0.58)$

(iv) (c) : As object is at the centre of the sphere, the image must be at the centre only.

∴ Distance of virtual image from centre of sphere = 6 cm.

(v) (c) : Speed of light in second medium is different than that in first medium

13. (i) (b): Here $f_0 = 2.0$, $f_e = 6.25$ cm, $u_0 = ?$

When the final image is obtained at the least distance of distinct vision :

$v_e = -25$ cm

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

$$\therefore\ \frac{1}{u_e}=\frac{1}{v_e}-\frac{1}{f_e}=\frac{1}{-25}-\frac{1}{6.25}$$

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

or $u_e = -5$ cm

(ii) (b): Distance between objective and eye-piece = 15 cm

∴ Distance of the image from objective is

$v_0 = 15 - 5 = 10$ cm

$$\therefore\ \frac{1}{u_0}=\frac{1}{v_0}-\frac{1}{f_0}=\frac{1}{10}-\frac{1}{2}=\frac{1-5}{10}=-\frac{2}{5}$$

or $u_0=-\frac{5}{2}=-2.5$ cm

∴ Distance of object from objective = 2.5 cm

(iii) (a) : Magnifying power,

$$m = m_0 \times m_e = \frac{v_0}{u_0}\left(1+\frac{D}{f_e}\right) = \frac{10}{2.5}\left(1+\frac{25}{6.25}\right) = 20$$

(iv) (a) : The intermediate image formed by the objective of a compound microscope is real, inverted and magnified.

(v) (d)

14. (i) (d) : Here, $\mu = 1.5$; $R_1 = 30$ cm

$R_2 = -30$ cm

As $\frac{1}{f} = (\mu - 1)\left[\frac{1}{R_1} - \frac{1}{R_2}\right]$

$$= (1.5 - 1)\left[\frac{1}{30} - \frac{1}{-30}\right] = -0.5 \times \frac{2}{30} = \frac{-1}{30}$$

$f = -30$ cm

(ii) (a) : Here, $f = 12$ cm ; $R_1 = 10$ cm

$R_2 = -15$ cm

As $\frac{1}{f} = (\mu - 1)\left[\frac{1}{R_1} - \frac{1}{R_2}\right]$

$$\frac{1}{12} = (\mu - 1)\left[\frac{1}{10} + \frac{1}{15}\right]$$

$\mu = 1.5$

(iii) (d) : The eye-lens is surrounded by a different medium than air. This will change the focal length of the eye-lens. The eye cannot accommodate all images as it would do in air.

(iv) (b): $\frac{1}{f} = (1.5 - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$

and $\frac{1}{f_w} = \left(\frac{1.5}{1.33} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$

$$\frac{f_w}{f} = \frac{0.5 \times 1.33}{0.17} = 4$$

$f_w = 4f = 4 \times 10 = 40$ cm

(v) (d): If the refractive index of two media are same, the surface of separation does not produce refraction or reflection which helps in visibility.

15. (i) (a) : Angle of deviation is minimum for the red colour.

(ii) (a) : In vacuum all colours have same speed, because there is no dispersion of light in vacuum.

(iii) (c) : The deviation is maximum when angle is 90°.

(iv) (a) : $A = 6°$; $\mu = 1.644$

$f = (\mu - 1)A$

$f = (1.644 - 1)6 = 0.644 \times 6$

$\delta = 3.864°$

(v) (d) : $i_1 = 50°$; $A = 60°$, $\delta_m = ?$

$A + \delta_m = i_1 + i_2 = 50° + 50° = 100°$

$\delta_m = 100° - A = 100 - 60° = 40°$

16. (i) (d): Total internal reflection is the basis for following phenomenon:

(a) Sparkling of diamond.

(b) Optical fibre communication.

(c) Instrument used by doctors for endoscopy.

(ii) (d) : Total internal reflection (TIR) is the phenomenon that involves the reflection of all the incident light off the boundary. TIR only takes place when both of the following two conditions are met:

The light is in the more denser medium and approaching the less denser medium.

The angle of incidence is greater than the critical angle.

(iii) (c) : If incidence of angle, i = critical angle C, then angle of refraction, $r = 90°$

(iv) (b) : In optical fibres, core is surrounded by cladding, where the refractive index of the material of the core is higher than that of cladding to bound the light rays inside the core.

(v) (b) : From Snell's law, $\sin C = {}_1n_2 = \frac{v_1}{v_2}$

where, C = critical angle = 30° and v_1 and v_2 are speed of light in medium and vacuum, respectively.

We know that, $v_2 = 3 \times 10^8$ m s^{-1}

$$\therefore \quad \sin 30° = \frac{v_1}{3 \times 10^8}$$

$$\Rightarrow \quad v_1 = 3 \times 10^8 \times \frac{1}{2} \Rightarrow v_1 = 1.5 \times 10^8 \text{ m s}^{-1}$$