CHAPTER

9

Ray Optics and Optical Instruments

CASE STUDY / PASSAGE BASED QUESTIONS

Syllabus

Ray optics : Refraction of light, total internal reflection and its applications, optical fibres, refraction at spherical surfaces, lenses, thin lens formula, lens maker's formula, magnification, power of a lens, combination of thin lenses in contact, refraction of light through a prism.

Optical instruments : Microscopes and astronomical telescopes (reflecting and refracting) and their magnifying powers

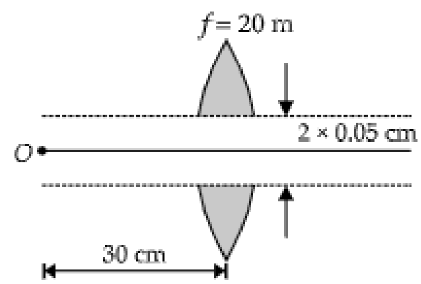
Questions 1-10 are Case Study based questions and are compulsory. Attempt any 4 sub parts from each question. Each question carries 1 mark.

1

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

2

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.*, $P = P_1 + P_2 + P_3 + ...$.

(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

3

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

4

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) $\frac{4}{5}$

5

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

6

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.

7

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.

8

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 (μ = 1.5) of focal length 10 cm is immersed in water (μ = 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.

9

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°

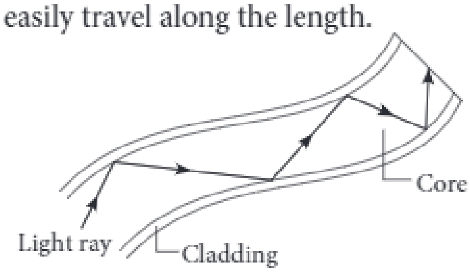
(v) A ray of light falling at an angle of 50° is refracted through a prism and suffers minimum deviation. If the angle of prism is 60°, then the angle of minimum deviation is

(a) 45°
(b) 75°
(c) 50°
(d) 40°

10

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

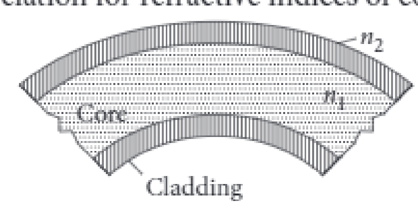
(ii) A ray of light will undergo total internal reflection inside the optical fibre, if it

(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}

ASSERTION & REASON

For question numbers 11-30, two statements are given-one labelled Assertion (A) and the other labelled Reason (R). Select the correct answer to these questions from the codes (a), (b), (c) and (d) as given below.

(a) Both A and R are true and R is the correct explanation of A

(b) Both A and R are true but R is NOT the correct explanation of A

(c) A is true but R is false

(d) A is false and R is also false

11. Assertion (A) : The minimum distance between an object and its real image formed by a convex lens is $2f$.
Reason (R) : The distance between an object and its real image is minimum when its magnification is two.

12. Assertion (A) : A convex lens of glass (μ = 1.5) behave as a diverging lens when immersed in carbon disulphide of higher refractive index (μ = 1.65).
Reason (R) : A diverging lens is thinner in the middle and thicker at the edges.

13. Assertion (A) : The images formed by total internal reflections are brighter than those formed by mirrors or lenses.
Reason (R) : There is no loss of intensity in total internal reflection.

14. Assertion (A) : The diamond shines due to multiple total internal reflections.
Reason (R) : The critical angle for diamond is 24.4°.

15. Assertion (A) : The focal length of an equiconvex lens placed in air is equal to radius of curvature of either face. Lens is made up of material of refractive index of 1.5.
Reason (R) : For an equiconvex lens, radius of curvature of both the faces is same.

16. Assertion (A) : The light travelling from air to glass can not suffer total internal reflection.
Reason (R) : Air is rarer than glass.

17. Assertion (A) : By increasing the diameter of the objective of telescope, we can increase its range.
Reason (R) : The range of a telescope tells us how far away a star of some standard brightness can be spotted by telescope.

18. Assertion (A) : A convex lens is made of two different materials. A point object is placed on the principal axis. The number of images formed by the lens will be two.
Reason (R) : The image formed by convex lens is always virtual.

19. Assertion (A) : The illuminance of an image produced by a convex lens is greater in the middle and less towards the edges.
Reason (R) : The middle part of image is formed by undeflected rays while outer part by inclined rays.

20. Assertion (A) : A single lens produces a coloured image of an object illuminated by white light.
Reason (R) : The refractive index of the material of lens is different for different wavelengths of light.

21. Assertion (A) : Optical fibers are used to transmit light without any loss in its intensity over distance of several kilometers.
Reason (R) : Optical fibers are very thick and all the light is passed through it without any loss.

22. Assertion (A) : Convergent lens property of converging remains same in all media.
Reason (R) : Property of lens whether the ray is diverging or converging is independent of the surrounding medium.

23. Assertion (A) : Endoscopy involves use of optical fibres to study internal organs.
Reason (R) : Optical fibres are based on phenomena of total internal reflection.

24. **Assertion (A) :** Optical fibres are used for telecommunication.
Reason (R) : Optical fibres are based on the phenomenon of total internal reflection

25. **Assertion (A) :** A double convex lens (μ = 1.5) has focal length 10 cm. When the lens is immersed in water (μ = 4/3) its focal length becomes 78.24 cm.
Reason (R) : $\frac{1}{f} = \frac{\mu_g - \mu_m}{\mu_m}\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$

26. **Assertion (A) :** If objective and eye lenses of a microscope are interchanged then it can work as telescope.
Reason (R) : The objective lens of telescope has small focal length.

27. **Assertion (A) :** If optical density of a substance is more than that of water, then the mass density of substance can be less than water.
Reason (R) : Optical density and mass density are not related.

28. **Assertion (A) :** It is possible to eliminate dispersion by combining two prism of same refracting angles but of different materials.
Reason (R) : The angular dispersion does not depend on refractive index of the material of the prism.

29. **Assertion (A) :** Microscope magnifies the image.
Reason (R) : Angular magnification for image is more than object in microscope.

30. **Assertion (A) :** Goggles have zero power.
Reason (R) : Radius of curvature of both sides of lens is same.

HINTS & EXPLANATIONS

1. (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)

2. (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.

3. (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 ${}^w\mu_g < {}^a\mu_w < {}^a\mu_g$; $\therefore \theta > \theta_2 > \theta_1$

4. (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,

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

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

$f_o = 7f_e$

In normal adjustment, distance between the lenses,

$f_o + f_e = 40$

$7f_o + f_e = 40 \Rightarrow f_e=\frac{40}{8}=5$ 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): $f_o >> f_e$

6. (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, $\mu=\frac{\sin i}{\sin r}$

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

$\sin r = 0.5773$ 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.

$\therefore$ 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

7. (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

$\therefore$ 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

$\therefore$ 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)

8. **(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.

9. **(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): $i_1 = 50°$; $A = 60°$, $\delta_m = ?$

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

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

10. **(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}

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

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

11. **(d):** The distance between the object and its real image is minimum when magnification is 1. We know that the magnification of convex lens is given by $(m) = -v/u$ for $m = 1$, $v = -u$.

Now from lens formula, $v = u = 2f$

Hence, minimum distance $v + u = 4f$.

12. **(b):** $\mu = \frac{\mu_g}{\mu_c} = \frac{1.5}{1.65} < 1$

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

f becomes negative.

Therefore, the lens behaves as a diverging lens.

13. (a): In total internal reflection, 100% of incident light is reflected back into the same medium, and there is no loss of intensity, while in reflection from mirrors and refraction from lenses, there is always some loss of intensity. Therefore images formed by total internal reflection are much brighter than those formed by mirrors or lenses.

14. (b): The brilliance of diamond is due to total internal reflection of light. μ for diamond is 2.42, so that critical angle for diamond air interface is $C = 24.4°$ (from $\sin C = 1/\mu$). The diamond is cut suitable so that light entering the diamond from any face suffers multiple total internal reflections at the various faces and remains within the diamond. Hence the diamond sparkles.

15. (b): For an equiconvex lens, $R_1 = R_2 = R$

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

Using lens maker's formula for glass, $\mu = 1.5$ placed in air $\frac{1}{f} = (1.5 - 1)\frac{2}{R} \Rightarrow f = R$.

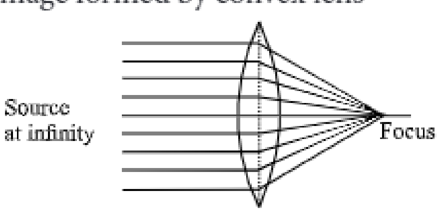
16. (b): The light travelling from air to glass cannot suffer total internal reflection because for total internal reflection, the essential condition is that light should travel from a denser medium to a rarer medium with incidence angle more than the critical angle.

17. (b): The light gathering power (or brightness) of a telescope is directly proportional to the area of the objective lens.

i.e., light gathering power $\propto \pi r^2 = \frac{\pi D^2}{4}$, where D is the diameter of the objective. Thus telescope will have large light gathering power if the diameter of the objective lens is large. So by increasing the objective diameter even far off stars may produce images of optimum brightness.

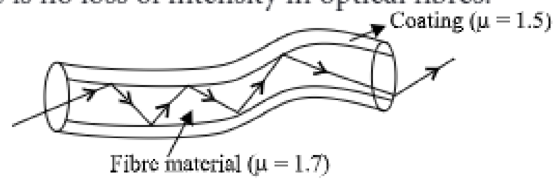
18. (c) : Since the lens is made of two different materials of different refractive indices, there will be two different focal lengths of the lens. Hence two images will be formed. The image formed by convex lens is always real except in case when object is placed between optical centre and focus.

19. (a) : Image formed by convex lens



20. (a) : Due to the variation of the refractive index of the material of the lens, the focal length also varies accordingly. Now as white light is composed of different colours of light, each colour will produce its own image based on the focal length for that colour. This particular phenomenon for a single lens is known as chromatic aberration.

21. (c) : Optical fiber is extremely thin (radius of few microns) and long strand of very fine quality glass or quartz. When light is incident at a small angle at one end, it gets refracted into the strands (or fibres) and incident on the interface of the fibres and the coating. The angle of incidence being greater than the critical angle, the ray of light undergoes total internal reflections. It suffers the internal reflection again and again, till the angle of incidence remains greater than the critical angle for fibre material with respect to coating. Due to successive total internal reflection there is no loss of intensity in optical fibres.



22. (d): A convex lens made of glass behaves as a convergent lens when placed in air or water. However when the same lens is immersed in carbon disulphide ($\mu = 1.63$), it behaves as a divergent lens. Therefore when a convergent lens is placed inside a transparent medium of refractive index greater than that of material of the lens, it behaves as a divergent lens. Behaviour of a lens depends on the refractive index of a surrounding medium.

23. (a) : An endoscope is made of optical fibres. Its core is made of optically denser material. Its outer cladding is made of optically rarer material. It is based on total internal reflection.

24. (a) : Optical fibers are used in communication and it is because of the phenomenon named as total internal reflection, taking place inside the fiber for the incident signal.

25. (a) : $\frac{1}{f} = ({}^{w}\mu_g - 1)\left[\frac{1}{R_1} - \frac{1}{R_2}\right] = \left(\frac{\mu_g}{\mu_w} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$

$$\frac{1}{f} = \left(\frac{\mu_g - \mu_w}{\mu_w}\right) \cdot \left[\frac{1}{R_1} - \frac{1}{R_2}\right] = \left(\frac{1.5 - 1.33}{1.33}\right) \cdot \left[\frac{1}{20} + \frac{1}{20}\right]$$

$\therefore \quad f = 78.24$ cm

26. **(d):** We cannot interchange the objective and eye lenses of a microscope to make a telescope. The reason is that the focal length of lenses in microscope are very small, of the order of mm or a few cm and the difference $(f_o - f_e)$ is very small, while the telescope objective have a very large focal length as compared to eye lens of microscope.

27. **(a):** Optical density and mass density are not related to each other. Mass density is mass per unit volume. It is possible that mass density of an optically denser medium be less than that of an optically rarer medium (optical density is the ratio of the speed of light in two media). *e.g.*, turpentine and water. Mass density of turpentine is less than that of water but its optical density is higher.

28. **(d):** For a prism of small angle A, the angular dispersion produced $= (\mu_v - \mu_R)A$. This can be cancelled by a second prism of angle A' made of different material such that $(\mu'_v - \mu'_R)A' = (\mu_v - \mu_R)A$

If only $A = A'$, then the dispersion produced by one prism cannot be cancelled by the dispersion produced by the other prism because,

$(\mu'_v - \mu'_R)A' = (\mu_v - \mu_R)A$ for different materials

Therefore in order to eliminate dispersion by combining two prism they should have same refracting angle and made of same material.

29. **(a):** Microscope is an optical instrument which forms a magnified image of a small nearby object and thus, increases the visual angle subtended by the image at the eye so that the object is seen to be bigger and distinct. Therefore, angular magnification for image is more than object.

30. **(a):** Goggles have zero power.

The focal length is given by $\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$. For goggle lenses, both sides are curved the same way. R_1 and R_2 are positive. If they are the same, $\frac{1}{f} = 0$ *i.e.*, power is zero.