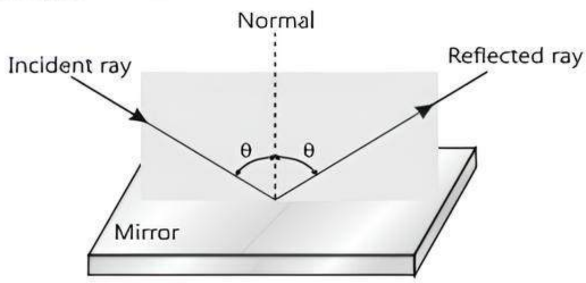
9 Ray Optics and Optical Instruments

Fastrack Revision

- **Ray Optics:** The branch of optics deals with propagation of light in terms of rays which are valid, if size of obstacles are large in comparison with wavelength of light (in nm range), is called ray optics.
- **Reflection of Light:** When light is incident on a polished smooth surface, then most of incident light returns to the same medium. This phenomenon of returning of light after striking a smooth polished surface is called reflection of light.

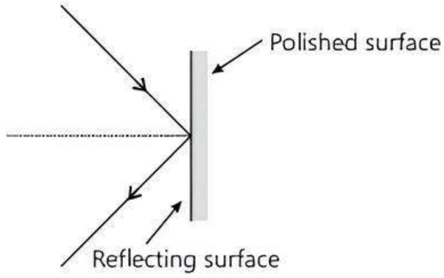


The incident ray, reflected ray and the normal to the reflecting surface lie in the same plane.

- **Laws of Reflection**
  - The angle of reflection (*i.e.* the angle between reflected ray and the normal to the reflecting surface or the mirror) equals the angle of incidence (angle between incident ray and the normal).
  - The incident ray, reflected ray and the normal to the reflecting surface at the point of incident lie in the same plane.
- **Mirror:** A mirror is defined as the reflecting surface and can be explained by the law of reflection.

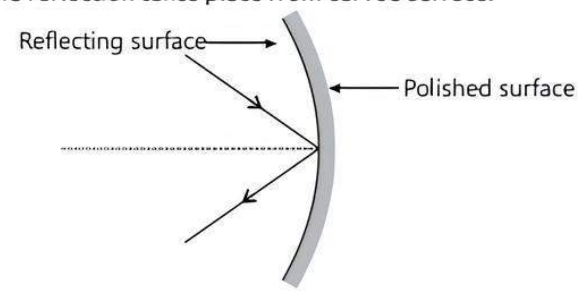
  There are two types of mirror :
  - **Plane Mirror:** The mirror whose reflecting surface is plane, is called plane mirror.

    Its one side is silvered and reflection takes place from other side.

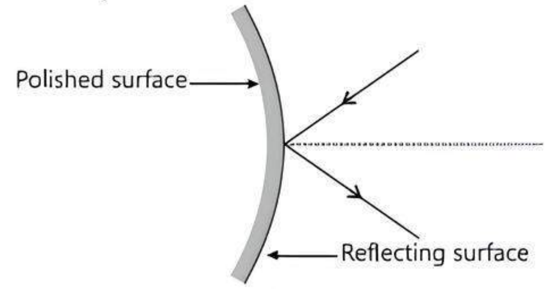


  - **Spherical Mirror:** It is the part of a spherical transparent medium. One of the curved surface is polished and reflection takes place from other side.

  Spherical mirrors are also two types:
  - **Concave Mirrors:** Its outer curved surface is polished and reflection takes place from curved surface.



  - **Convex Mirrors:** Its inner curved surface is polished and reflection take place from outer curved surface.



- **Mirror Formula:** The relation between focal length of the mirror (f), distances of object (u) and image from the mirror (v) is called mirror formula or mirror equation. *i.e.,*

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

- **Focal Length of the Mirror:** The distance between pole and focus of a spherical mirror is its called focal length (f). It is equal to the half of radius of curvature (R) of the mirror,

i.e., $$f=\frac{R}{2}$$

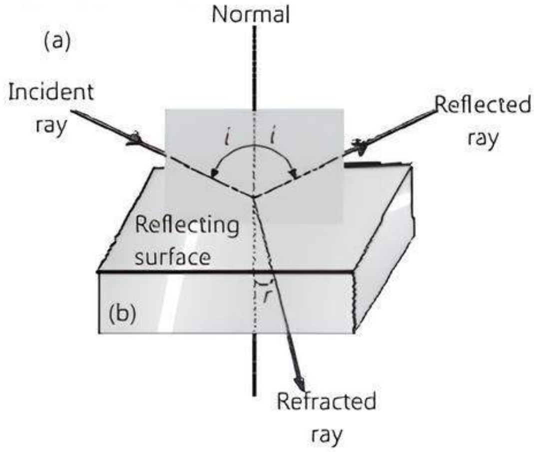
- **Linear Magnification:** The ratio of the size of the image formed by a spherical mirror to the size of the object is called the linear magnification (m) produced by the spherical mirror.

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

Or $$\text{Linear Magnification}=\frac{\text{Height of image}}{\text{Height of object}}$$

It is negative for real image and positive for virtual image.

- **Refraction:** When a beam of light encounters another transparent medium, a part of light gets reflected back into the first medium while the rest enters the other. A ray of light represents a beam. The direction of propagation of an obliquely incident ray of light that enters the other medium, changes at the interface of the two media. This phenomenon is called refraction of light.



Refraction and reflection of light

- **Laws of Refraction**
  - The incident ray, the normal at the point of incidence and the refracted ray all lie in the same plane.
  - For the same pair of media and the same colour of light, the ratio of the sine of the angle of incidence to the sine of the angle of refraction is constant

    i.e., $\dfrac{\sin i}{\sin r} = {}_a\mu_b = n_{ba}$ (this is known as Snell's law)

where, ${}_a\mu_b(n_{ba})$ is a constant known as refractive index of the medium b with respect to the medium a, i is the angle of incidence in medium a and r is the angle of refraction in medium b.

- **Refractive Index:** Refractive index or index of refraction (μ) of a material is the ratio of the speed of light in vacuum to the speed of light in the medium.

i.e., $$\mu = \frac{c}{v}$$

- **Principle of Reversibility of Light:** As light follows a reversible path,

$$\frac{\sin r}{\sin i} = {}_b\mu_a$$

Multiplying this by $\dfrac{\sin i}{\sin r} = {}_a\mu_b$, we get

$${}_a\mu_b \times {}_b\mu_a = \frac{\sin i}{\sin r} \times \frac{\sin r}{\sin i} = 1$$

$${}_a\mu_b = \frac{1}{{}_b\mu_a}$$

- **Critical Angle:** The critical angle is the angle of incidence in a denser medium corresponding to which the refracted ray just brushes the surface of separation.

Or

Critical angle is that value of angle of incidence for which angle of refraction is 90°.

- **Total Internal Reflection:** If the angle of incidence is more than the critical angle, refraction is not possible and incident ray is reflected back to the medium. This is called total internal reflection.

Following are the two conditions of TIR:
  - Incident ray is in denser medium.
  - The angle of incidence must be greater than the critical angle.
  - **TIR in Nature**

    (i) Mirage (ii) Brilliance of diamond.

- **Apparent Depth of a Liquid:** If the object be placed at the bottom of a transparent medium, say water, and viewed from above, it will appear higher than it actually is. The refractive index μ in this case is:

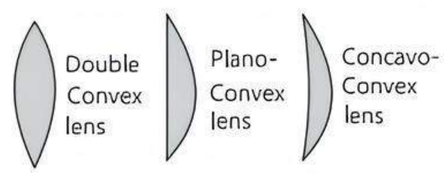
Refractive index of the medium, $\mu = \dfrac{\text{Real depth}}{\text{Apparent depth}}$

- **Refraction at a Spherical Surface:** If μ_1, μ_2 are refractive indices of first and second media, R is the radius of curvature of spherical surface, formula is

$$\frac{\mu_2}{v} - \frac{\mu_1}{u} = \frac{\mu_2 - \mu_1}{R}$$

where, u and v are the distances of the object and the image from the centre of the refracting surface of radius of curvature R respectively.

- **Lens:** Lens is a transparent medium bounded by two surfaces out of which one or both surfaces are spherical. There are two types of lens:
  - **Convex or Converging Lens:** A lens which is thicker at the centre and thinner at its end is known as a convex lens.

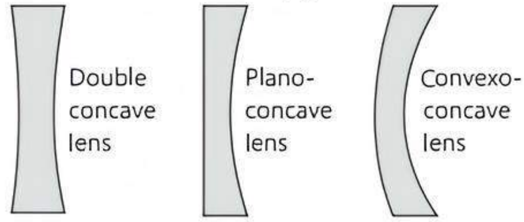


Convex or converging lenses

A convex lens is also called as converging lens because it converges a parallel beam of light rays passing through it. A double convex lens is simply called a convex lens.

  - **Concave or Diverging Lens:** A lens which is thinner at the centre and thicker at its end is known as a concave lens.

A concave lens is also known as diverging lens because it diverges a parallel beam of light rays passing through it. A double concave lens is simply called a concave lens.



Concave or diverging lenses

- **Refraction by a Lens:** If R_1 and R_2 are radii of curvature of first and second refracting surfaces of a thin lens of focal length f, then lens maker's formula is

$$\frac{1}{f} = \left(\frac{\mu_2 - \mu_1}{\mu_1}\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

If the lens is surrounded by air, $\mu_1 = 1$ and $\mu_2 = \mu$, then

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

- **Thin Lens Formula**

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

- **Magnification Produced by a Lens**

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

m is negative for inverted (and real) image while for an erect (and virtual) image, m is positive.

- **Power of a Lens:** The power (p) of a lens is defined as the tangent of the angle by which it converges or diverges a beam of light parallel to the principal axis falling at unit distance from the optical centre.

$$\tan\delta=\frac{h}{f}$$

If $h = 1$, $\tan\delta=\frac{1}{f}$

or $\delta=\frac{1}{f}$ for small value of δ.

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

The SI unit for power of a lens is dioptre (D).

$$1\text{ D} = 1\text{m}^{-1}$$

Power of a lens is positive for converging (convex) lens and negative for diverging (concave) lens.

- **Focal Length of Thin Lenses in Contact:** The focal length (f) of thin lenses of focal lengths f_1, f_2, f_3, ... placed in contact of each other is:

$$\frac{1}{f}=\frac{1}{f_1}+\frac{1}{f_2}+\frac{1}{f_3}+\cdots\cdots$$

In terms of power, it can be written as

$$P=P_1+P_2+P_3+\ldots$$

where, P is the net power of lens combination.

Magnification of lens in combination (m) is given by:

$m = m_1 \times m_2 \times \ldots$ and so on.

Such a system of combination of lenses is commonly used in designing lenses for cameras, microscopes, telescopes and other optical instruments.

- **Refraction through a Prism:** When a ray of monochromatic light is refracted by a prism, the deviation δ produced by the prism is:

$$\delta=i+e-A$$

where, i = angle of incidence,

e = angle of emergence,

A = angle of the prism.

- **Angle of Deviation:** The angle of deviation δ_m is minimum, when ray passes symmetrically through the prism. The refractive index μ of the prism is:

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

- **Dispersion:** The splitting of white light into constituent colours is called the dispersion. A prism causes deviation as well as dispersion.

- **Optical Instruments:** Optical instruments are the devices which help human eye in observing highly magnified images of tiny objects, for detailed examination and in observing very far objects whether terrestrial or astronomical.

- **Microscope**
  - A **simple microscope** is a short focal length convex lens which helps us to see and study micro-organisms.
  - **Compound microscope** is a combination of two convex lens, where the lens towards the object is called objective and that towards the eye is called eyepiece.
  - The magnifying power of a simple microscope is:

$$m=1+\frac{D}{f}$$

where, D = 25 cm and f is the focal length of convex lens.

  - The magnifying power, m of a compound microscope is

$$m=m_o\times m_e=\frac{L}{f_o}\left(1+\frac{D}{f_e}\right)$$

where, m_o and m_e denote the magnification produced by the objective and eyepiece and L is called the tube length of compound microscope.

- **Astronomical Telescopes:** These are used to see and study far off objects.
  - **Reflecting Astronomical Telescope:** A reflecting telescope is also called a reflector. Telescopes with mirror objectives are called reflecting telescopes. These form image free from chromatic aberration and spherical aberration.
  - **Refracting Astronomical Telescope:** A refracting telescope is also called a refractor telescope. It consists of an objectives lens of a large focal length and large aperture, also an eye lens of small aperture and focal length.
    - The magnifying power m of refracting telescope when the final image is formed at infinity is:

$$m=-\frac{f_o}{f_e}$$

and length of the telescope $L=(f_o+f_e)$

where, L is the length of the telescope tube.

    - For the final image is formed at the least distance of distant vision, the magnifying power is:

$$m=-\frac{f_o}{f_e}\left(1+\frac{f_e}{D}\right)$$

Practice Exercise

Multiple Choice Questions

Q 1. The light reflected by a plane mirror may form a real image.

a. If the rays incident on the mirror are diverging.
b. If the ray incident on the mirror are converging.
c. If the object is placed very close to the mirror.
d. Under no circumstances.

Q 2. For reflection through spherical surfaces, the normal at the point of incidence is:

a. perpendicular to the principal axis and passes through the centre of curvature.
b. perpendicular to the focal plane and passes through the pole.
c. perpendicular to the tangent plane at pole and passes through the focus.
d. perpendicular to the tangent plane at the point of incidence and passes through the centre of curvature.

Q 3. The turning back of light into the same medium after incident on a boundary separating two media is called:

a. reflection of light b. refraction of light.
c. dispersion of light. d. interference of light.

Q 4. The field of view is maximum for:

a. plane mirror b. concave mirror
c. convex mirror d. cylindrical mirror

Q 5. A virtual image larger than the objected can be obtained by:

a. concave mirror b. convex mirror
c. plane mirror d. cylindrical mirror

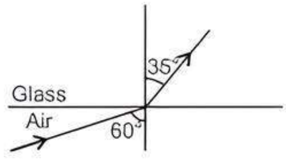
Q 6. In image formation from spherical mirror, only paraxial rays are considered because they:

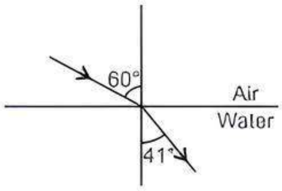
a. are easy to handle geometrically.
b. contain most of the intensity of the incident light.
c. form nearly a point image of a point source.
d. show minimum dispersion effect.

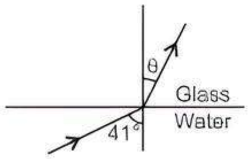
Q 7. A ray incident at a point at an angle of incidence of 60° enters a glass sphere of refractive index $\sqrt{3}$ and is reflected and refracted at the farther surface of the sphere. The angle between the reflected and refracted rays at this surface is:

a. 50° b. 60° c. 90° d. 40°

Q 8. Refraction of light from air to glass and from air to water are shown in figure (i) and (ii) given below. The value of the angle θ in the case of refraction as shown in figure (iii) will be:

(i)


(ii)


(iii)


a. 30° b. 35° c. 60° d. 41°

Q 9. A ray of light incident at an angle θ on a refracting face of a prism emerges from the other face normally. If the angle of the prism is 5° and the prism is made of a material of refractive index 1.5, the angle of incidence is: *(NCERT EXEMPLAR)*

a. 7.5° b. 5°
c. 15° d. 2.5°

Q 10. Why is refractive index in a transparent medium greater than one?

a. Because the speed of light in vacuum is always less than speed in a transparent medium.
b. Because the speed of light in vacuum is always greater than the speed in a transparent medium.
c. Frequency of wave changes when it crosses medium.
d. None of the above.

Q 11. A short pulse of white light is incident from air to a glass slab at normal incidence. After travelling through the slab, the first colour to emerge is: *(NCERT EXEMPLAR)*

a. blue b. green
c. violet d. red

Q 12. 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.

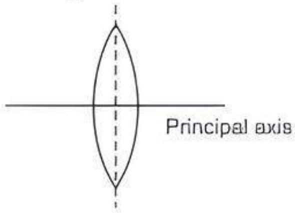
Q 13. A biconcave lens of power P vertically splits into two identical plano-concave parts. The power of each part will be:

a. $2P$ b. $\frac{P}{2}$
c. P d. $\frac{P}{\sqrt{2}}$

Q 14. A biconvex lens of glass having refractive index 1.47 is immersed in a liquid. It becomes invisible and behaves as a plane glass plate. The refractive index of the liquid is: *(CBSE 2020)*

a. 1.47 b. 1.62
c. 1.33 d. 1.51

Q 15. An equiconvex lens of focal length 15 cm is cut into two halves as shown in figure. Find the focal length of each part.



a. –30 cm b. –20 cm c. 30 cm d. –15 cm

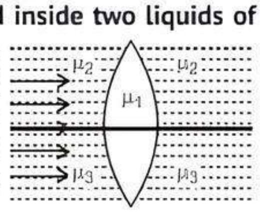
Q 16. How does the focal length of a convex lens changes if monochromatic red light is used instead of violet light?

a. Focal length is increased when red light is used.
b. Focal length is decreased when red light is used.
c. Focal length is remain same when red light is used.
d. Not depend on colour of light

Q 17. A glass lens is immersed in water. What will be the effect on the power of lens?

a. Increase b. Decrease
c. Constant d. Not depends

Q 18. A double convex lens, made of a material of refractive index μ_1, is placed inside two liquids of refractive indices μ_2 and μ_3 as shown. $\mu_2 > \mu_1 > \mu_3$. A wide, parallel beam of light is incident on the lens from the left. The lens will give rise to:



a. a single convergent beam.
b. two different convergent beams.
c. two different divergent beams.
d. a convergent and a divergent beam.

Q 19. The radius of curvature of the curved surface of a plano-convex lens is 20 cm. If the refractive index of the material of the lens be 1.5, it will: *(NCERT EXEMPLAR)*

a. act as a convex lens only for the objects that lie on its curved side.
b. act as a concave lens for the objects that lie on its curved side.
c. act as a convex lens irrespective of the side on which the object lies.
d. act as a concave lens irrespective of side on which the object lies.

Q 20. Radii of curvature of a converging lens are in the ratio 1 : 2. Its focal length is 6 cm and refractive index is 1.5. Then its radii of curvature are:

a. 9 cm and 18 cm b. 6 cm and 12 cm
c. 3 cm and 6 cm d. 4.5 cm and 9 cm

Q 21. Real image of an object is formed at a distance of 20 cm from a lens. On putting another lens in contact with it, the image is shifted 10 cm towards the combination. The power of the lens is:

a. 2 D b. 5 D c. 6 D d. 10 D

Q 22. For a glass prism, the angle of minimum deviation will be smallest for the light of: *(CBSE 2020)*

a. red colour b. blue colour
c. yellow colour d. green colour

Q 23. For a glass prism $(\mu = \sqrt{3})$, angle of minimum deviation is equal to angle of the prism. The angle of the prism is:

a. 45° b. 30° c. 90° d. 60°

Q 24. The focal length of the objective of a compound microscope is: *(CBSE 2020)*

a. greater than the focal length of eyepiece.
b. lesser than the focal length of eyepiece.
c. equal to the focal length of eyepiece.
d. equal to the length of its tube.

Q 25. An astronomical telescope has a large aperture to:

a. increase span of observation.
b. have low dispersion.
c. reduce spherical aberration.
d. have high resolution.

Q 26. How does the magnifying power of a telescope change on increasing the linear diameter of its objective?

a. Power increases on increasing diameter.
b. Power decreases on decreasing diameter.
c. Power remain constant on increasing diameter.
d. Power doesn't depend on diameter.

Q 27. In a reflecting telescope, a large concave mirror bounces all the light coming through the

a. sky b. sun
c. telescope barrel d. telescope tip

Q 28. An astronomical refractive telescope has an objective of focal length 20 m and an eyepiece of focal length 2 cm. Then:

a. the magnification is 1000.
b. the length of the telescope tube is 20.02 m.
c. the image formed is inverted.
d. All of the above

Assertion & Reason Type Questions

Directions (Q.Nos. 29-39): *In the following questions, a statement of Assertion (A) is followed by a statement of Reason (R). Mark the correct choice as:*

a. Both Assertion (A) and Reason (R) are true and Reason (R) is the correct explanation of Assertion (A).
b. Both Assertion (A) and Reason (R) are true but Reason (R) is not the correct explanation of Assertion (A).
c. Assertion (A) is true but Reason (R) is false.
d. Both Assertion (A) and Reason (R) are false.

Q 29. Assertion (A): The centre of curvature is not a part of the mirror. It lies outside its reflecting surface.
Reason (R): The reflecting surface of a spherical mirror forms a part of a sphere. This sphere has a centre.

Q 30. Assertion (A): The air bubble shines in water.
Reason (R): Air bubble in water shines due to refraction of light.

Q 31. Assertion (A): The images formed by total internal reflections are much brighter than those formed by mirrors or lenses.
Reason (R): There is no loss of intensity in total internal reflection.

Q 32. Assertion (A): Propagation of light through an optical fibre is due to total internal reflection taking place at the core-cladding interface.
Reason (R) : Refractive index of the material of the cladding of the optical fibre is greater than that of the core. *(CBSE SQP 2023-24)*

Q 33. Assertion (A): A convex lens of glass ($\mu_g = 1.5$) behave as a diverging lens when immersed in carbon disulphide of higher refractive index ($\mu_c = 1.65$).
Reason (R): A diverging lens is thinner in the middle and thicker at the edges.

Q 34. Assertion (A): Combination of lenses helps to obtain diverging or converging lenses of desired magnification.
Reason (R): It enhances sharpness of the image.

Q 35. Assertion (A): The focal length of an equiconvex lens placed in air is equal to radius of curvature of either face.
Reason (R): For an equiconvex lens radius of curvature of both the faces is same.

Q 36. 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.

Q 37. Assertion (A): A double convex lens $(\propto = 1.5)$ has focal length 10 cm. When the lens is immersed in water $(\propto = 4/3)$ its focal length becomes 40 cm.

Reason (R): $\frac{1}{f} = \frac{\mu_1 - \mu_m}{\mu_m}\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$

Q 38. Assertion (A): Angle of deviation depends on the angle of prism.
Reason (R): For thin prism, $\delta = (\mu - 1) A$.

Q 39. Assertion (A): Microscope magnifies the image.
Reason (R): Angular magnification for image is more than object in microscope.

Fill in the Blanks Type Questions

Q 40. The angle of reflection is .... to the angle of incidence.

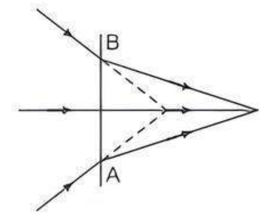
Q 41. The reflective surface of a .... bends out like the exterior profile of a bowl.

Q 42. The basic cause of refraction is change in .... of light in going from one medium to another.

Q 43. For the same angle of incidence, the angles of refraction in the different medium A, B and C are 15°, 25° and 35° respectively. The velocity of light will be minimum in ....

Q 44. Total internal reflection must occur when angle of incidence is more than the ....

Q 45. The lines A and B in the ray diagram of figure represent a .... lens.



Q 46. A ray of light on passing through an equilateral glass prism, suffers a minimum deviation equal to the angle of the prism. The value of refractive index of the material of the prism is .... *(CBSE 2020)*

Q 47. The deviation through a prism is minimum when angle of incidence is equal to angle of ....

Q 48. A ray of light undergoes .... twice on passing through a prism.

Q 49. In the minimum deviation position, the refracted ray in the prism is .... to the base of prism.

Q 50. In a reflecting type telescope, a .... of large aperture is used as objective in place of a convex lens.

Q 51. Microscope is also known as ....

Answers

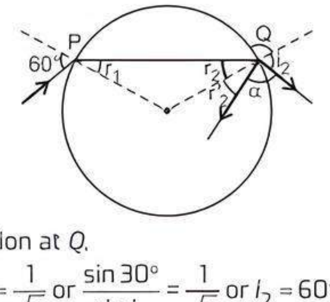
1. (b) If the ray incident on the mirror are converging.
2. (d) perpendicular to the tangent plane at the point of incidence and passes through the centre of curvature.
3. (a) reflection of light
4. (c) convex mirror
5. (a) concave mirror
6. (c) form nearly a point image of a point source.
7. (c) 90°

Refraction at P.

$$\frac{\sin 60°}{\sin r_1} = \sqrt{3}$$

$$\sin r_1 = \frac{1}{2} \text{ or } r_1 = 30°$$

Since, $r_2 = r_1 \quad \therefore \; r_2 = 30°$



Refraction at Q.

$$\frac{\sin r_2}{\sin i_1} = \frac{1}{\sqrt{3}} \text{ or } \frac{\sin 30°}{\sin i_2} = \frac{1}{\sqrt{3}} \text{ or } i_2 = 60°$$

At point Q, $r_2' = r_2 = 30°$

$\therefore\ \alpha = 180° - (r_2' + i_2) = 180° - (30° + 60°) = 90°$

8. (b) 35°

Using Snell's law,

$${}^{a}\mu_g = \frac{\sin 60°}{\sin 35°},\ {}^{a}\mu_w = \frac{\sin 60°}{\sin 41°} \text{ and } {}^{w}\mu_g = \frac{\sin 41°}{\sin \theta}.$$

${}^{a}\mu_g \times {}^{w}\mu_g = {}^{a}\mu_g$

$$\Rightarrow \frac{\sin 60°}{\sin 41°} \times \frac{\sin 41°}{\sin \theta} = \frac{\sin 60°}{\sin 35°}$$

$\Rightarrow \qquad \sin\theta = \sin 35°$ or $\theta = 35°$

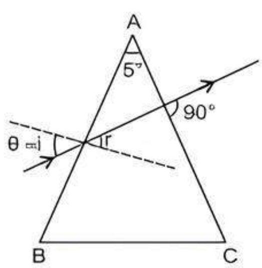
9. (a) 7.5°

According to the question, ray emerges from other surface of prism normally.

$\therefore$ Angle of incidence at second face, $r' = 0°$

Now, $r + r' = A$

$\Rightarrow \quad r = A - r' = 5° - 0° = 5°$



Using Snell's law,

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

or $\sin i = \mu \sin r$

$= 1.5 \times \sin 5° = 0.131$

$\Rightarrow \quad \theta = i = \sin^{-1}(0.131)$

$= 7.5°$

10. (b) Because the speed of light in vacuum is always greater than the speed in a transparent medium.

11. (d) red

Since $\lambda_r > \lambda_g > \lambda_b > \lambda_v$,

then $\mu_r < \mu_g < \mu_b < \mu_v \qquad (\because\ \mu = a + b/\lambda^2)$

$\therefore \quad v_r > v_g > v_b > v_v \qquad (\because\ v = c/\mu)$

After travelling through the slab, red colour will emerge first because it has largest velocity in slab.

12. (c) greater than θ_2

$$\because\ {}^{w}\mu_g = \frac{\mu_g}{\mu_w} = \frac{3/2}{4/3} = \frac{9}{8}$$

As ${}^{w}\mu_g = \frac{9}{8} < {}^{a}\mu_w < {}^{a}\mu_g$

$\therefore \quad \theta > \theta_2 > \theta_1$

13. (b) $P/2$

14. (a) 1.47

According to the question,

When a biconvex lens of glass is immersed in a liquid and behaves as a plane glass plate, then

$$f = \infty \text{ or } \frac{1}{f} = 0$$

Now from Lens maker's formula,

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

$$\frac{\mu_g}{\mu_L} - 1 = 0$$

or $\mu_g = \mu_L = 1.47$

15. (c) 30 cm

Given that,

Focal length of equiconvex lens = 15 cm

from lens maker's formula, $\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$

Taking $R_1 = R$ and $R_2 = -R$

$$\therefore \quad \frac{1}{f} = (\mu - 1)\left(\frac{1}{R} + \frac{1}{R}\right) = (\mu - 1) \times \frac{2}{R} \qquad ...(1)$$

For each part (plano convex lens), $R_1 = R$ and $R_2 = \infty$

$$\therefore\ \frac{1}{f'} = (\mu - 1)\left(\frac{1}{R} - \frac{1}{\infty}\right) = \frac{\mu - 1}{R}$$

$$\text{or } \frac{2}{f'} = (\mu - 1) \times \frac{2}{R} \qquad ...(2)$$

From eqs. (1) and (2), we get

$$\frac{1}{f} = \frac{2}{f'} \Rightarrow f' = 2f$$

$f' = 2 \times 15 = 30$ cm

16. (a) Focal length is increased when red light is used.

17. (b) Decrease

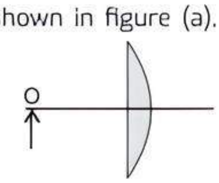
18. (d) a convergent and a divergent beam.

As $\mu_2 > \mu_1$, the upper half of the lens will become diverging and $\mu_1 > \mu_3$, the lower half of the lens will become converging.

19. (c) act as a convex lens irrespective of the side on which the object lies.

Here, $\mu = 1.5$

If object lies on plane side as shown in figure (a), then $R_1 = \infty$, $R_2 = -20$ cm



(a)

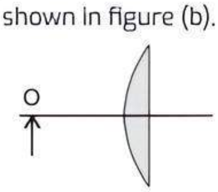
$$\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

$$= (1.5 - 1)\left(\frac{1}{\infty} + \frac{1}{20}\right) = \frac{1}{40}$$

or $f = +40$ cm

The lens behaves as convex lens.

If object lies on its curved side as shown in figure (b), then $R_1 = 20$ cm, $R_2 = \infty$



(b)

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

$$= (1.5 - 1)\left(\frac{1}{20} - \frac{1}{\infty}\right) = \frac{1}{40}$$

or $f' = +40$ cm

The lens also behaves as convex lens.

20. (d) 4.5 cm and 9 cm

Here, $f = 6$ cm, $\mu = 1.5$, $R_1 = R$, $R_2 = -2R$

According to lens maker's formula,

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

$$\therefore\ \frac{1}{6} = (1.5 - 1)\left(\frac{1}{R} - \frac{1}{-2R}\right) = 0.5\left(\frac{1}{R} + \frac{1}{2R}\right)$$

$$R = \frac{1.5 \times 6}{2} = 4.5 \text{ cm}$$

$\therefore\ R_1 = 4.5$ cm and $R_2 = 2 \times 4.5 = 9$ cm

21. (b) 5 D

As the image formed is real, therefore lens must be convex, $v = 20$ cm. Let f_1 be focal length for this lens.

$$\therefore \frac{1}{f_1} = \frac{1}{v} - \frac{1}{u} = \frac{1}{20} - \frac{1}{u}$$

After placing it in contact with another lens, the image shifted to 10 cm towards the combination.
i.e., $v = (20 - 10)$ cm $= 10$ cm

$$\therefore \frac{1}{10} - \frac{1}{u} = \frac{1}{f_1} + \frac{1}{f_2} = \left(\frac{1}{20} - \frac{1}{u}\right) + \frac{1}{f_2} \Rightarrow f_2 = 20\text{ cm}$$

$$\therefore P = \frac{100}{20}\text{m}^{-1} = 5\text{D}$$

22. (a) red colour

23. (d) 60°

Using, $\mu = \dfrac{\sin\left(\dfrac{A+\delta_m}{2}\right)}{\sin\dfrac{A}{2}}$

According to the question, $\delta_m = A$

$$\therefore \sqrt{3} = \frac{\sin\left(\dfrac{A+A}{2}\right)}{\sin\dfrac{A}{2}} \qquad (\text{Given, } \mu = \sqrt{3})$$

$$\sqrt{3} = \frac{\sin A}{\sin\dfrac{A}{2}} = \frac{2\sin\dfrac{A}{2}\cos\dfrac{A}{2}}{\sin\dfrac{A}{2}} \text{ or } \cos\frac{A}{2} = \frac{\sqrt{3}}{2} = \cos 30°$$

$$\Rightarrow \frac{A}{2} = 30° \Rightarrow A = 60°$$

24. (b) lesser than the focal length of eyepiece

25. (d) have high resolution

26. (d) Power doesn't depends on diameter.

27. (c) telescope barrel

28. (d) All of the above

Given, $f_o = 20$ m and $f_e = 2$ cm $= 0.02$ m
In normal adjustment,
Length of telescope tube, $L = f_o + f_e$
$= 20 + 0.02 = 20.02$ m

and magnification, $m = \dfrac{f_o}{f_e} = \dfrac{20}{0.02} = 1000$

The image formed is inverted with respect to the object.

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

30. (c) Shining of air bubble in water is on account of total internal reflection.

31. (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.

32. (c) Assertion (A) is true but Reason (R) is false.

33. (b) Refractive index, $\mu = \dfrac{\mu_g}{\mu_c} = \dfrac{1.5}{1.65} < 1$

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

$\therefore$ f becomes negative and the lens behaves as a diverging lens.

34. (b) Combination of lenses helps to obtain desired magnification. It also enhances the sharpness of the image. Since the image formed by the first lens becomes the object for the second, the total magnification of the combination is a product of magnification of individual lenses.

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

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

for lens, $\mu = 1.5$ placed in air,

$$\frac{1}{f} = (1.5 - 1)\frac{2}{R} \Rightarrow f = R.$$

36. (d) The distance between the object and its real image is minimum when its 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 $v + u = 4f$

37. (a) Focal length of lens immersed in water is four times the focal length of lens in air. It means $f_w = 4f_a = 4 \times 10 = 40$ cm.

38. (a) For a thin prism, the relation between angle of deviation δ, angle of prism A and refractive index μ is $\delta = (\mu - 1)A$.

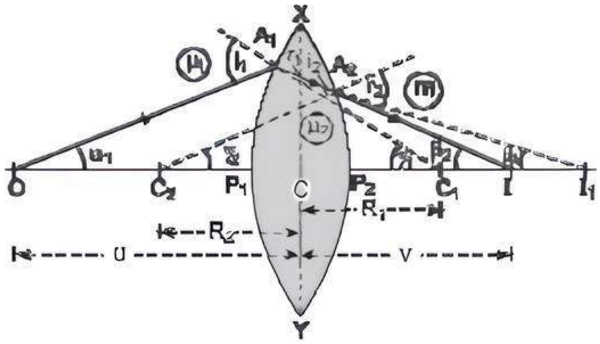
39. (a) Microscope is an optical instrument which forms a magnified image of a small nearby object and thus, increases the visual angle subtended by the image at the eye so that the object is seen to be bigger and distinct. Therefore, angular magnification for image is more than object.

40. equal
41. convex mirror
42. velocity
43. medium A
44. critical angle
45. diverging/concave
46. $\sqrt{3}$
47. emergence
48. refraction
49. parallel
50. concave mirror
51. simple magnifier

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:

Q 1. **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

Q 2. **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

Q 3. **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

Q 4. **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

Answers

1. (b) 1.33

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

Since, $R_2 \to \infty$

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

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

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

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

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

and in terms of power, we can write

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

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:

Q 1. **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

Q 2. **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

Q 3. **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

Q 4. **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 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

Answers

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,

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

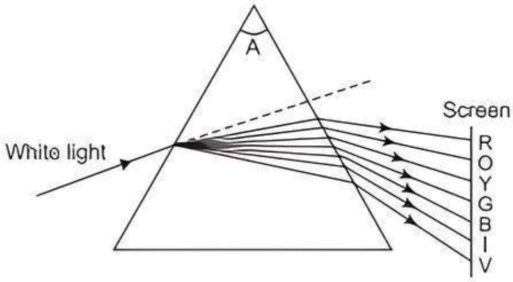
$$\frac{1}{20}=\frac{-1}{3u}-\frac{1}{u}$$

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

$$u=\frac{-4\times20}{3}=\frac{-80}{3}=26.66\text{cm}$$

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:

Q 1. **Which one of the following colours will suffer greatest dispersion?**

a. Violet b. Indigo

c. Blue d. Red

Q 2. **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.

Q 3. **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

Q 4. **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°

Answers

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, $A = 60°$, $\mu = \sqrt{2}$

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

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

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

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

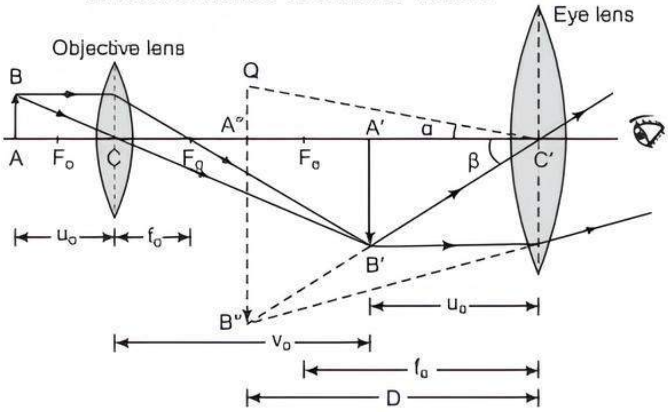
$\delta_m = 90° - 60° = 30°$ and $\delta_m = 2i - A$

$30° = 2i - 60°$

$i = 45°$

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:

Q 1. 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

Q 2. 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

Q 3. 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

Q 4. Final image formed by compound microscope is:

a. inverted b. erect
c. virtual d. highly diminished

Answers

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 as 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:

Q 1. Refractive index of a medium depend upon which factors?

Q 2. 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?

Q 3. 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?

Q 4. When light is refracted into a medium, what will be change in its wavelength and frequency?

Answers

1. Refractive index of a medium depends upon nature and temperature of the medium and wavelength of light.
2. Given, $v = 5 \times 10^{14}$ Hz; $\lambda = 450 \times 10^{-9}$ m.
$c = 3 \times 10^8$ ms^{-1}
Refractive index of the liquid,
$$\mu = \frac{c}{v} = \frac{c}{v\lambda} = \frac{3 \times 10^8}{5 \times 10^{14} \times 450 \times 10^{-9}} = 1.33$$
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)*

Q 1. Why the image formed at infinity is often considered most suitable for viewing? Explain.

Q 2. In modern microscopes, multi-component lenses are used for both the objective and the eyepiece. Why?

Q 3. 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.**

Answers

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.

Very Short Answer Type Questions

Q 1. Is it possible that the laws of reflection change, if we use spherical mirror instead of a plane mirror?

Ans. No, it is not possible to change the law of reflection.

Q 2. Out of convex mirror and concave mirror whose focus is situated behind the mirror?

Ans. Convex mirror has the focus situated behind the mirror.

Q 3. When a wave is propagating from a rarer to a denser medium, which characteristic of the wave does not change and why? *(CBSE 2015)*

Ans. Frequency, because frequency is a characteristic of the source of waves.

Q 4. For the same angle of incidence, the angle of refraction into two media *A* and *B* are 25° and 35° respectively. In which medium is the speed of the light less? *(CBSE 2015)*

Ans. In medium *A*, speed of light is less.
As we know,
$$\mu = \frac{\sin i}{\sin r} = \frac{c}{v} \Rightarrow v = \frac{c \times \sin r}{\sin i} \Rightarrow v \propto \sin r$$
[$\because$ angle of incidence is same]

But $r_A < r_B \Rightarrow v_A < v_B$

Q 5. What is the ratio of the velocity of the wave in the two media of refractive indices μ_1 and μ_2? *(CBSE 2015)*

Sol. The ratio of the velocity, $\frac{v_1}{v_2} = \frac{\mu_2}{\mu_1}$

Q 6. How does the refractive index of a transparent medium depend on wavelength of light used? *(CBSE 2015)*

Ans. Refractive index of a medium decreases with increase in wave length of light because the refractive index of a medium is inversely proportional to the wavelength of the light used.

$\because$ Refractive index of medium $\mu = \frac{c}{v}$

or $\mu \propto \frac{1}{v}$

and $c = v\lambda$

$\therefore$ $c \propto \lambda$

Hence, $\mu \propto \frac{1}{\lambda}$

Q 7. When monochromatic light is incident on a surface separating two media, the reflected and refracted light both have the same frequency as the incident frequency. Why? *(CBSE 2016)*

Ans. Reflection and refraction arise through interaction of incident light with atomic constituents of matter which vibrate with the same frequency as that of incident light. Hence, frequency remains unchanged.

Q 8. When a glass slab is placed on an ink dot, ink dot appears to be raised. Why?

Ans. Due to refraction of light.

Q 9. When monochromatic light travels from one medium to another, its wavelength changes but its frequency remains same. Why?

Ans. Frequency is a characteristic of the source of waves. That is why, it remains the same. But wavelength is a characteristic of medium, so wavelength changes.

Q 10. When light travels from a rarer to a denser medium, the speed decreases. Does this decrease in speed imply a reduction in the energy carried by the wave? *(CBSE 2016)*

Ans. No, energy carried out by a wave depends on the amplitude of the wave, not on the speed of wave propagation.

Q 11. The refractive index of diamond is much greater than that of glass. How does a diamond cutter make use of this fact?

Ans. The refractive index of diamond is much higher than that of glass. Due to high refractive index, the critical angle for diamond-air interface is low. The diamond is cut suitably so that the light entering the diamond from any face suffers multiple total internal reflections at the various surfaces.

Q 12. State one assumption made in deriving the formula $\frac{n_2}{v}-\frac{n_1}{u}=\frac{n_2-n_1}{R}$ for refraction at a spherical interface.

Ans. The aperture of the spherical surface is small.

Q 13. Define the power of a lens. Write its SI unit. *(CBSE 2018)*

Ans. The ability of lens to converge or diverge the rays of incident light on it, is called the power of a lens. Its S.I. unit is dioptre (D) or m^{-1}.

Q 14. A concave lens of refractive index 1.5 is immersed in a medium of refractive index 1.65. What is the nature of the lens? *(CBSE 2015)*

Ans. A concave lens is made up of certain material behaves as a diverging lens, when it is placed in a medium of refractive index less than the refractive index of the material of the lens and behaves as a converging lens, when it is placed in a medium of refractive index greater than the refractive index of the material of the lens.

In the given case, concave lens is immersed in medium having refractive index greater than the refractive index of the material of the lens $(1.65 > 1.5)$. Therefore, it will behave as a converging lens.

Q 15. A biconvex lens made of a transparent material of refractive index 1.25 is immersed in water of refractive index 1.33. Will the lens behave as a converging or a diverging lens? Give reason.

Ans. When a lens is placed in a liquid, where refractive index is more than that of the material of lens, then the nature of the lens changes. So, when a biconvex lens of refractive index 1.25 is immersed in water (refractive index 1.33), *i.e.*, in the liquid of higher refractive index, its nature will change. So, biconvex lens will act as biconcave lens or diverging lens.

Q 16. A biconvex lens of focal length *f* is cut into two identical plano-convex lenses. What will be the focal length of each part? *(CBSE 2020)*

Ans. The focal length will be $2f$.

Q 17. How does the angle of minimum deviation of a glass prism vary, if the incident violet light is replaced by red light? Give reason. *(CBSE 2017)*

Ans. When incident violet light is replaced with red light, the angle of minimum deviation of glass decreases because, as $\lambda_{red} > \lambda_{violet}$, so $\mu_{red} < \mu_{violet}$ and $\delta_{red} < \delta_{violet}$.

Q 18. Write the relationship between angle of incidence *i*, angle of prism *A* and angle of minimum deviations from a triangular prism.

Ans. The relation between the angle of incidence *i*, angle of prism *A* and the angle of minimum deviation δ_m for a triangular prism is given by

$$i=\frac{A+\delta_m}{2}$$

Q 19. For a glass prism $(\mu=\sqrt{3})$, the angle of minimum deviation is equal to the angle of prism. Find the angle of prism.

Sol. For the condition of minimum deviation, the angle of prism should be equal to the angle of minimum deviation.

We know, $\mu=\dfrac{\sin\left(\dfrac{A+\delta_m}{2}\right)}{\sin\dfrac{A}{2}}$

$$\sqrt{3}=\frac{\sin\left(\dfrac{A+A}{2}\right)}{\sin\dfrac{A}{2}}=\frac{\sin A}{\sin\dfrac{A}{2}}$$

$$\Rightarrow \quad \frac{2\sin\dfrac{A}{2}\cdot\cos\dfrac{A}{2}}{\sin\dfrac{A}{2}}=\sqrt{3}$$

$$\Rightarrow \quad \cos\frac{A}{2}=\frac{\sqrt{3}}{2}=\cos 30^\circ$$

$$\therefore \quad A=30^\circ\times 2=60^\circ$$

The angle of prism is 60°.

Q 20. Does the magnifying power of a microscope depend on the colour of the light used? Justify your answer. *(CBSE 2017)*

Ans. A microscope consists of two lenses and we know focal length of a lens depends on the refractive index of the lens which itself depends on the wave length or colour of the light used. Therefore, we can say the magnifying power of a microscope depends on the colour of the light used.

Q 21. An astronomical telescope may be a refracting type or a reflecting type. Which of the two produces image of better quality? Justify your answer.

Ans. Reflecting type astronomical telescope produces better quality image since, due to reflection, there is no loss in intensity of light.

Q 22. A giant refracting telescope at an observatory has an objective lens of focal length 15 m. If an eyepiece lens of focal length 1.0 cm is used, find the angular magnification of the telescope.

Sol. Given, $f_o = 15$ cm, $\Rightarrow$ $f_e = 1.0$ cm $= 1.0 \times 10^{-2}$ m

Angular magnification of telescope,

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

Short Answer Type-I Questions

Q 1. Use the mirror equation to show that an object placed between F and $2F$ of a concave mirror produces a real image beyond $2F$. *(CBSE 2015)*

Sol. According to the mirror equation, we have

$$1/v + 1/u = 1/F$$

where, u = distance to the object from the mirror

v = distance of the image from the mirror hand

F = focal length of the mirror.

Applying new cartesian sign convention, we get

$F = -$ ve and $u = -$ve

Given, $F < u < 2F$

When $u = -F$, we get $\frac{1}{v} = \frac{1}{(-F)} - \frac{1}{(-F)} = 0$

$\Rightarrow \quad v = \infty$

From the mirror formula, when $u = -2F$

$$\Rightarrow \frac{1}{-2F} + \frac{1}{v} = \frac{1}{-F}$$

$$\Rightarrow \frac{1}{v} = \frac{1}{2F} - \frac{1}{F} = \frac{-1}{2F}$$

$\therefore$ $F < u < 2F$, $\infty < v < 2F$

Q 2. When monochromatic light travels from a rarer to a denser medium, explain the following giving reasons.

(i) Is the frequency of reflected and refracted light same as the frequency of incident light?

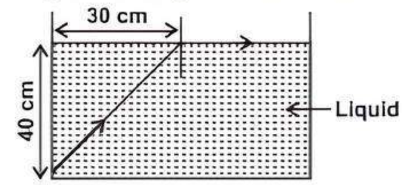
(ii) Does the decrease in speed imply a reduction in the energy carried by light wave?

Ans. (i) The frequency of reflected and refracted light remains same as the frequency of incident light because frequency only depends on the source of light.

(ii) Since, the frequency remains same, hence there is no reduction in energy.

Q 3. (i) Define refractive index of a medium.

(ii) In the following ray diagram, calculate the speed of light in the liquid of unknown refractive index.



Ans. (i) Refractive index of a medium is the ratio of speed of light (c) in free space to the speed of light (v) in that medium.

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

(ii) Refractive index, $\mu = \frac{c}{v} = \frac{1}{\sin i_C} \Rightarrow \frac{3 \times 10^8}{v} = \frac{1}{\frac{30}{50}}$

$$v = \frac{30}{50} \times 3 \times 10^8$$

$$= 1.8 \times 10^8 \text{ m/s}$$

Q 4. When light travels from an optically denser medium to a rarer medium, why does the critical angle of incidence depend on the colour/wavelength of light? *(CBSE 2015)*

Ans. Refractive index, $\mu = \frac{1}{\sin i_C} \Rightarrow i_C = \sin^{-1}\left(\frac{1}{\mu}\right)$

As $\mu = a + \frac{b}{\lambda^2}$.

Hence, critical angle would also be different for different colours/wavelengths of light.

Q 5. The refractive indices of two media A and B are 2 and $\sqrt{2}$ respectively. What is the critical angle for their interface? *(CBSE 2023)*

Sol. Given,

Refractive index of media, $A = 2$

Refractive index of media, $B = \sqrt{2}$

or $\quad \mu_A = 2$ and $\mu_B = \sqrt{2}$

$$\therefore \quad \mu = \frac{\mu_A}{\mu_B} = \frac{2}{\sqrt{2}}$$

Now, critical angle, $\sin C = \frac{1}{\mu}$

$$\therefore \quad \sin C = \frac{1}{\frac{2}{\sqrt{2}}} = \frac{\sqrt{2}}{2} = \frac{1}{\sqrt{2}}$$

Thus, $\quad C = \sin^{-1}\left(\frac{1}{\sqrt{2}}\right) = 45°$

Q 6. How does the refractive index of a transparent medium depend on the wavelength of incident light used? Velocity of light in glass is 2×10^8 m/s and in air is 3×10^8 m/s. If the ray of light passes from glass to air, calculate the value of critical angle. *(CBSE 2015)*

Ans. The refractive index of a transparent medium is inversely proportional to the wavelength of incident light. The relationship between the two is given by,

$$\mu = \lambda_0/\lambda$$

where,

μ = Refractive index of medium,

λ_0 = Wavelength of incident light in vacuum

and λ = Wavelength of incident light in medium

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

Velocity of light in glass, $v_g = 2 \times 10^8$ m/s

The refractive index of glass is given by, $\mu_g = c/v_g$

Where c is speed of light in vacuum.

The refractive index of air is given by, $\mu_a = \dfrac{c}{v_a}$

$\therefore$ The refractive index of glass w.r.t. air will be

$${}^a\mu_g = \frac{\mu_g}{\mu_a}$$

$${}^a\mu_g = \frac{v_a}{v_g} = \frac{3 \times 10^8}{2 \times 10^8} = 1.5$$

We know that ${}^a\mu_g = 1/\sin C$

where, C is the critical angle for the interface.

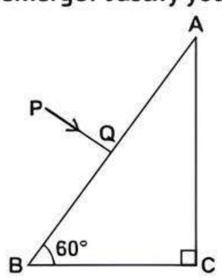
$\therefore$ $1/\sin C = 1.5$

$\Rightarrow$ $\sin C = 1/1.5 \Rightarrow C = \sin^{-1}(0.66)$

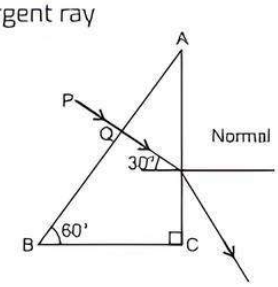
COMMON ERROR

Several students could not get angle C correctly from $\dfrac{1}{\sin C} = \mu$ well understood.

Q 7. A ray *PQ* incident normally on the refracting face *BA* is refracted in the prism *BAC* index 1.5. Complex the path of ray through the prism. From which face will the ray emerge? Justify your answer.



Ans. Path of emergent ray



Ray will emerge from face-AC

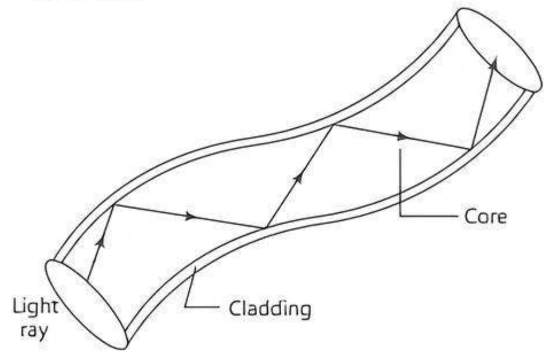
Justification: Here, $i_c = \sin^{-1}\left(\dfrac{2}{3}\right) = \sin^{-1}(0.6)$

$\angle i$ on face AC is 30° which is less than $\angle i_c$. Hence, the ray gets refracted here.

Q 8. State with the help of a ray diagram the working principle of optical fibres. Write one important use of optical fibres. *(CBSE 2019)*

Ans. Optical fibre works on the principle of total internal reflection.

When a light ray, travelling from denser to a rarer medium is incident at an angle greater than the critical angle, then it is reflected back into the same medium. This phenomenon is called total internal reflection.



Optical fibre

Optical 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.

Optical fibre is used in communication system.

Q 9. Using lens maker's formula, derive the thin lens formula $\dfrac{1}{f} = \dfrac{1}{v} - \dfrac{1}{u}$ for a biconvex lens. *(CBSE 2020)*

Ans. A lens is called thin lens when its thickness is negligible in comparison of its radius of curvature.

Here, we assume that the medium on the both sides of the lens is same.

The formula of reflection,

$$\frac{1}{v} - \frac{1}{u} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \quad ...(1)$$

We know that, when an object is placed at infinity, its image will formed on second focus *i.e.*, when $u = \infty$ then $v = f$.

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

$$\Rightarrow \quad \frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \quad ...(2)$$

This is called lens maker's formula.

Now, from eqs. (1) and (2), we get

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

This is the formula of focal length of thin lens.

TiP

When $u = \infty$, $v = f$

Q 10. Calculate the radius of curvature of an equi-concave lens of refractive index 1.5, when it is kept in a medium of refractive index 1.4, to have a power of −5D? *(CBSE 2019)*

Sol. Given, $\mu_1 = 1.4$, $\mu_2 = 1.5$, $P = -5D$

Using lens maker's formula,

$$P = \frac{1}{f} = \left(\frac{\mu_2 - \mu_1}{\mu_1}\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

$$\therefore \quad -5 = \left(\frac{1.5 - 1.4}{1.4}\right)\left(-\frac{1}{R} - \frac{1}{R}\right)$$

[$\because$ for equi-concave lens, $R_1 = -R$ and $R_2 = R$]

$$\therefore \quad -5 = \frac{0.1}{1.4}\left(-\frac{2}{R}\right)$$

$$R = \frac{1}{14} \times \frac{2}{5} = \frac{1}{35} = 0.0286\text{m} = 2.86\text{cm}$$

Q 11. Show that the least possible distance between an object and its real image in a convex lens is $4f$, where f is the focal length of the lens. *(CBSE SQP 2023-24)*

Sol. Suppose I is the real image of an object O. Let d be the distance between them. If the image distance is x, the object distance will be $(d - x)$.

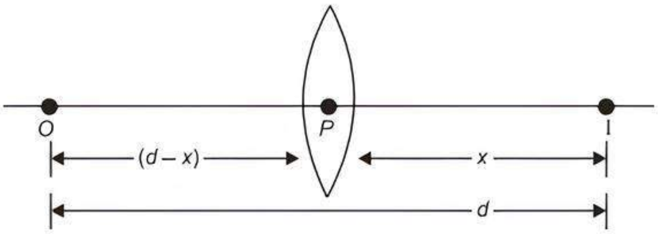
Thus, $u = -(d - x)$ and $v = +x$

Substituting in the lens formula, we have

$$\frac{1}{x} - \frac{1}{-(d-x)} = \frac{1}{f}$$

or $$\frac{1}{x} + \frac{1}{(d-x)} = \frac{1}{f}$$

or $$x^2 - xd - fd = 0$$



For a real image, the value of x must be real, *i.e.*, the roots of the above equation must be real. This is possible if

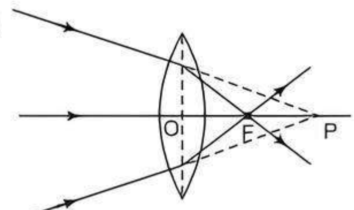
$$d^2 \leq 4fd$$

or $$d \geq 4f$$

Hence, $4f$ is the minimum distance between the object and its real image formed by a convex lens.

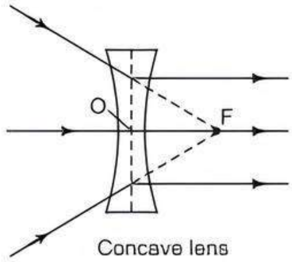
Q 12. A beam of light converges at a point P. Draw ray diagrams to show where the beam will converge if: (i) a convex lens and (ii) a concave lens is kept in the path of the beam. *(CBSE 2019)*

Ans. (i)



Convex lens

(ii)



Concave lens

Q 13. (i) An equi-convex lens of focal length f is cut into two identical plane convex lenses. How will the power of each part be related to the focal length of the original lens?

(ii) A double convex lens of + 5D is made of glass of refractive index 1.55 with both faces of equal radii of curvature. Find the value of its radius of curvature. *(CBSE 2015)*

Sol. (i) The focal length of original equi-convex lens is f. Let the focal length of each part after cutting be F.

Here, $$\frac{1}{f} = \frac{1}{F} + \frac{1}{F} \Rightarrow \frac{1}{f} = \frac{2}{F}$$

$\Rightarrow$ $$f = \frac{F}{2} \Rightarrow F = 2f$$

Power of each part will be given by

$$P = \frac{1}{F} \Rightarrow P = \frac{1}{2f}$$

(ii) From lens maker's formula, we have

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

$$5 = (1.55 - 1)\left\{\frac{1}{R} - \left(\frac{1}{-R}\right)\right\} \quad \left[\because \begin{array}{l} R_1 = R \text{ and} \\ R_2 = -R \end{array}\right]$$

or $$5 = 0.55 \times \frac{2}{R}$$

$$R = \frac{0.55 \times 2}{5}$$

$$= 0.22 \text{ m} = 22 \text{ cm}$$

Q 14. Write two characteristics of image formed when an object is placed between the optical centre and focus of a thin convex lens. Draw the graph showing variation of image distance v with object distance u in this case.

Ans. Characteristics of the image formed

(i) Virtual (ii) Enlarged.

(iii) On the same side of the object (any two)

The lens formula:

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

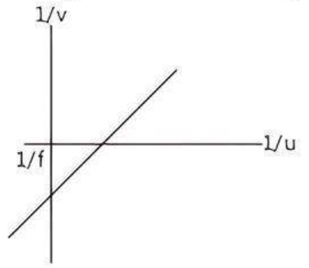
For virtual image

u is –ve, v is –ve and f is +ve

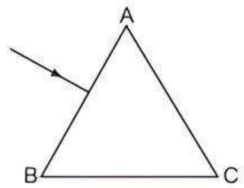
So, the equation becomes,

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

which is a straight line in the form $y = mx - c$

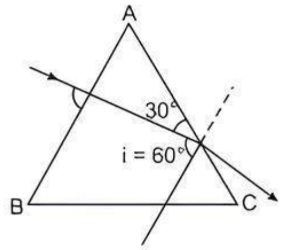


Q 15. The figure shows a ray of light falling normally on the face AB of an equilateral glass prism having refractive index $\frac{3}{2}$, placed in water of refractive index $\frac{4}{3}$. Will this ray suffer total internal reflection on striking the face AC? Justify your answer. *(CBSE 2018)*



Ans. Given, refractive index of water, $\mu_w = \frac{4}{3}$

Refractive index of glass prism, $\mu_g = \frac{3}{2}$



For total internal reflection occurrence the incident angle must be greater than critical angle.

Let us calculate critical angle C.

As we know that, $\sin C = \frac{1}{\mu}$

where, $\mu = \frac{\text{refractive index of glass } ({}_a\mu_g)}{\text{refractive index of water } ({}_a\mu_w)}$

$$\sin C = \frac{1}{\left(\frac{{}_a\mu_g}{{}_a\mu_w}\right)} = \frac{1}{\left(\frac{3/2}{4/3}\right)} = \frac{1}{9/8}$$

$$\Rightarrow \quad \sin C = \frac{8}{9} = 0.88$$

$$\Rightarrow \quad C = \sin^{-1}(0.88) = 61.6^\circ$$

As the critical angle, *i.e.*, 61.6° is greater than the angle of incidence, *i.e.*, 60°, hence total internal reflection will not occur.

COMMON ERROR

Students often get confused between ${}_a\mu_g$ and ${}_g\mu_a$.

Q 16. An equilateral glass prism has a refractive index 1.6 in air. Calculate the angle of minimum deviation of the prism, when kept in a medium of refractive index $4\sqrt{2}/5$. *(CBSE 2019)*

Sol. Given, $A = 60^\circ$ (for equilateral prism), $\mu_1 = \frac{4\sqrt{2}}{5}$, $\mu_2 = 1.6$

The refractive index is given by

$$\frac{\mu_2}{\mu_1} = \frac{\sin\left(\frac{A+\delta_m}{2}\right)}{\sin\left(\frac{A}{2}\right)}$$

where, δ_m = angle of minimum deviation.

$$\frac{1.6}{\frac{4\sqrt{2}}{5}} = \frac{\sin\left(\frac{60^\circ+\delta_m}{2}\right)}{\sin\left(\frac{60^\circ}{2}\right)}$$

$$\Rightarrow \quad \sqrt{2} \times \sin 30^\circ = \sin\left(\frac{60^\circ+\delta_m}{2}\right)$$

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

$$\Rightarrow \quad \sin 45^\circ = \sin\left(\frac{60^\circ+\delta_m}{2}\right)$$

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

$$\Rightarrow \quad 90^\circ = 60^\circ + \delta_m$$

$$\Rightarrow \quad \delta_m = 30^\circ$$

Q 17. A ray of monochromatic light passes through an equilateral glass prism in such a way that the angle of incidence is equal to the angle of emergence and each of these angles is 3/4 times the angle of the prism. Determine the angle of deviation and the refractive index of the glass prism. *(CBSE SQP 2023-24)*

Sol. Here angle of prism $A = 60^\circ$, angle of incidence i = angle of emergence e and under this condition angle of deviation is minimum

$\therefore$ $i = e = \frac{3}{4}A = \frac{3}{4} \times 60^\circ = 45^\circ$ and $i + e = A + \delta$.

hence, $\delta_m = 2i - A = 2 \times 45^\circ - 60^\circ = 30^\circ$

$\therefore$ Refractive index of glass prism

$$n = \frac{\sin\left(\frac{A+\delta_m}{2}\right)}{\sin\left(\frac{A}{2}\right)} = \frac{\sin\left(\frac{60^\circ+30^\circ}{2}\right)}{\sin\left(\frac{60^\circ}{2}\right)} = \frac{\sin 45^\circ}{\sin 30^\circ} = \frac{1/\sqrt{2}}{1/2} = \sqrt{2}.$$

Q 18. Define the magnifying power of a compound microscope when the final image is formed at infinity. Why must both the objective and the eyepiece of a compound microscope has short focal lengths? Explain. *(CBSE 2017)*

Ans. Magnifying Power of Compound Microscope: Angular magnification or magnifying power of compound microscope is defined as ratio of angle made at eye by image formed at infinity to the angle made by object, if placed at distance of distinct vision from an unaided eye.

Magnification, $m = \frac{L}{f_o}\left(1+\frac{D}{f_e}\right)$

where L is length of the tube of microscope.

As, $m \propto \frac{1}{f_o}$ and $m \propto \frac{1}{f_e}$

$\therefore$ Both eyepiece and objective must be of smaller focal lengths, so that magnification is higher.

TiP

Angular magnification and magnifying power are same.

Q 19. You are given two converging lenses of focal lengths 1.25 cm and 5 cm to design a compound microscope. If it is desired to have a magnification of 30, find out the separation between the objective and the eyepiece. *(CBSE 2015)*

Sol. Given,

$$f_o = 1.25 \text{ cm}$$
$$f_e = 5 \text{ cm and } m = 30$$

$\therefore$ Magnification of compound microscope

$$m = m_o \times m_e = \frac{L}{f_o}\left(1+\frac{D}{f_e}\right)$$

$$30 = \frac{L}{1.25}\left(1+\frac{25}{5}\right)$$

$$30 \times 1.25 = 6L$$

$$L = \frac{30 \times 1.25}{6} = 5 \times 1.25$$

$$= 6.25 \text{ cm}$$

Q 20. A small telescope has an objective lens of focal length 150 cm and eyepiece of focal length 5 cm. What is the magnifying power of the telescope for viewing distant objects in normal adjustments?

If this telescope is used to view a 100m tall tower 3km away, then what is the height of the tower formed by the objective lens? *(CBSE 2015)*

Sol. For telescope,

Focal length of objective lens, $f_o = 150$ cm

Focal length of eye lens, $f_e = 5$ cm

$$\therefore m = \frac{f_o}{f_e}$$

$$= \frac{150}{5} = 30$$

For objective lens, $\frac{1}{v_o} - \frac{1}{u_o} = \frac{1}{f_o}$

$$\Rightarrow \quad \frac{1}{1.5} = \frac{1}{v_o} - \frac{1}{(-3000)}$$

$$\Rightarrow \quad \frac{1}{v_o} = \frac{1}{1.5} - \frac{1}{3000}$$

$$v_o = 1.5 \text{ m}$$

$\therefore$ Magnification, $\frac{h_i}{h_o} = \frac{v_o}{u_o}$

$$h_i = \frac{v_o}{u_o} \times h_o$$

$$\Rightarrow \quad \frac{1.5}{3000} \times 100 = 0.05\text{m}$$

Hence, height of the tower = 5 cm

Q 21. In an astronomical telescope, in normal adjustment a straight black line of length L is drawn on the objective lens. The eyepiece forms a real image of this line whose length is l. What is the angular magnification of the telescope? *(CBSE SQP 2023-24)*

Ans. Let f_o and f_e be the focal lengths of the objective and eyepiece respectively. For normal adjustment, distance from the objective to the eyepiece (tube length) = $f_o + f_e$. Treating the line on the objective as the object and the eyepiece as the lens, $u = -(f_o + f_e)$ and $f = f_e$

$1/v - 1/-(f_o + f_e) = 1/f_e$

or $1/v = 1/f_e - 1/f_o + f_e = f_o/(f_o + f_e)\, f_e$

or $v = (f_o + f_e) f_e / f_o$

Magnification = $|v/u| = f_e/f_o$ = image size/object size = l/L

$\therefore f_o/f_e = L/l$ = magnification of telescope in normal adjustment.

Short Answer Type-II Questions

Q 1. An object is placed at (i) 10 cm, (ii) 5 cm in front of a concave mirror of radius of curvature 15 cm. Find the position, nature and magnification of the image in each case. *(NCERT EXERCISE)*

Sol. The focal length, $f = -15/2$ cm $= -7.5$ cm

(i) The object distance, $u = -10$ cm.

$$\therefore \quad \frac{1}{v} + \frac{1}{-10} = \frac{1}{-7.5}$$

$$\text{or } v = \frac{10 \times 7.5}{-2.5} = -30 \text{ cm}$$

The image is 30 cm from the mirror on the same side as the object.

Also magnification, $m = -\frac{v}{u} = -\frac{(-30)}{(-10)} = -3$

The image is magnified, real and inverted.

(ii) The object distance, $u = -5$ cm.

$$\therefore \quad \frac{1}{v} + \frac{1}{-5} = \frac{1}{-7.5}$$

or $v=\frac{5\times7.5}{(7.5-5)}=15$ cm

This image is formed at 15 cm behind the mirror. It is a virtual image.

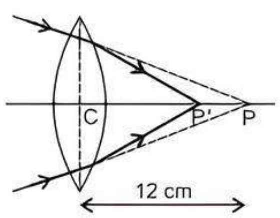
Magnification $m=-\frac{v}{u}=-\frac{15}{(-5)}=3$

The image is magnified virtual and erect.

Q 2. 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 (i) a convex lens of focal length 20 cm and (ii) a concave lens of focal length 16 cm?

(NCERT EXERCISE)

Ans. The point *P* on the right of lens works as a virtual source whose real image is formed at *P'*.



(i) For Convex Lens:

$u=+12$ cm,

$f=+20$ cm.

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

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

$=\frac{1}{12}+\frac{1}{20}=\frac{5+3}{60}=\frac{8}{60}$

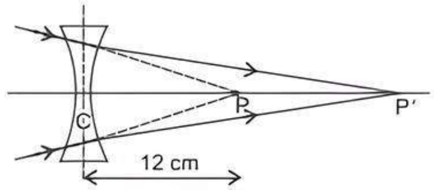
or $v=\frac{60}{8}=7.5$ cm.

The beam converges at 7.5 cm from the lens.

(ii) For Concave Lens: $u=+12$ cm, $f=-16$ cm.

$\frac{1}{v}=\frac{1}{u}+\frac{1}{f}=\frac{1}{12}-\frac{1}{16}=\frac{1}{48}$

$v=48$ cm.



The beam diverges at 48 cm from the lens.

Q 3. (i) Monochromatic light of wavelength 589 nm is incident from air on a water surface. If μ for water is 1.33, find the wavelength, frequency and speed of the refracted light.

(ii) A double convex lens is made of a glass of refractive index 1.55, with both faces of the same radius of curvature. Find the radius of curvature required, if the focal length is 20 cm.

(CBSE 2017)

Sol. (i) In refraction, frequency remains same so,

$v_{\text{refracted beam}}=v_{\text{incident beam}}$

Also, $\mu_{21}=\frac{v_1}{v_2}=\frac{v\lambda_1}{v\lambda_2}=\frac{\lambda_1}{\lambda_2}$ $[\because v=v\lambda]$

$\Rightarrow\ v_2=\frac{v_1}{\mu_{21}}=\frac{3.0\times10^8}{1.33}=2.25\times10^8\,\text{ms}^{-1}$

$\therefore\ \lambda_2=\frac{\lambda_1}{\mu_{21}}=\frac{589}{1.33}=442.85\approx443\text{nm}$

So, wavelength of refracted beam = 443 nm and its speed = $2.25\times10^8\,\text{ms}^{-1}$.

(ii) For a biconvex (double convex) lens, using lens maker's formula,

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

Here, $f=20$ cm, $\mu=1.55\ \Rightarrow\ R_1=+R$ and $R_2=-R$

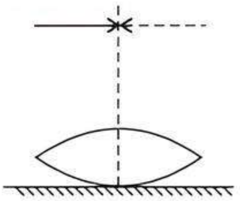
$\therefore$ We have, $\frac{1}{f}=(\mu-1)\frac{2}{R}$

$\Rightarrow\ R=2(\mu-1)f=2(1.55-1)\times20$

$=22$ cm

$\therefore$ Required radius of curvature is 22 cm.

Q 4. A symmetric bi-convex lens of radius of curvature *R* and made of glass of refractive index 1.5 is placed on a layer of liquid placed on top of a plane mirror as shown in the figure. An optical needle with its tip on the principal axis of the lens in moved along the axis until its real, inverted image coincides with the needle itself. The distance of the needle from the lens is measured to be *x*. On removing the liquid layer and repeating the experiment, the distance is found to be *y*. Obtain the expression for the refractive index of the liquid in terms of *x* and *y*.



(CBSE 2018)

Ans. First measurement gives the focal length $(f_{eq}=x)$ of the combination of the convex lens and the plano-convex liquid lens. Second measurement gives the focal length $(f_1=y)$ of the convex lens. Focal length (f_2) of plano-convex lens is given by

$$\frac{1}{f_2}=\frac{1}{f_{eq}}-\frac{1}{f_1}=\frac{1}{x}-\frac{1}{y}$$

$\Rightarrow\ f_2=\frac{xy}{y-x}$ ...(1)

For equi-convex glass lens using lens maker's formula,

$$\frac{1}{f_1}=(\quad-1)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)$$

$\frac{1}{y}=(1.5-1)\left(\frac{2}{R}\right)$ $(\because R_1=R$ and $R_2=-R)$

$\Rightarrow\ \frac{1}{y}=\frac{1}{2}\times\frac{2}{R}$

$\Rightarrow\ y=R$ ...(2)

On applying lens maker's formula for plano-convex lens.

Here, $R_1 = -R$ and $R_2 = \infty$ and let μ_l = refractive index of liquid

$$\frac{1}{f_2} = (\mu_l - 1)\left(\frac{1}{-R} - \frac{1}{\infty}\right)$$

$$\Rightarrow \quad \frac{1}{f_2} = (\mu_l - 1)\left(\frac{1}{-R}\right)$$

$$\Rightarrow \quad \mu_l = 1 - \frac{R}{f_2}$$

From eqs. (1) and (2), we have

$$\mu_l = 1 - \frac{y}{\left(\frac{xy}{y-x}\right)} = 1 - \frac{y-x}{x}$$

$$= \frac{2x-y}{x}$$

Q 5. The focal length of a convex lens made of glass of refractive index (1.5) is 20 cm. What will be its new focal length when placed in a medium of refractive index 1.25? Is focal length positive or negative? What does it signify?

Sol. Focal length of convex lens in air, $f_a = 20\,\text{cm}$

Refractive index, ${}^a\mu_g = 1.5$

Refractive index of medium, ${}^a\mu_m = 1.25 < {}^a\mu_g$

If f_m is the focal length of lens in medium, then using lens maker's formula,

$$\frac{1}{f_a} = ({}^a\mu_g - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \quad \text{...(1)}$$

and $$\frac{1}{f_m} = \left(\frac{{}^a\mu_g}{{}^a\mu_m} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \quad \text{...(2)}$$

Dividing eq. (1) by eq. (2), we get

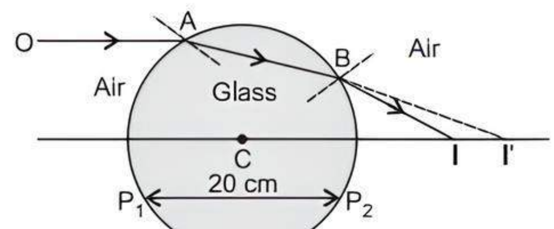
$$\frac{\frac{1}{f_a}}{\frac{1}{f_m}} = \frac{({}^a\mu_g - 1)}{\left(\frac{{}^a\mu_g}{{}^a\mu_m} - 1\right)} \quad \Rightarrow \quad f_m = f_a\left[\frac{1.5-1}{\left(\frac{1.5}{1.25} - 1\right)}\right]$$

$$= 20 \times 2.5 = 50\text{ cm}$$

Hence, focal length of lens in medium is positive which signifies that nature of convex lens will remain same in medium.

Q 6. A parallel beam of light strikes a glass ($n = 3/2$) sphere of 20 cm diameter. Where will it get focused on the other side of the sphere?

Sol. Let C be the centre and P_1 and P_2 be the poles of the sphere. A ray OA parallel to a diameter is first refracted into the glass along AB, appearing to meet the diameter at I', and then refracted out into air along BI, being finally focused at I.



For refraction at A from air to glass, we have

$$\frac{n}{v} - \frac{1}{u} = \frac{n-1}{R}$$

Here, $u = \infty$, $R = +10$ cm and $n = 3/2$.

$$\therefore \quad \frac{3/2}{v} - \frac{1}{\infty} = \frac{(3/2)-1}{10}$$

or $$v = P_1I' = +30\text{ cm}.$$

I' serves as virtual object for refraction at B, from glass to air. For this, we have

$$\frac{1/n}{v} - \frac{1}{u} = \frac{(1/n)-1}{R}.$$

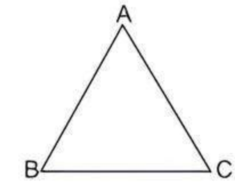
Now, $u = P_2I' = P_1I' - P_1P_2 = 30 - 20 = +10$ cm and $R = -10$ cm.

$$\therefore \quad \frac{2/3}{v} - \frac{1}{10} = \frac{-1/3}{-10} = \frac{1}{30}$$

or $$v = P_2I = +5\text{ cm}.$$

The beam is finally focussed at 5cm behind the sphere.

Q 7. (i) A ray of light incident on face AB of an equilateral glass prism, shows minimum deviation of 30°. Calculate the speed of the light through the prism. *(CBSE 2017)*



(ii) Find the angle of incidence at face AB so that the emergent ray grazes along the face AC.

Sol. (i) Given, angle of minimum deviation, $\delta_m = 30°$

$\therefore$ Angle of prism, $A = 60°$

By prism formula, refractive index,

$$\mu = \frac{\sin\left(\frac{A+\delta_m}{2}\right)}{\sin\left(\frac{A}{2}\right)} = \frac{\sin\left(\frac{30°+60°}{2}\right)}{\sin\left(\frac{60°}{2}\right)}$$

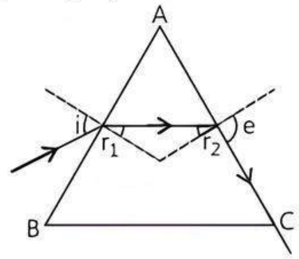
$$= \frac{\sin 45°}{\sin 30°} = \frac{1}{\sqrt{2}} \times 2 = \sqrt{2}$$

$$\mu = \frac{\text{Speed of light in vacuum } (c)}{\text{Speed of light in prism } (v)}$$

$$\Rightarrow \quad v = \frac{c}{\mu} = \frac{3 \times 10^8}{\sqrt{2}}\text{ms}^{-1} = 2.12 \times 10^8\text{ ms}^{-1}$$

Speed of light through prism is $2.12 \times 10^8\text{ ms}^{-1}$.

(ii) At face AC, let the angle of incidence be r_2.
For grazing ray, $e = 90°$



$$\Rightarrow \quad \mu = \frac{1}{\sin r_2} \Rightarrow r_2 = \sin^{-1}\left(\frac{1}{\sqrt{2}}\right) = 45°$$

Let angle of refraction at face AB be r_1.
Now $r_1 + r_2 = A$

$$\therefore \quad r_1 = A - r_2 = 60° - 45° = 15°$$

Let angle of incidence at this face be i.

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

$$\Rightarrow \quad \mu = \sqrt{2} = \frac{\sin i}{\sin 15°}$$

$$\therefore \quad i = \sin^{-1}(\sqrt{2}\sin 15°)$$

Q 8. Draw a ray diagram to show the refraction of light through a glass prism. Hence derive the relation

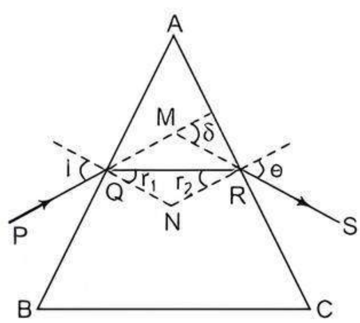
$$\mu = \frac{\sin\left(\frac{A+\delta_m}{2}\right)}{\sin A/2}$$

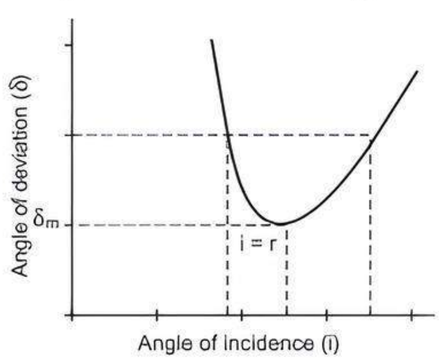
(CBSE 2017, 16)

Ans. Refraction through a glass prism: Let a light ray is incident on the principal section ABC of a glass prism as shown in figure
In quadrilateral $AQNR$,

$$\angle A + 90° + \angle QNR + 90° = 360°$$

$$\Rightarrow \quad \angle A + \angle QNR = 180° \quad ...(1)$$





In ΔQNR, $\quad r_1 + r_2 + \angle QNR = 180° \quad ...(2)$

From eqs. (1) and (2), we have

$$r_1 + r_2 = A \quad ...(3)$$

Now, total deviation

$$\delta = (i - r_1) + (e - r_2) = (i + e) - (r_1 + r_2)$$

$$\Rightarrow \quad \delta = i + e - A \quad ...(4)$$

But when $\delta = \delta_m$, $i = e$

and $\quad r_1 = r_2 = r$

From eq. (3), $\quad 2r = A$

$$r = A/2$$

From eq. (4), $\quad \delta_m = 2i - A$

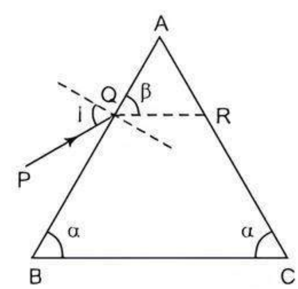
$$\Rightarrow \quad i = (A + \delta_m)/2$$

Hence, $\quad \mu = \frac{\sin i}{\sin r} = \frac{\sin\left(\frac{A+\delta_m}{2}\right)}{\sin A/2}$

TiP

Graph is very important (for practical and viva also).

Q 9. A ray of light incident on the face AB of an isosceles triangular prism makes an angle of incidence i and deviates by angle β as shown in the figure. Show that in the position of minimum deviation $\angle\beta = \angle\alpha$. Also find out the condition, when the refracted ray QR suffer total internal reflection. *(CBSE 2019)*



Ans. Given, $\alpha = 60°$ (for isosceles triangle)
$r_1 = 90° - \beta$ and $r_2 = \beta - 30°$
For minimum deviation, $r_1 = r_2$

$$\Rightarrow \quad 90° - \beta = \beta - 30°$$

$$\Rightarrow \quad 2\beta = 120° \text{ or } \beta = 60° = \alpha$$

$$\angle\beta = \angle\alpha$$

For total internal reflection, $\frac{1}{\sin i_c} \le \mu$

$$\frac{1}{\sin 30°} \le \mu \qquad [\because r_2 = i_c = 60° - 30° = 30°]$$

$$\Rightarrow \quad \mu \ge 2$$

TiP

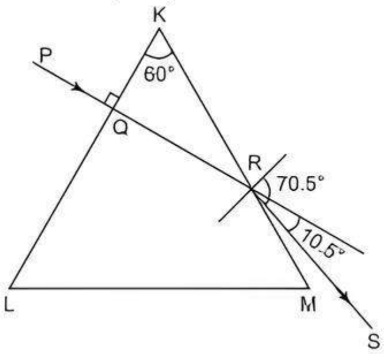
Students should practise a few numerical problems based on the relationship between the refractive index and critical angle.

Q 10. A triangular prism of refracting angle 60° is made of a transparent material of refractive index $2/\sqrt{3}$. A ray of light is incident normally on the face KL as shown in the figure. Trace the path of the ray as it passes through the prism and calculate the angle of emergence and angle of deviation. *(CBSE 2019)*

Sol. Given, $A = 60°$, $\mu = \dfrac{2}{\sqrt{3}}$, $i = 0°$

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

$$\Rightarrow \quad \frac{2}{\sqrt{3}} = \frac{\sin\left(\dfrac{60°+\delta_m}{2}\right)}{\sin\left(\dfrac{60°}{2}\right)}$$



$$\Rightarrow \quad \frac{2}{\sqrt{3}} \times \frac{1}{2} = \sin\left(\frac{60°+\delta_m}{2}\right)$$

$$\Rightarrow \quad \frac{60°+\delta_m}{2} = \sin^{-1}\left(\frac{1}{\sqrt{3}}\right) = 35.3°$$

$$\delta_m = 35.3° \times 2 - 60°$$

$\therefore$ Angle of deviation, $\delta_m = 10.5°$

Also, $A + \delta_m = i + e$

Angle of deviation,

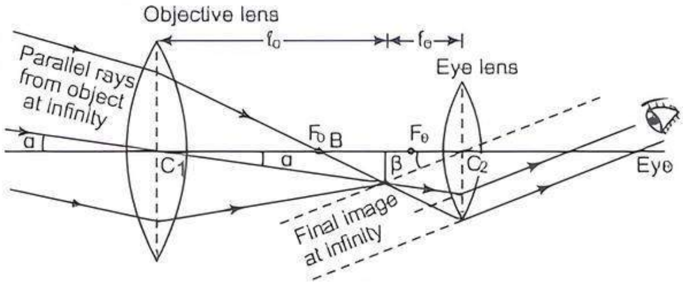
$e = 60° + 10.5° - 0° = 70.5°$

Q 11. (i) Draw a ray diagram depicting the formation of the image by an astronomical telescope in normal adjustment.

(ii) You are given the following three lenses. Which two lenses will you use as an eyepiece and as an objective to construct an astronomical telescope? Give reason. *(2017)*

Lenses	Power (D)	Aperture (cm)
L_1	3	8
L_2	6	1
L_3	10	1

Ans. (i) An astronomical telescope is an optical instrument which is used for observing distinct images of heavenly bodies like planets, stars etc. It has two convex lens (objective and eye lens) placed coaxially and separated by some distance in normal adjustment. Final image is formed at infinity as shown below.



(ii) In the astronomical telescope, aperture of objective must be less than eyepiece. Therefore, possible combinations are L_1 and L_3 or L_1 and L_2. Also, focal length of the objective (f_o) must be greater than that of eyepiece (f_e).

$\therefore \quad f_o > f_e \Rightarrow \dfrac{1}{f_o} < \dfrac{1}{f_e}$

$\Rightarrow \quad P_o < P_e$

$\therefore$ Power of objective (P_o) must be less than power of eyepiece (P_e).

Now, for L_1 and L_3 combination,

$$\left(\frac{f_o}{f_e}\right)_1 = \frac{P_e}{P_o} = \frac{10}{3}$$

For L_1 and L_2 combination,

$$\left(\frac{f_o}{f_e}\right)_2 = \frac{P_e}{P_o} = \frac{6}{3} = 2$$

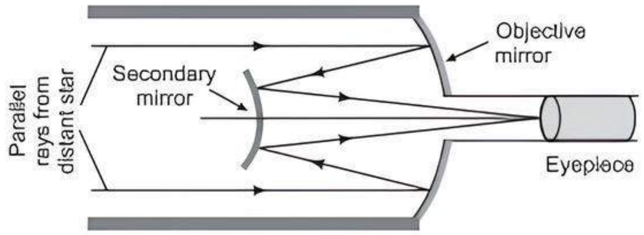
Therefore, $$\left(\frac{f_o}{f_e}\right)_1 > \left(\frac{f_o}{f_e}\right)_2$$

The best combination of the lenses is L_1 and L_3.

Q 12. (i) Draw a ray diagram showing the formation of image by a reflecting telescope.

(ii) Write two advantages of a reflecting telescope over a refracting telescope. *(CBSE 2017, 16, 15)*

Ans. (i) Ray diagram showing the formation of image by a reflecting telescope.



(ii) **Advantages of Reflecting Telescope:**

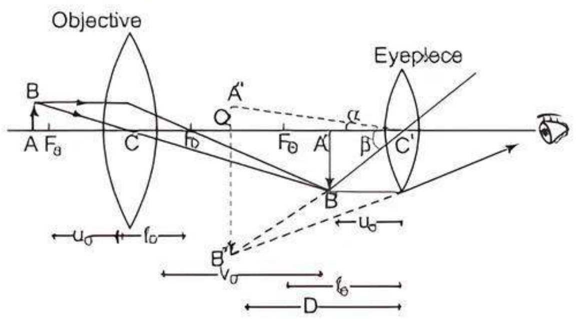
(a) Reflecting telescopes have high resolving power due to a large aperture of mirrors.

(b) Due to availability of paraboloidal mirror, the image is free from chromatic and spherical aberration.

Q 13. (i) Draw a ray diagram of compound microscope for the final image formed at least distance of distinct vision.

(ii) An angular magnification of 30 times is desired using an objective of focal length 1.25 cm and an eye piece of focal length 5 cm. How will you set up the compound microscope for the final image formed at least distance of distinct vision? *(CBSE SQP 2022 Term-2)*

Ans. (i) Ray diagram of compound microscope, when final image is formed at least distance of distinct vision, shown below.



(ii) Given angular magnification, $m = 30$

Focal length of objective, $f_o = 1.25$ cm

Focal length of eyepiece, $f_e = 5$ cm

When image is formed at least distance of distinct vision, then $D = 25$ cm.

$\therefore$ Angular magnification of eyepiece,

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

$\therefore$ Total angular magnification,

$$m = m_o \cdot m_e$$

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

As the objective lens forms the real image.

Hence, $m_o = \frac{v_o}{u_o} = -5$

$$\Rightarrow \quad v_o = -5u_o \qquad \text{...(1)}$$

Now, using lens formula for objective

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

$$\Rightarrow \quad -\frac{1}{5u_o} - \frac{1}{u_o} = \frac{1}{1.25}$$

$$\Rightarrow \quad u_o = -1.5 \text{ cm}$$

$\therefore$ From eq. (1), $v_o = -5 \times (1.5) = 7.5$ cm

Again, for eyepiece: $v_e = -D = -25$ cm

$f_e = 5$ cm, $u_e = ?$

Using lens formula, $\frac{1}{v_e} - \frac{1}{u_e} = \frac{1}{f_e}$

$$\Rightarrow \quad \frac{1}{-25} - \frac{1}{u_e} = \frac{1}{5}$$

$$\Rightarrow \quad u_e = \frac{25}{6} \text{ cm}$$

Thus, object should be placed at 1.5 cm from the objective.

Separation between the two lenses,

$$L = v_o + |u_e|$$

$$= 7.5 + \left|\frac{25}{6}\right| = 11.67 \text{ cm}$$

Q 14. (i) Draw a ray diagram of Astronomical Telescope for the final image formed at infinity.

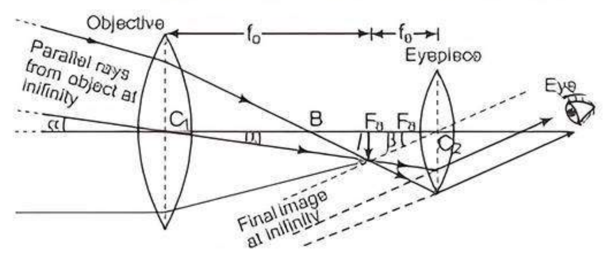
(ii) A small telescope has an objective lens of focal length 140 cm and an eyepiece of focal length 5.0 cm. Find the magnifying power of the telescope for viewing distant objects when

(a) the telescope is in normal adjustment,

(b) the final image is formed at the least distance of distinct vision.

(CBSE SQP 2022, Term-2)

Ans. (i) The ray diagram of astronomical telescope for the final image formed at infinity is shown below:



(ii) Given, $f_o = 140$ cm, $f_e = 5$ cm

(a) In normal adjustment, magnifying power of telescope, $m = \frac{f_o}{f_e} = \frac{140}{5} = 28$

(b) Magnifying power of telescope, when final image is formed at least distance of distinct vision,

$$m = \frac{f_o}{f_e}\left(1 + \frac{f_e}{D}\right)$$

$$= \frac{140}{5}\left(1 + \frac{5}{25}\right)$$

$$= 28\left(\frac{6}{5}\right) = 33.6$$

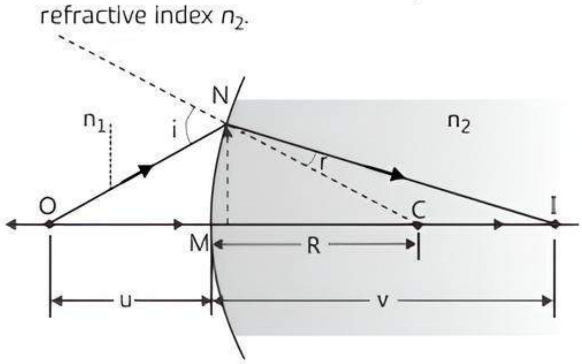
Long Answer Type Questions

Q 1. (i) Derive the mathematical relation between refractive indices n_1 and n_2 of two radii and radius of curvature R for refraction at a convex spherical surface. Consider the object to be a point since lying on the principle axis in rarer medium of refractive index n_1 and a real image formed in the denser medium of refractive index n_2. Hence, derive lens maker's formula.

(ii) Light from a point source in air falls on a convex spherical glass surface of refractive index 1.5 and radius of curvature 20 cm. The distance of light source from the glass surface is 100 cm. At what position is the image formed?

(CBSE 2016)

Ans. (i) Figure shows the geometry of formation of image I of an object O on the principal axis of a spherical surface with centre of curvature C, and radius of curvature R. The rays are incident from a medium of refractive index n_1 to another of refractive index n_2.



We have, for small angles,

$$\tan \angle NOM = \frac{MN}{OM}$$

$$\tan \angle NCM = \frac{MN}{MC}$$

$$\tan \angle NIM = \frac{MN}{MI}$$

Now, for ΔNOC, i is the exterior angle. Therefore,

$$i = \angle NOM + \angle NCM$$

$$i = \frac{MN}{OM} + \frac{MN}{MC} \qquad \text{...(1)}$$

Similarly,

$$r = \angle NCM - \angle NIM$$

i.e., $$r = \frac{MN}{MC} - \frac{MN}{MI} \qquad \text{...(2)}$$

Now, by Snell's law

$n_1 \sin i = n_2 \sin r$

or for small angles

$$n_1 i = n_2 r$$

Substituting i and r from eqs. (1) and (2), we get

$$\frac{n_1}{OM} + \frac{n_2}{MI} = \frac{n_2 - n_1}{MC} \qquad \text{...(3)}$$

Here, OM, MI and MC represent magnitudes of distances. Applying the cartesian sign convention.

$$OM = -u,\ MI = +v,\ MC = +R$$

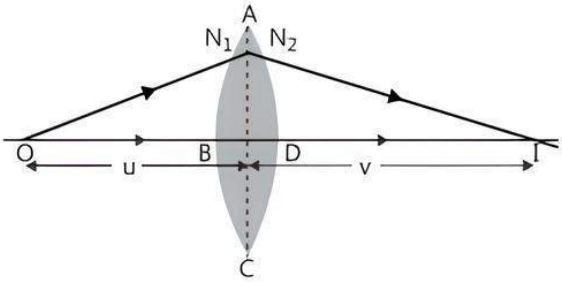
Substituting these in eq. (3), we get

$$\frac{n_2}{v} - \frac{n_1}{u} = \frac{n_2 - n_1}{R} \qquad \text{...(4)}$$

Eq. (4) gives us a relation between object and image distance in terms of refractive index of the medium and the radius of curvature of the curved spherical surface.

Apply above relation to refraction through a lens.

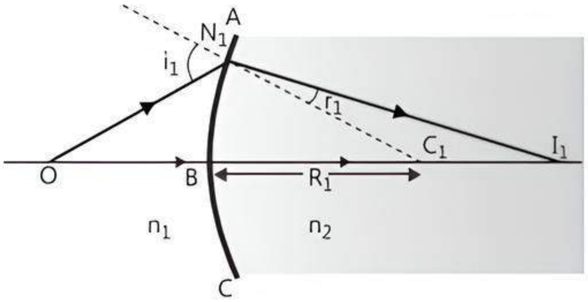
From the figure (a).



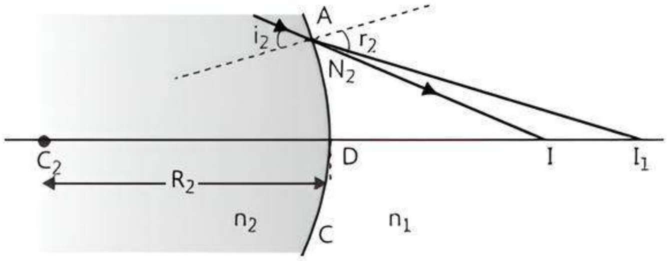
(a)

$$\frac{n_1}{OB} + \frac{n_2}{BI_1} = \frac{n_2 - n_1}{BC_1} \qquad \text{...(5)}$$

A similar procedure applied to the second interface ADC gives (see fig. (b) and (c))



(b)



(c)

$$-\frac{n_2}{DI_1} + \frac{n_1}{DI} = \frac{n_2 - n_1}{DC_2} \qquad \text{...(6)}$$

For a thin lens $BI_1 = DI_1$.

Adding eqs. (5) and (6), we get

$$\frac{n_1}{OB} + \frac{n_1}{DI} = (n_2 - n_1)\left(\frac{1}{BC_1} + \frac{1}{DC_2}\right) \qquad \text{...(7)}$$

Suppose the object is at infinity, i.e., $OB \to \infty$ and $DI = f$, eq. (7) gives

$$\frac{n_1}{f} = (n_2 - n_1)\left(\frac{1}{BC_1} + \frac{1}{DC_2}\right) \qquad \text{...(8)}$$

By the sign convention

$$BC_1 = +R_1$$
$$DC_2 = -R_2$$

So, eq. (8) can be written as

$$\frac{1}{f} = (n_{21} - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \quad \left(\because n_{21} = \frac{n_2}{n_1}\right) \quad ...(9)$$

Eq. (9) is known as the lens maker's formula.

TiP

The focal length of a lens is minimum when it is placed in vacuum. When it is taken in some other medium focal length increases.

(ii) Finding position of image formed by convex spherical glass surface.

Given,

$$R = 20 \text{ cm},$$
$$n_2 = 1.5,$$
$$n_1 = 1,$$
$$u = -100 \text{ cm}$$

from eq. (4),

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

$$\frac{1.5}{v} = \frac{1.5 - 1}{20} + \frac{1}{(-100)}$$

$$\frac{1.5}{v} = \frac{0.5}{20} - \frac{1}{100}$$

$$v = 100 \text{ cm}$$

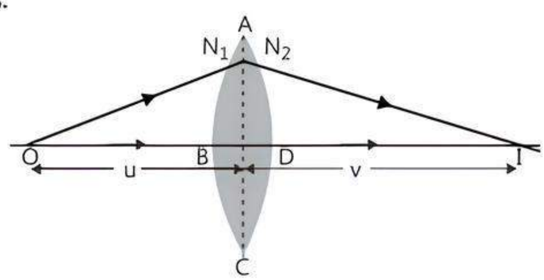
Hence, $v = 100$ cm, a real image on the other side, 100 cm away from the surface.

Q 2. (i) Draw a ray diagram for the formation of image of a point object by a thin double convex lens having radii of curvature R_1 and R_2. Hence derive lens maker's formula.

(ii) A converging lens has a focal length of 10 cm in air. It is made of a material of refractive index 1.6. If it is immersed in a liquid of refractive index 1.3, find its new focal length.

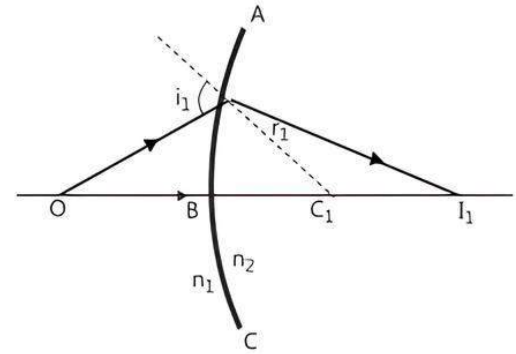
(CBSE SQP 2023-24)

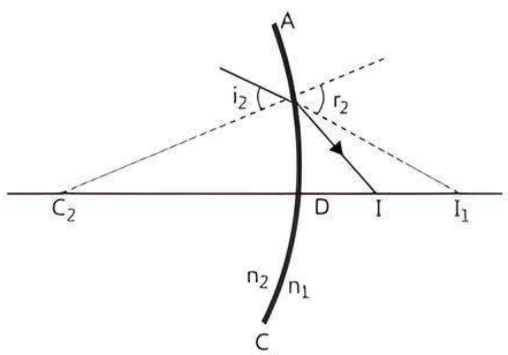
Ans.

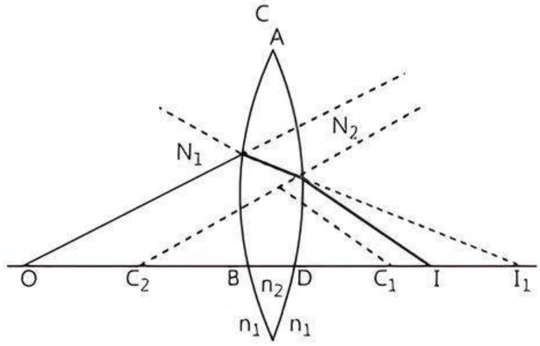


When a ray refracts from a lens (double convex), in above figure, then its image formation can be seen in term of two steps:

Step 1: The first refracting surface forms the image I_1 of the object O







Step 2: The image of object O for first surface acts like a virtual object for the second surface. Now for the first surface ABC, ray will move from rarer to denser medium, then

$$\frac{n_2}{BI_1} + \frac{n_1}{OB} = \frac{n_2 - n_1}{BC_1} \quad ...(1)$$

Similarly, for the second interface, ADC we can write

$$\frac{n_2}{DI} - \frac{n_2}{DI_1} = \frac{n_2 - n_1}{DC_2} \quad ...(2)$$

DI_1 is negative as distance is measured against the direction of incident light.

Adding eqs. (1) and (2), we get

$$\frac{n_2}{BI_1} + \frac{n_1}{OB} + \frac{n_1}{DI} - \frac{n_2}{DI_1} = \frac{n_2 - n_1}{BC_1} + \frac{n_2 - n_1}{DC_2}$$

or
$$\frac{n_1}{DI} + \frac{n_1}{OB} = (n_2 - n_1)\left(\frac{1}{BC_1} + \frac{1}{DC_2}\right) \quad ...(3)$$

(for thin lens $BI_1 = DI_1$)

Now, if we assume the object to be at infinity *i.e* $OB \to \infty$, then its image will form at focus F (with focal length f), *i.e.*

$DI = f$, thus eq. (3) can be rewritten as

$$\frac{n_1}{f_1} + \frac{n_1}{\infty} = (n_2 - n_1)\left(\frac{1}{BC_1} + \frac{1}{DC_2}\right)$$

or $$\frac{n_1}{f_1} = (n_2 - n_1)\left(\frac{1}{BC_1} + \frac{1}{DC_2}\right) \quad ...(4)$$

Now according to the sign conventions

$$BC_1 = +R_1 \text{ and } DC_2 = -R_2 \quad ...(5)$$

Substituting eq. (5) in eq. (4), we get

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

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

$$\frac{1}{f} = (n_{21} - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

This is the lens maker's formula

(ii) $$\frac{1}{f_a} = (1.6 - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \quad ...(1)$$

$$\frac{1}{f_l} = \left[\frac{1.6}{1.3} - 1\right]\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \quad ...(2)$$

From eqs. (1) and (2),

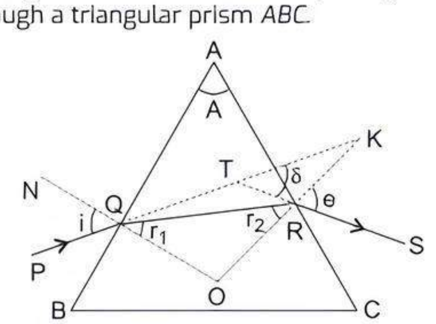
$$\frac{f_l}{f_a} = \left[\frac{0.6}{0.3} \times 1.3\right] \Rightarrow f_l = 2.6 \times 10\,\text{cm} \Rightarrow f_l = 26\,\text{cm}$$

Q 3. (i) Draw a ray diagram showing refraction of a ray of light through a triangular glass prism. Hence, obtain the relation for the refractive index (μ) in terms of angle of prism (A) and angle of minimum deviation (δ_m).

(ii) The radii of curvature of the two surfaces of a concave lens are 20 cm each. Find the refractive index of the material of the lens if its power is – 5.0 D. *(CBSE 2023)*

Ans. (i) Refraction of ray of light through a triangular glass prism:

The figure below shows the passage of light through a triangular prism ABC.



The angles of incidence and refraction at first face AB are i and r_1. The angle of incidence at the second face AC is r_2 and the angle of emergence is e.

The angle between the emergent ray RS and incident ray PQ is called angle of deviation (δ).

$$\delta = (i + e) - (r_1 + r_2)$$

$\because$ $$r_1 + r_2 = A$$

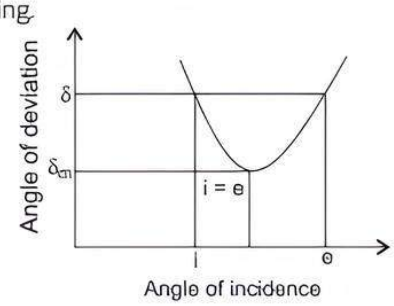
$\therefore$ $$\delta = (i + e) - A$$

If μ is the refractive index of material of the prism, then

$$\delta = (\mu - 1)A$$

This is the angle through which a ray deviates on passing through a thin prism of small refracting angle A.

If the angle of incidence is increased gradually, then the angle of deviation first decreases, attains a minimum value (δ_m) and then again starts increasing.



When angle of deviation is minimum, the prism is said to be placed in the minimum deviation position. There is only one angle of incidence for which the angle of deviation is minimum.

When $\delta = \delta_m$ (prism in minimum deviation position)

$$e = i$$

and $$r_2 = r_1 \quad ...(1)$$

$$r_1 + r_2 = A$$

$$r + r = A$$

or $$r = \frac{A}{2}$$

Also, we have

$$A + \delta = i + e \quad ...(2)$$

Putting $\delta = \delta_m$ and $e = i$ in eq. (2), we get

$$A + \delta_m = i + i$$

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

From Snell's law, $\mu = \dfrac{\sin i}{\sin r}$

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

This relation is called a prism formula.

(ii) Given that,

$$R_1 = -20 \text{ cm} = -0.2 \text{ m}$$

$$R_2 = 20 \text{ cm} = 0.2 \text{ m}$$

$$P = 5.0 \text{ D}$$

From lens maker's formula,

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

$$-5 = (\mu - 1)\left(\frac{1}{-0.2} - \frac{1}{0.2}\right)$$

$$-5 = (\mu - 1)\left(\frac{-1-1}{-0.2}\right)$$

$$-5 = (\mu - 1)\left(\frac{-2}{0.2}\right)$$

$$-5 = (\mu - 1) \times -10$$

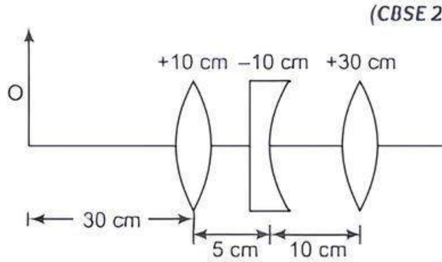
$$-5 - 10 = -\mu \times 10$$

$$\mu = \frac{15}{10} = \frac{3}{2}$$

Q 4. (i) Under what conditions is the phenomenon of total internal reflection of light observed? Obtain the relation between the critical angle of incidence and the refractive index of the medium.

(ii) Three lenses of focal lengths +10 cm, –10 cm and +30 cm are arranged coaxially as in the figure given below. Find the position of the final image formed by the combination.

(CBSE 2019)

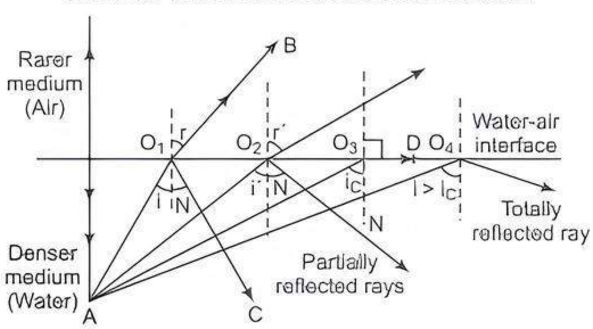


Ans. (i) The conditions for total internal reflection are:

(a) light must be trying to travel from optically denser medium to optically light medium.

(b) the angle of incidence must be greater than a certain angle known as critical angle.

Derivation: Suppose light is travelling from medium 1 to medium 2. When light strikes the surface separating the media, some of it refracts and some of it reflects. If we keep increasing the angle of incidence, the refracted ray becomes parallel to the surface. This value of angle of incidence is known as the critical angle. If we increase the angle of incidence, even further, we will have a reflected ray and no refracted ray. Thus, we will have total internal reflection.



Total Internal Reflection

Let us consider the condition when the angle of incidence is equal to critical angle, i_C.

By Snell's law, $\dfrac{\sin i_C}{\sin 90°} = \dfrac{n_2}{n_1}$

where, n_1 and n_2 are the refractive indices of medium 1 and medium 2 respectively. Let n_{12} be the refractive index of medium 1 with respect to medium 2.

Then,

$$\sin i_C = \frac{1}{n_{12}}$$

$$i_C = \sin^{-1}\left(\frac{1}{n_{12}}\right)$$

Thus, we have obtained the required relation.

(ii) Let us consider the lenses one by one.

The first lens forms an image of the given object.

Here, object distance, $u = -30$ cm

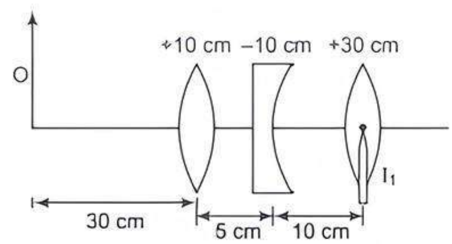
Focal length, $f = +10$ cm

Using the lens formula,

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

or $$\frac{1}{10} = \frac{1}{v} - \frac{1}{-30}$$

$$v = 15 \text{ cm}$$



The image I_1 formed by the first lens acts as an object for the second lens.

Here, object distance, $u = +10$ cm

Focal length, $f = -10$ cm

Using lens formula,

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u} \quad \text{or} \quad \frac{1}{-10} = \frac{1}{v} - \frac{1}{10}$$

$$v = \infty$$

Let us now consider the third lens. It is a converging lens as it has a positive focal point. An object at infinity would have its image at the focal point (either of the focal points as the object is in either direction).

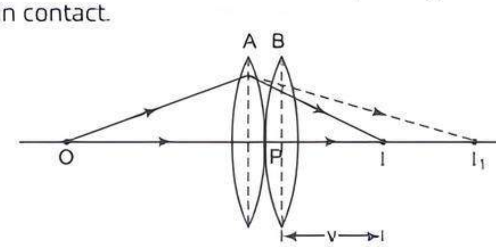
Hence, the final image is formed at 30 cm from the third lens at either side.

Q 5. (i) Draw a ray diagram to show the image formation by a combination of two thin convex lenses in contact. Obtain the expression for the power of this combination in terms of the focal lengths of the lenses.

(ii) A ray of light passing from air through an equilateral glass prism undergoes minimum deviation when the angle of incidence is $\frac{3}{4}$th of the angle of prism. Calculate the speed of light in the prism.

(CBSE 2017)

Ans. (i) Two thin lenses of focal length f_1 and f_2 are kept in contact.



Let O be the position of object and u be the object distance. The distance of the image, which is at I_1, for the first lens is v_1. This image serves as object for the second lens.

Let the final image be at I. Then we have,

$$\frac{1}{f_1}=\frac{1}{v_1}-\frac{1}{u} \text{ and } \frac{1}{f_2}=\frac{1}{v}-\frac{1}{v_1}$$

Adding, we get $\frac{1}{f_1}+\frac{1}{f_2}=\frac{1}{v}-\frac{1}{u}=\frac{1}{f}$

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

$$\therefore \qquad P=P_1+P_2$$

(ii) Since $A = 60°$ (For equilateral glass prism)

At minimum deviation, $r=\frac{A}{2}=30°$

We have given that, $i=\frac{3}{4}A=45°$

$$\therefore \qquad \mu=\frac{\sin 45°}{\sin 30°}=\sqrt{2}$$

Thus, speed of light in the prism

$$=\frac{c}{\sqrt{2}}=\frac{3\times10^8}{\sqrt{2}}=2.1\times10^8 \text{ m/s}$$

Q 6. (i) When a convex lens of focal length 30 cm is in contact with a concave lens of focal length 20 cm, find out if the system is converging or diverging.

(ii) Obtain the expression for the angle of incidence of a ray of light which is incident on the face of a prism of refracting angle A, so that it suffers total internal reflection at the other face. (Given the refractive index of the glass of the prism is μ). *(CBSE 2019)*

Ans. (i) Given focal length of convex lens, $f_1 = 30$ cm

Focal length of concave lens, $f_2 = -20$ cm

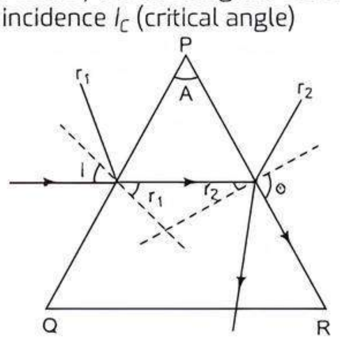
Let f be the combined focal length, then

$$\frac{1}{f}=\frac{1}{f_1}+\frac{1}{f_2}=\frac{1}{30}-\frac{1}{20}=\frac{2-3}{60}=-\frac{1}{60}$$

$$\Rightarrow \qquad f=-60 \text{ cm}$$

Since, f is negative, therefore combined system is diverging.

(ii) Let the ray travel along the face PR for an angle of incidence i_C (critical angle)



$\therefore \quad e = 90°$

From Snell's law, $\frac{\sin i_C}{\sin r_1}=\mu=\frac{\sin e}{\sin r_2}$ ...(1)

$$\Rightarrow \quad \frac{\sin 90°}{\sin r_2}=\mu \Rightarrow \sin r_2=\frac{1}{\mu} \Rightarrow r_2=\sin^{-1}\left(\frac{1}{\mu}\right)$$

Also, $r_1+r_2=A$

$$\Rightarrow \qquad r_1=A-\sin^{-1}\left(\frac{1}{\mu}\right)$$

From eq. (1),

$$\frac{\sin i_C}{\sin\left[A-\sin^{-1}\left(\frac{1}{\mu}\right)\right]}=\mu$$

$$\Rightarrow \qquad \sin i_C=\mu\sin\left[A-\sin^{-1}\left(\frac{1}{\mu}\right)\right]$$

$$\Rightarrow \qquad i_C=\sin^{-1}\left[\mu\sin\left(A-\sin^{-1}\left(\frac{1}{\mu}\right)\right)\right]$$

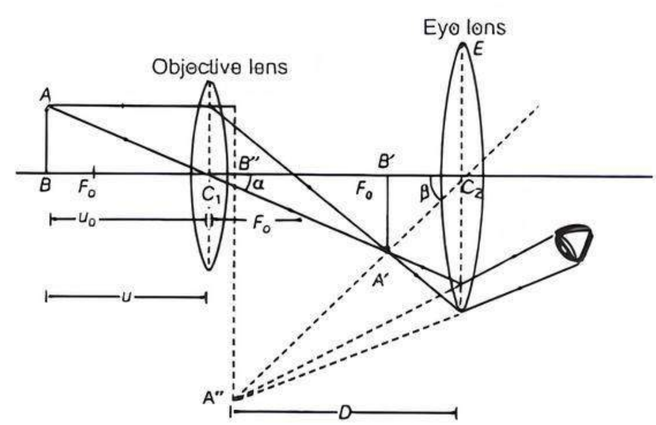
For total internal reflection, the angle of incidence is

$$i\geq i_C=\sin^{-1}\left[\mu\sin\left(A-\sin^{-1}\left(\frac{1}{\mu}\right)\right)\right]$$

Q 7. (i) Draw a ray diagram to show the working of a compound microscope. Obtain the expression for the total magnification for the final image to be formed at the near point.

(ii) In a compound microscope, an object is placed at a distance of 1.5 cm from the objective of focal length 1.25 cm. If the eye-piece has a focal length of 5 cm and the final image is formed at the near point, find the magnifying power of the microscope. *(CBSE 2023)*

Ans. (i) A compound microscope consists of two convex lenses co-axially separated by some distance. The lens nearer to the object is called the **objective**. The lens through which the final image is viewed is called the **eyepiece**. The focal length of objective lens is smaller than eyepiece.



The objective lens forms real and inverted magnified images $A'B'$ of object AB in such a way that $A\ B'$ fall some where between pole and focus of eye lens.

So, $A'B'$ acts as an object for eyepiece and its virtual magnified image $A''B''$ formed by the lens.

The magnifying power of a compound microscope is defined as the ratio of the visual angle subtended by final image at eye (β) and the visual angle subtended by object at naked eye, when both are at the least distance of distinct vision from the eye.

$$m = \frac{\text{Visual angle with instrument } (\beta)}{\text{Visual angle when object is placed at least distance of distinct vision } (\alpha)}$$

$$\Rightarrow m = \frac{\beta}{\alpha} = \frac{\tan\beta}{\tan\alpha} = \frac{B'A'/u_e}{BA/D}$$

$$= \left(\frac{B'A'}{BA}\right) \times \frac{D}{u_e} = m_o m_e$$

$m = m_o\, m_e$, where m_o and m_e are magnification produced by objective and eyepiece, respectively.

Now, $$m_o = \frac{B'A'}{BA} = \frac{v_o}{-u_o}$$

$$m_e = \frac{D}{u_e} = 1 + \frac{D}{f_e} \quad \text{(by lens formula)}$$

$$m = -\left(\frac{v_o}{u_o}\right)\left(1 + \frac{D}{f_e}\right)$$

This is the required expression.

(ii) $u_o = -1.5$ cm

$f_o = 1.25$ cm, $f_e = 5$ cm

$v_e = -D = -25$ cm

For objective lens,

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

$$\frac{1}{1.25} = \frac{1}{v_o} + \frac{1}{1.5}$$

$$\frac{1}{v_o} = \frac{1}{1.25} - \frac{1}{1.5}$$

$$= \frac{1.5 - 1.25}{1.5 \times 1.25}$$

$$= \frac{0.25}{1.5 \times 1.25} = \frac{1}{7.50}$$

$v_o = 7.5$ cm

$$m = \frac{7.5}{2.5}\left(1 + \frac{25}{5}\right) = -5 \times 6 = -30$$

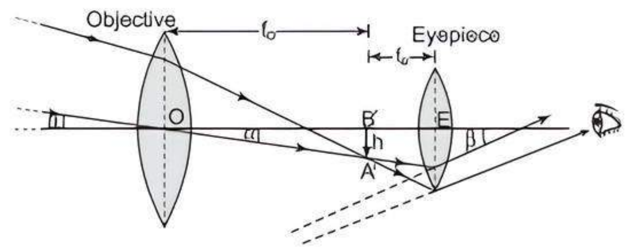
Q 8. (i) Draw the ray diagram of an astronomical telescope when the final image is formed at infinity.

(ii) An astronomical telescope has an objective lens of focal length 20 m and eyepiece of focal length 1 cm.

(a) Find the angular magnification of the telescope.

(b) If this telescope is used to view the Moon, find the diameter of the image formed by the objective lens. Given the diameter of the Moon is 3.5×10^6 m and radius of lunar orbit is 3.8×10^8 m. *(CBSE 2020)*

Ans. (i) Ray diagram of an astronomical telescope in which final image is formed at infinity, is given below:



(ii) (a) Angular magnification,

$$M = \frac{\beta}{\alpha} = \frac{f_o}{f_e} = \frac{20\text{ m}}{10^{-2}\text{ m}} = 2000 \quad (\because 1\text{ cm} = 10^{-2}\text{ m})$$

(b) Diameter, $$d = \frac{Df_o}{r} = \frac{3.5 \times 10^6 \times 20}{3.8 \times 10^8} = 0.18 \text{ m}$$

Chapter Test

Multiple Choice Questions

Q 1. A ray of monochromatic light propagating in air, is incident on the surface of water. Which of the following will be the same for the reflected and refracted rays? *(CBSE 2023)*

a. Energy carried
b. Speed
c. Frequency
d. Wavelength

Q 2. A beam of light travels from air into a medium. Its speed and wavelength in the medium are 1.5×10^5 ms^{-1} and 230 nm respectively. The wavelength of light in air will be: *(CBSE 2023)*

a. 230 nm
b. 345 nm
c. 460 nm
d. 690 nm

Assertion and Reason Type Questions

Directions (Q.Nos. 3-4): *In the following questions, a statement of Assertion (A) is followed by a statement of Reason (R). Mark the correct choice as:*

a. Both Assertion (A) and Reason (R) are true and Reason (R) is the correct explanation of Assertion (A).
b. Both Assertion (A) and Reason (R) are true but Reason (R) is not the correct explanation of Assertion (A).
c. Assertion (A) is true but Reason (R) is false.
d. Both Assertion (A) and Reason (R) are false.

Q 3. Assertion (A): Propagation of light through an optical fibre is due to total internal reflection taking place at the core-cladding interface.

Reason (R): Refractive index of the material of the core of the optical fibre is greater than that of cladding.

Q 4. Assertion (A): The focal length of an equiconvex lens placed in air is equal to radius of curvature of either face.

Reason (R): For an equi-convex lens, radius of curvature of both the faces is same.

Fill in the blanks

Q 5. Prisms are designed to bend ray by 90° and 180° or to .... without changing its size by the use of the total internal reflection.

Q 6. Simple microscope is a .... lens of small focal length.

Case Study Based Question

Q 7. 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 with respect to 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 $f = \sqrt{f_r \times f_v}$.

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

(i) Focal length of a equi-convex lens of glass $\left(\mu = \frac{3}{2}\right)$ 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. $\frac{7}{4}$

Very Short Answer Type Questions

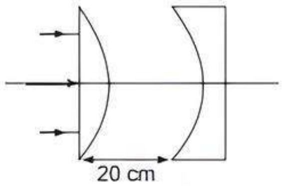
Q 8. When a glass slab is placed on an ink dot, ink dot appears to be raised. Why?

Q 9. Show analytically from the lens equation that when the object is at the principal focus, the image is formed at infinity.

Short Answer Type-I Questions

Q 10. Light from a point source in air falls on a spherical glass surface (n = 1.5 and radius of curvature = 20 cm). The distance of the light source from the glass surface is 100 cm. At what position the image is formed?

Q 11. In the given figure, the radius of curvature of curved face in the plano-convex and the plano-concave lens is 15 cm each. The refractive index of the material of the lenses is 1.5. Find the final position of the image formed. *(CBSE 2023)*



Q 12. (i) The radii of curvature of the faces of a double convex lens are 10 cm and 15 cm. Its focal length is 12 cm. What is the refractive index of glass?

(ii) Calculate the speed of light in a medium whose critical angle is 30°.

Short Answer Type-II Questions

Q 13. (i) Calculate the distance of an object of height h from a concave mirror of radius of curvature 20cm, so as to obtain a real image of magnification 2. Find the location of image also.

(ii) Using mirror formula, explain why does a convex mirror always produce a virtual image?

Q 14. Define critical angle for a given pair of media and total internal reflection. Obtain the relation between the critical angle and refractive index of the medium. *(CBSE 2023)*

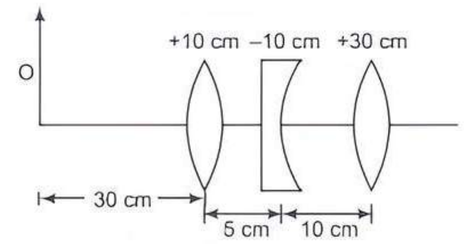
Q 15. (i) How is the working of a telescope different from that of a microscope?

(ii) The focal lengths of the objective and eyepiece of a microscope are 1.25 cm and 5 cm, respectively. Find the position of the object relative to the objective in order to obtain an angular magnification of 30 in normal adjustment.

Long Answer Type Questions

Q 16. (i) Under what conditions is the phenomenon of total internal reflection of light observed? Obtain the relation between the critical angle of incidence and the refractive index of the medium.

(ii) Three lenses of focal lengths +10 cm, –10 cm and +30 cm are arranged coaxially as in the figure given below. Find the position of the final image formed by the combination.



Q 17. (i) Derive the mathematical relation between refractive indices n_1 and n_2 of two radii and radius of curvature R for refraction at a convex spherical surface. Consider the object to be a point since lying on the principle axis in rarer medium of refractive index n_1 and a real image formed in the denser medium of refractive index n_2. Hence, derive lens maker's formula.

(ii) Light from a point source in air falls on a convex spherical glass surface of refractive index 1.5 and radius of curvature 20 cm. The distance of light source from the glass surface is 100 cm. At what position is the image formed?