Ray Optics and Optical Instruments

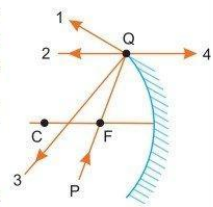
Multiple Choice Questions

Choose and write the correct option(s) in the following questions.

1. **For a concave mirror of focal length 'f', the minimum distance between the object and its real image is:** [*CBSE 2023 (55/1/1)*]

   (*a*) zero (*b*) f (*c*) $2f$ (*d*) $4f$

2. **The direction of ray of light incident on a concave mirror is shown by PQ while directions in which the ray would travel after reflection is shown by four rays marked 1, 2, 3 and 4 (Fig. given alongside). Which of the four rays correctly shows the direction of reflected ray?** [*NCERT Exemplar*]



   (*a*) 1 (*b*) 2
   (*c*) 3 (*d*) 4

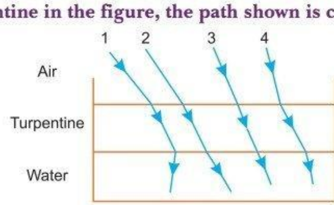
3. **A ray of monochromatic light propagating in air, is incident on the surface of water. Which of the following will be the same for the reflected and refracted rays?** [*CBSE 2023 (55/2/1)*]

   (*a*) Energy carried (*b*) Speed (*c*) Frequency (*d*) Wavelength

4. **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

5. **The optical density of turpentine is higher than that of water while its mass density is lower. Figure shows a layer of turpentine floating over water in a container. For which one of the four rays incident on turpentine in the figure, the path shown is correct?** [*NCERT Exemplar*]



   (*a*) 1 (*b*) 2 (*c*) 3 (*d*) 4

6. **A beam of light travels from air into a medium. Its speed and wavelength in the medium are 1.5×10^8 ms^{-1} and 230 nm respectively. The wavelength of light in air will be** [*CBSE 2023(55/2/1)*]

   (*a*) 230 nm (*b*) 345 nm (*c*) 460 nm (*d*) 690 nm

7. **Transmission of light in optical fibre is due to**
(*a*) scattering
(*b*) diffraction
(*c*) refraction
(*d*) multiple total internal reflection

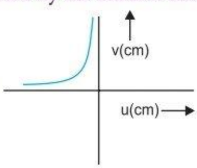
8. **You are given four sources of light each one providing a light of a single colour – red, blue, green and yellow. Suppose the angle of refraction for a beam of yellow light corresponding to a particular angle of incidence at the interface of two media is 90°. Which of the following statements is correct if the source of yellow light is replaced with that of other lights without changing the angle of incidence?** [*NCERT Exemplar*]
(*a*) The beam of red light would undergo total internal reflection.
(*b*) The beam of red light would bend towards normal while it gets refracted through the second medium.
(*c*) The beam of blue light would undergo total internal reflection.
(*d*) The beam of green light would bend away from the normal as it gets refracted through the second medium.

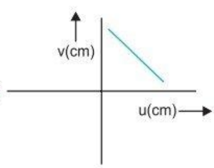
9. **Which of the following is not due to total internal reflection ?**
(*a*) Working of optical fibre
(*b*) Difference between apparent and real depth of a pond
(*c*) Mirage on hot summer days
(*d*) Brilliance of diamond

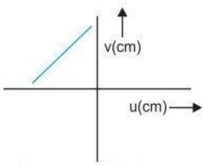
10. **An object approaches a convergent lens from the left of the lens with a uniform speed 5 m/s and stops at the focus. The image** [*NCERT Exemplar*]
(*a*) moves away from the lens with an uniform speed 5 m/s.
(*b*) moves away from the lens with an uniform accleration.
(*c*) moves away from the lens with a non-uniform acceleration.
(*d*) moves towards the lens with a non-uniform acceleration.

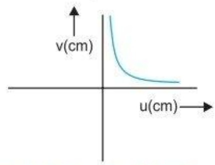
11. **The radius of curvature of the curved surface of a plano-convex lens is 20 cm. If the refractive index of the material of the lens be 1.5, it will** [*NCERT Exemplar*]
(*a*) act as a convex lens only for the objects that lie on its curved side.
(*b*) act as a concave lens for the objects that lie 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.

12. **A student measures the focal length of a convex lens by putting an object pin at a distance '*u*' from the lens and measuring the distance '*v*' of the image pin. The graph between '*u*' and '*v*' plotted by the student should look like**

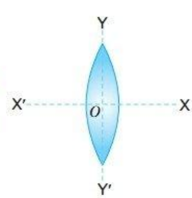
(*a*)


(*b*)


(*c*)


(*d*)


13. **An equiconvex lens is cut into two halves along (*i*) *XOX'* and (*ii*) *YOY'* as shown in the figure. Let f, f' and f'' be the of the focal lengths of complete lens of each half in case (*i*) and of each half in case (*ii*) respectively. Choose the correct statement from the following :**



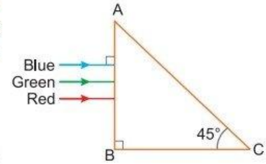
(*a*) $f' = 2f$ and $f'' = f$
(*b*) $f' = f$ and $f'' = f$
(*c*) $f' = 2f$ and $f'' = 2f$
(*d*) $f' = f$ and $f'' = 2f$

14. **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°

15. **A beam of light consisting of red, green and blue colours is incident on a right angled prism. The refractive index of the material of the prism for the above red, green and blue wavelengths are 1.39, 1.44 and 1.47 respectively.**

The prism will



(*a*) not separate the three colours at all

(*b*) separate the red colour part from the green and blue colours

(*c*) separate the blue colour part from the red and green colours

(*d*) separate all the three colours from one another

16. **A thin prism having refracting angle 10° is made of glass of refractive index 1.42. This prism is combined with another thin prism of glass of refractive index 1.7. This combination produces dispersion without deviation. This refracting angle of second prism should be**

(*a*) 6° (*b*) 8° (*c*) 10° (*d*) 4°

17. **A biconcave lens of power *P* vertically splits into two identical plano concave parts. The power of each part will be** [*CBSE 2020 (55/5/1)*]

(*a*) $2P$ (*b*) $P/2$ (*c*) P (*d*) $P/\sqrt{2}$

18. **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 (55/1/1)*]

(*a*) 1.47 (*b*) 1.62 (*c*) 1.33 (*d*) 1.51

19. **For a glass prism, the angle of minimum deviation will be smallest for the light of** [*CBSE 2020 (55/1/1)*]

(*a*) red colour (*b*) blue colour (*c*) yellow colour (*d*) green colour

20. **If the focal length of objective lens is increased then magnifying power of**

(*a*) microscope will increase but that of telescope decrease

(*b*) microscope and telescope both will increase

(*c*) microscope and telescope both will decrease

(*d*) microscope will decrease but that of telescope will increase

21. **Four lenses of focal length ±15 cm and ±150 cm are available for making a telescope. To produce the largest magnification, the focal length of the eyepiece should be**

(*a*) +15 cm (*b*) +150 cm (*c*) –150 cm (*d*) –15 cm

22. **The magnifying power of a telescope is 9. When it is adjusted for parallel rays the distance between the objective and eyepiece is 20 cm. The focal length of lenses are**

(*a*) 11 cm, 9 cm (*b*) 10 cm, 10 cm (*c*) 15 cm, 5 cm (*d*) 18 cm, 2 cm

23. **The focal length of the objective of a compound microscope is** [*CBSE 2020 (55/1/3)*]

(*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

24. **Larger aperture of objective lens in an astronomical telescope** [*CBSE 2020 (55/1/1)*]

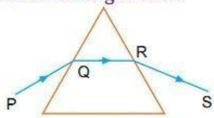
(*a*) increases the resolving power of telescope.

(*b*) decreases the brightness of the image.

(*c*) increases the size of the image.

(*d*) decreases the length of the telescope.

25. **A ray of light is incident on an equilateral glass prism placed on a horizontal table. For minimum deviation which of the following is true?**



(*a*) PQ is horizontal
(*b*) QR is horizontal
(*c*) RS is horizontal
(*d*) Either PQ or RS is horizontal

26. **A thin glass (refractive index 1.5) lens has optical power of – 5 D in air. Its optical power in liquid with refractive index 1.7 will be**

(*a*) – 1 D (*b*) + 1 D (*c*) – 25 D (*d*) + 25 D

27. **Refractive index of water is $\frac{5}{3}$. A light source is placed in water at a depth of 4 m. Then what must be the minimum radius of disc placed at water surface so that the light of source can be stopped?** [*HOTS*]

(*a*) 3 m (*b*) 4 m (*c*) 5 m (*d*) infinite

Answers

1. (*a*)	**2.** (*b*)	**3.** (*c*)	**4.** (*d*)	**5.** (*b*)	**6.** (*c*)	**7.** (*d*)
8. (*c*)	**9.** (*b*)	**10.** (*c*)	**11.** (*c*)	**12.** (*a*)	**13.** (*d*)	**14.** (*a*)
15. (*b*)	**16.** (*a*)	**17.** (*b*)	**18.** (*a*)	**19.** (*a*)	**20.** (*d*)	**21.** (*a*)
22. (*d*)	**23.** (*b*)	**24.** (*a*)	**25.** (*b*)	**26.** (*b*)	**27.** (*a*)	

Assertion-Reason Questions

In the following questions, a statement of Assertion (A) is followed by a statement of Reason (R). Choose the correct answer out of the following choices.

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

1. **Assertion(*A*) :** Diamond glitters brilliantly.
Reason (*R*) : Diamond reflects sunlight strongly.

2. **Assertion (*A*) :** A convex mirror cannot form real images.
Reason (*R*) : Convex mirror converges the parallel rays that are incident on it.
[*CBSE Sample Paper-2021*]

3. **Assertion(*A*) :** In a telescope, objective lens has greater focal length than eye piece but in a microscope objective has smaller focal length than eye piece. By inverting a telescope, a microscope cannot be formed.
Reason (*R*) : The difference in focal lengths of objective and eye lens in telescope is much larger than in microscope.

4. **Assertion (*A*) :** A convex lens of focal length 30 cm can't be used as a simple microscope in normal setting.
Reason (*R*) : For normal setting, the angular magnification of simple microscope is $M = D/f$.
[*CBSE Sample Paper-2021*]

5. **Assertion** (*A*) : For observing traffic at back, the driver mirror is convex mirror.
Reason (*R*) : A convex mirror has much larger field of view than a plane mirror.

6. **Assertion** (*A*) : In astronomical telescope, the objective lens is of large aperture.
Reason (*R*) : Larger is the aperture, smaller is the magnifying power.

7. **Assertion** (*A*) : The speed of light in glass depends on colour of light.
Reason (*R*) : The speed of light in glass $v_g = \frac{c}{n_g}$, the refractive index (n_g) of glass is different for different colours.

8. **Assertion** (*A*) : A ray of light is incident from outside on a glass sphere surrounded by air. This ray may suffer total internal reflection at second interface.
Reason (*R*) : If a ray of light goes from denser to rarer medium, it bends away from the normal. [*AIIMS 2017*]

9. **Assertion** (*A*) : In compound microscope, the objective lens is taken of small focal length.
Reason (*R*) : This increases the magnifying power of microscope.

10. **Assertion** (*A*) : If a convex lens is kept in water, its convergence power decreases.
Reason (*R*) : The refractive index of convex lens relative to water is less than that relative to air.

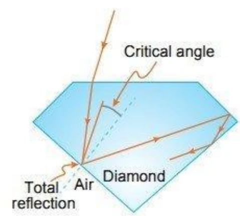
Answers

1. (*c*) **2.** (*c*) **3.** (*a*) **4.** (*b*) **5.** (*a*) **6.** (*c*) **7.** (*a*)
8. (*a*) **9.** (*b*) **10.** (*a*)

Case-based/Passage-based Questions

Read the paragraph given below and answer the questions that follow:

1. **Sparking Brilliance of Diamond:** The total internal reflection of the light is used in polishing diamonds to create a sparking brilliance. By polishing the diamond with specific cuts, it is adjusted so that the most of the light rays approaching the surface are incident with an angle of incidence more than critical angle. Hence, they suffer multiple reflections and ultimately come out of diamond from the top. This gives the diamond a sparking brilliance. [*CBSE Sample Paper-2021*]

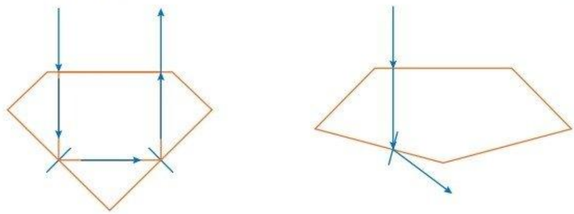


(*i*) **Light cannot easily escape a diamond without multiple internal reflections. This is because**
(*a*) its critical angle with reference to air is too large.
(*b*) its critical angle with reference to air is too small.
(*c*) the diamond is transparent.
(*d*) rays always enter at angle greater than critical angle.

(*ii*) **The critical angle for a diamond is 24.4°. Then its refractive index is**
(*a*) 2.42 (*b*) 0.413
(*c*) 1 (*d*) 1.413

(*iii*) **The basic reason for the extraordinary sparkle of suitably cut diamond is that**
(*a*) it has low refractive index
(*b*) it has high transparency
(*c*) it has high refractive index
(*d*) it is very hard

(*iv*) **The following diagram shows same diamond cut in two different shapes.**



The brilliance of diamond in the second diamond will be:

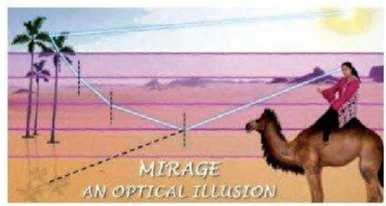
(*a*) less than the first
(*b*) greater than first
(*c*) same as first
(*d*) will depend on the intensity of light

OR

A diamond is immersed in a liquid with a refractive index greater than water. Then the critical angle for total internal reflection will

(*a*) depend on the nature of the liquid
(*b*) decrease
(*c*) remain the same
(*d*) increase

2. **Mirage in Deserts:**



To a distant observer, the light appears to be coming from somewhere below the ground. The observer naturally assumes that light is being reflected from the ground, say, by a pool of water near the tall object.

Such inverted images of distant tall objects cause an optical illusion to the observer. This phenomenon is called mirage. This type of mirage is especially common in hot deserts.

[*CBSE Sample Paper-2022, Term-2*]

(*i*) **Which of the following phenomena is prominently involved in the formation of mirage in deserts?**

(*a*) Refraction, Total internal Reflection
(*b*) Dispersion and Refraction
(*c*) Dispersion and scattering of light
(*d*) Total internal Reflection and diffraction

(*ii*) **A diver at a depth 12 m inside water** $\left({}^{a}\mu_{w} = \frac{4}{3}\right)$ **sees the sky in a cone of semi- vertical angle**

(*a*) $\sin^{-1}\frac{4}{3}$
(*b*) $\tan^{-1}\frac{4}{3}$
(*c*) $\sin^{-1}\frac{3}{4}$
(*d*) $90°$

(*iii*) **In an optical fibre, if n_1 and n_2 are the refractive indices of the core and cladding, then which among the following, would be a correct equation?**

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

(*iv*) **A diamond is immersed in such a liquid which has its refractive index with respect to air as greater than the refractive index of water with respect to air. Then the critical angle of diamond-liquid interface as compared to critical angle of diamond -water interface will**

(*a*) depend on the nature of the liquid only
(*b*) decrease
(*c*) remain the same
(*d*) increase

(*iii*) **Which of the following is not correct in the context of a compound microscope?**

(*a*) Both the lenses are of short focal lengths.

(*b*) The magnifying power increases by decreasing the focal lengths of the two lenses.

(*c*) The distance between the two lenses is more than $(f_o + f_e)$.

(*d*) The microscope can be used as a telescope by interchanging the two lenses.

(*iv*) **A compound microscope consists of an objective of 10X and an eye-piece of 20X. The magnification due to the microscope would be**

(*a*) 2 (*b*) 10

(*c*) 30 (*d*) 200

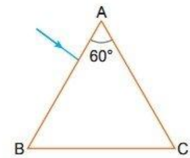
OR

The focal lengths of objective and eye-piece of a compound microscope are 1.2 cm and 3.0 cm respectively. The object is placed at a distance of 1.25 cm from the objective. If the final image is formed at infinity, the magnifying power of the microscope would be

(*a*) 100 (*b*) 150

(*c*) 200 (*d*) 250

4. **Refraction through Prism:** Strontium titanate is a rare oxide a natural mineral found in Siberia. It is used as a substitute for diamond because its refractive index and critical angle are 2.41 and 24.5°, respectively, which are approximately equal to the refractive index and critical angle of diamond. It has all the properties of diamond. Even an expert jeweller is unable to differentiate between diamond and strontium titanate. A ray of light is incident normally on one face of an equilateral triangular prism *ABC* made of strontium titanate.



[*CBSE 2023 (55/1/1), Modified*]

(*i*) **The necessary conditions for total internal reflection is**

(*a*) the angle of incidence in denser medium must be smaller than the critical angle for two media

(*b*) the angle of refraction in denser medium must be greater than the critical angle for two media

(*c*) the angle of incidence in denser medium must be greater than the critical angle for two media

(*d*) none of these

(*ii*) **The speed of light in a medium whose critical angle is 30° is**

(*a*) 3×10^8 m/s (*b*) 2×10^8 m/s

(*c*) 1.5×10^8 m/s (*d*) 2.5×10^8 m/s

(*iii*) **Dispersion power depends upon**

(*a*) height of the prism (*b*) angle of prism

(*c*) material of prism (*d*) the shape of prism

(*iv*) **A ray of light incident at an angle θ on refracting face of a prism emerges from the other normally. If the angle of the prism is 30° and the prism is made up of a material of refractive index 1.5, the angle of incidence is**

(*a*) 30° (*b*) 45°

(*c*) 60° (*d*) 90°

OR

When light rays are incident on a prism at an angle of 45°, the minimum deviation is obtained. If refractive index of prism is $\sqrt{2}$, then the angle of prism will be

(*a*) 60° (*b*) 40°

(*c*) 50° (*d*) 30°

5. **Lens Maker's Formula:** The lens maker's formula is useful to design lenses of desired focal lengths using surfaces of suitable radii of curvature. The focal length also depends on the refractive index of the material of the lens and the surrounding medium. The refractive index depends on the wavelength of the light used. The power of a lens is related to its focal length.

[*CBSE 2023 (55/4/1), Modified*]

(*i*) How will the power of lens affected with an increase of wave length of light?

(*a*) increases
(*b*) decreases
(*c*) first increases then decreases
(*d*) first decreases then increases

(*ii*) The radius of curvatures of two surface of a convex lens is *R*. For what value of μ of its material will its focal length become equal to *R*?

(*a*) 1
(*b*) 1.5
(*c*) 2
(*d*) infinite

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

(*a*) behave as perfect reflector
(*b*) absorb all the light falling on it
(*c*) have refractive index 1
(*d*) have refractive index exactly matching with that of the surrounding fluid

(*iv*) An object is placed in front of a Lens Which forms its erect image of magnification 3. The Power of the lens is 5D. Calculate the distance of the image from the lens.

(*a*) – 40 cm
(*b*) 40 cm
(*c*) – 80 cm
(*d*) 80 cm

OR

The focal length of a concave lens of μ = 1.5 is 20 cm is air. It is completely immersed in water $\mu = \frac{4}{3}$. Its focal length in water will be

(*a*) 20 cm
(*b*) 40 cm
(*c*) 60 cm
(*d*) 80 cm

Explanations

1. (*i*) (*b*) Its critical angle of light with reference to air is too small.

(*ii*) (*a*) Given critical angle, $i_c = 24.4°$

Refractive index, $n = \frac{1}{\sin i_c} = \frac{1}{\sin 24.4°}$

$\therefore \quad n = 2.42$

(*iii*) (*c*) Because it has high refractive index.

(*iv*) (*a*) The brilliance of second diamond will be less than that of first because critical angle for first diamond w.r.t. air is very small as compared to second diamond. So, more TIR takes place in first diamond as compared to the second.

OR

(*d*) increase (*i.e.*, $\sin i_c = \frac{1}{n}$)

2. (*i*) (*a*) Refraction, Total internal reflection

(*ii*) (*c*) By Snell's Law,

$${}^a\mu_w = \frac{1}{\sin C} \qquad \left[{}^a\mu_w = \frac{4}{3} \text{ (given)}\right]$$

$$\Rightarrow \quad \sin C = \frac{1}{{}^a\mu_w}$$

$$\therefore \quad C = \sin^{-1}\left(\frac{1}{{}^a\mu_w}\right) = \sin^{-1}\left(\frac{3}{4}\right)$$

(iii) (d) The refractive index of the core should be greater than the refractive index of the cladding. (*i.e.*, $n_1 > n_2$)

(iv) (d) By Snell's Law, $^{l}\mu_d = \frac{1}{\sin C} = \frac{\mu_d}{\mu_l}$, $^{w}\mu_d = \frac{1}{\sin C'} = \frac{\mu_d}{\mu_w}$

$$\mu_l > \mu_w$$

Thus, $C > C'$ (increases)

OR

(b) By Snell's Law, $^{1}\mu_2 = \frac{1}{\sin C'}$

$$\sin C' = \frac{1.44}{1.68} = 0.8571$$

$\Rightarrow \quad C' = 59°$

Total internal reflection will occur if the angle $i' = i'_c$,

i.e., if $i' > 59°$ or when $r < r_{max}$, where $r_{max} = 90° - 59° = 31°$.

Using Snell's law,

$$\frac{\sin i_{max}}{\sin r_{max}} = 1.68$$

or $\quad \sin i_{max} = 1.68 \times \sin r_{max}$

$$= 1.68 \times \sin 31°$$

$$= 1.68 \times 0.5150 = 0.8662$$

$\therefore \quad i_{max} = 60°$

Thus all incident rays which make angles in the range $0 < i < 60°$ with the axis of the pipe will suffer total internal reflections in the pipe.

3. (i) (b) Real, Virtual

(ii) (a) Magnifying power of compound microscope,

$$M = -\frac{v_0}{u_0}\left(1 + \frac{D}{f_e}\right) \quad \text{[For final image formed at near point]}$$

$$M = -\frac{L}{f_0}\left(\frac{D}{f_e}\right) \quad \text{[For final image formed at infinity]}$$

Hence M does not depends upon the aperture of the objective and the eye-piece.

(iii) (d) The microscope can be used as a telescope by interchanging the two lenses.

(iv) (d) Magnifying power,

$$M = M_0 \times M_e$$

$$= 10 \times 20 = 200$$

OR

(c) Given, $f_o = 1.2$ cm, $f_e = 3.0$ cm, $u_o = -1.25$ cm

Using lens formula at objective lens.

$$\frac{1}{f_0} = \frac{1}{v_0} - \frac{1}{u_0}$$

$$\Rightarrow \quad \frac{1}{v_0} = \frac{1}{f_0} + \frac{1}{u_0} = \frac{1}{1.2} - \frac{1}{1.25} = \frac{1.25 - 1.2}{1.2 \times 1.25} = \frac{0.05}{1.2 \times 1.25} = \frac{1}{30}$$

$\therefore \quad v_0 = 30$ cm.

When final image formed at infinity,

$$M = -\frac{v_0}{u_0} \times \frac{D}{f_e} = \frac{-30}{-1.25} \times \frac{25}{3} = 200$$

4. (i) (c) For TIR, $i > i_c$

(ii) (c) Here, $i_c = 30°$

As $n = \frac{c}{v} = \frac{1}{\sin i_c}$

$$v = c \sin i_c = 3 \times 10^8 \times \sin 30°$$

$$v = 3 \times 10^8 \times 0.5$$

$$\therefore \quad v = 1.5 \times 10^8 \text{ m/s}$$

(iii) (c) Dispersive power of prism depends upon nature of material of prism.

(iv) (b) We know that,

$$\delta = (n-1)A \text{ and } \delta = i - r$$

$$\delta = (1.5-1)30 = 0.5 \times 30 = 15°$$

Also, $\delta = i - r = \theta - r$

$$15° = \theta - 30° \qquad [\because \angle r = 30°]$$

$$\therefore \quad \theta = 15° + 30° = 45°$$

$$\therefore \quad \theta = i = 45°$$

OR

(a) $n = \dfrac{\sin\left(\dfrac{A+\delta_m}{2}\right)}{\sin\dfrac{A}{2}}$ But $\dfrac{A+\delta_m}{2} = i = 45°$

$$\sqrt{2} = \frac{\sin 45°}{\sin\frac{A}{2}} \Rightarrow \sin\frac{A}{2} = \frac{1}{2} \Rightarrow \frac{A}{2} = 30° \Rightarrow A = 60°$$

5. (i) (b) As from lens make's formula,

$$\frac{1}{f} \propto (n-1) \text{ and } P = \frac{1}{f} \quad \Rightarrow \quad P \propto (n-1)$$

Also, $n \propto \frac{1}{\lambda}$, Hence, $P \propto \frac{1}{\lambda}$

Thus, if wavelength (λ) of light increases then power of lens decreases.

(ii) (b) From Lens maker's formula, $\frac{1}{f} = (n-1)\left(\frac{1}{R_1} + \frac{1}{R_2}\right)$

$$\Rightarrow \quad \frac{1}{f} = (n-1)\left(\frac{2}{f}\right) \qquad (\therefore f = R)$$

$$\Rightarrow \quad \frac{1}{2} = (n-1)$$

$$\therefore \quad n = 1.5$$

(iii) (d) When the refractive index of the object is same as that of the media around it, then the rays pass undeflected and the object appears to be invisible.

(iv) (a) For virtual and erect image,

$$m = \frac{v}{u} \Rightarrow 3 = \frac{v}{u} \Rightarrow v = 3u,$$

and $f = \frac{1}{P} = f = \frac{1}{5} = 0.2 \text{ m} = 20 \text{ cm}$

Using lens formula, $\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$

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

$$\Rightarrow \qquad u = -\frac{40}{3} \text{ cm}$$

And $$v = 3u = -3 \times \frac{40}{3} = -40 \text{ cm}$$

OR

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

$$\frac{1}{20} = (1.5 - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \qquad ...(i)$$

And, $$\frac{1}{f_w} = \left(\frac{1.5}{\frac{4}{3}} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \qquad ...(ii)$$

From equation (*i*) and (*ii*), we get,

$$\frac{\frac{1}{20}}{\frac{1}{f_w}} = \frac{0.5}{\frac{1}{8}} = 4 \Rightarrow \frac{f_w}{20} = 4 \Rightarrow f_w = 80 \text{ cm}$$

CONCEPTUAL QUESTIONS

Q. 1. When light travels from an optically denser medium to a rarer medium, why does the critical angle of incidence depend on the colour of light? **[*CBSE Ajmer 2015*]**

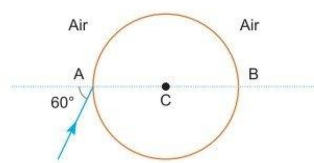
Ans. The refractive index is different for different colour wavelength as $n = a + \frac{b}{\lambda^2}$. Hence, critical angle $\sin i_c = \frac{1}{n}$ would also be different for different colour of light.

Q. 2. How does the angle of minimum deviation of a glass prism vary if the incident violet light is replaced by red light? **[*CBSE 2019 (55/3/1)*]**

Ans. The angle of minimum deviation decreases, if violet light is replaced by red light *i.e.*, $\delta_r < \delta_v$.

Q. 3. A ray of light falls on a transparent sphere with centre *C* as shown in the figure. The ray emerges from the sphere parallel to the line *AB*. Find the angle of refraction at *A* if refractive index of the material of the sphere is $\sqrt{3}$. **[*CBSE (F) 2014*]**

Ans. Refractive index, $n = \frac{\sin i}{\sin r}$



$$\sqrt{3} = \frac{\sin 60^\circ}{\sin r}$$

$$\sin r = \frac{\sqrt{3}}{2} \times \frac{1}{\sqrt{3}} = \frac{1}{2}$$

$$\sin r = \sin 30^\circ \Rightarrow r = 30^\circ$$

Angle of refraction = **30°**.

Q. 4. For the same angle of incidence, the angle of refraction in two media A and B are 25° and 35° respectively. In which one of the two media is the speed of light lesser? **[*CBSE Bhubaneshwar 2015*]**

Ans. By snell's Law, $n = \frac{\sin i}{\sin r} = \frac{v_1}{v_2}$

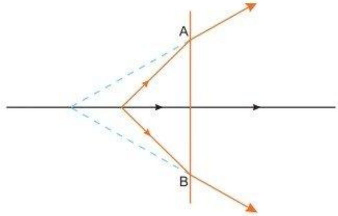
$$\frac{n_A}{n_B} = \frac{\sin i/\sin r_A}{\sin i/\sin r_B} = \frac{\sin r_B}{\sin r_A} = \frac{v_1/v_A}{v_1/v_B}$$

$$\frac{\sin r_B}{\sin r_A} = \frac{v_B}{v_A}$$

$$r_A < r_B \qquad \sin r_A < \sin r_B \quad \Rightarrow \quad v_A < v_B$$

Speed of light in A is lesser.

Q. 5. The line AB in the ray diagram represents a lens. State whether the lens is convex or concave. [*CBSE Chennai 2015*]



Ans. It is a concave or diverging lens.

Reason: The refracted ray is bending away from the principal axis.

Q. 6. An object is placed in front of a converging lens. Obtain the conditions under which the magnification produced by the lens is (*i*) negative and (*ii*) positive. [*CBSE 2022 (55/3/1), (55/3/3), Term-2*]

Ans. An object is placed in front of a converging lens.

(*i*) If, $m = -\text{ve}$, then real and inverted image is formed. Hence object should placed beyond F.

(*ii*) If, $m = +\text{ve}$, then virtual and erect image is formed. Hence object should placed between F and O.

Q. 7. 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 Delhi 2015*]

Ans. Concave lens, in medium of high refractive index, behaves as a convex lens (or a converging lens).

Reason: $$\frac{1}{f_m} = \left(\frac{n_g}{n_m} - 1\right)\left(-\frac{1}{R} - \frac{1}{R}\right)$$

Since $$n_m > n_g$$

$$\frac{1}{f_m} = +\text{ ve}$$

So, $f_m > 0$. Hence acts a convex lens.

Q. 8. What is the focal length of a combination of a convex lens of focal length 30 cm and a concave lens of focal length 20 cm in contact? Is the system a converging or a diverging lens? Ignore thickness of lenses. [*NCERT*]

Ans. Given $f_1 = +30$ cm, $f_2 = -20$ cm

The focal length (F) of combination of given by

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

$$\Rightarrow \qquad F = \frac{f_1 f_2}{f_1 + f_2} = \frac{30 \times (-20)}{30 - 20} = \mathbf{-60\text{ cm}}$$

That is, the focal length of combination is 60 cm and it acts like a diverging lens.

Q. 9. A ray of light passes through an equilateral glass prism such that the angle of incidence is equal to angle of emergence and each of these angles is equal to $\frac{3}{4}$th of angle of prism. What is the value of angle of deviation? [*CBSE Patna 2015*]

Ans. In prism $i + e = A + D =$ and $i = e = \frac{3}{4}A$ (given)

So, $$A + D = \frac{3}{4}A + \frac{3}{4}A$$

$$\Rightarrow \quad D = \frac{3A}{2} - A = \frac{A}{2}$$

Since $A = 60°$ (being an equilateral glass prism)

So, $$D = \frac{60°}{2} = \mathbf{30°}$$

Q. 10. An astronomical telescope may be a refracting type or a reflecting type. Which of the two produces image of better quality? Justify your answer. [*CBSE 2020 (55/4/1)*]

Ans. Reflecting telescope is preferred over refracting telescope because:

(*a*) No chromatic aberration, because mirror is used.

(*b*) Spherical aberration can be removed by using a parabolic mirror.

(*c*) Image is bright because no loss of energy due to reflection.

(*d*) Large mirror can provide easier mechanical support.

Q. 11. You are given following three lenses. Which two lenses will you use as an eyepiece and as an objective to construct an astronomical telescope? Give reason.

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

[*CBSE Delhi 2009, CBSE (AI) 2017*]

Ans. Objective : Lens L_1

Eyepiece : Lens L_3

Reason: The objective lens should have large aperture (here, 8 cm) and large focal length $\left(f = \frac{1}{\text{Power}}\right)$ while the eyepiece should have small aperture and small focal length.

Q. 12. Does the magnifying power of a microscope depend on the colour of the light used? Justify your answer. [*CBSE (F) 2017*]

Ans. Yes, since magnification depends upon focal length and focal length depends on the colour and different colours have different wavelengths (*i.e.*, different refractive indices).

$$\frac{1}{f} = (n-1)\left[\frac{1}{R_1} - \frac{1}{R_2}\right] \quad \text{(By Lens Maker's Formula)}$$

Also, magnification of compound microscope

$$M = \frac{-L}{f_0}\left(1 + \frac{D}{f_e}\right)$$

Q. 13. (*a*) Explain briefly how the focal length of a convex lens changes with increase in wavelength of incident light.

(*b*) What happens to the focal length of convex lens when it is immersed in water? Refractive index of the material of lens is greater than that of water. [*HOTS*] [*CBSE (South) 2016*]

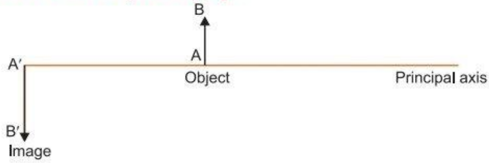
Ans. (*a*) Focal length increases with increase of wavelength.

$\frac{1}{f} = \left(\frac{n_2}{n_1} - 1\right)\frac{2}{R}$ as wavelength increases, $\frac{n_2}{n_1}$ decreases hence focal length increases.

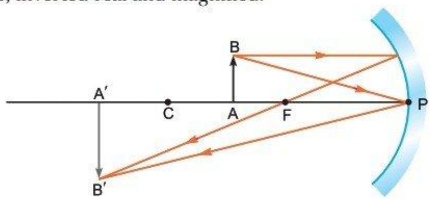
(*b*) As $n_2 > n_1$, $\left(\frac{n_2}{n_1} - 1\right)$ decreases so, focal length increases.

$$\frac{1}{f} = \left(\frac{n_2}{n_1} - 1\right)\frac{2}{R}$$

Q. 14. Redraw the diagram given below and mark the position of the centre of curvature of the spherical mirror used in the given set up. [*CBSE Sample Paper*]



Ans. If the object is in between focus '*F*' and centre of curvature '*C*', image would be beyond the centre of curvature, inverted real and magnified.



Q. 15. A concave mirror and a converging lens have the same focal length in air. Which one of the two will have greater focal length when both are immersed in water? [*HOTS*]

Ans. Converging lens; the focal length of a spherical mirror remains unaffected.

For converging lens, $\frac{1}{f} = \left(\frac{n_2}{n_1} - 1\right)\left(\frac{1}{R_2} + \frac{1}{R_2}\right)$

When it is immersed in water

$$n_2 \text{ (in water)} < n_2 \text{ (in air)}$$

$\left(\frac{n_2}{n_1} - 1\right)$ decreases hence focal length of converging lens increases in water.

Q. 16. A concave lens is placed in water. Will there be any change in focal length? Give reason. [*HOTS*]

Ans. Focal length of lens in water $f_w = \dfrac{n_g - 1}{\dfrac{n_g}{n_w} - 1} f_a$

$As\, n_g > n_w, \frac{n_g}{n_w} > 1,$ so $f_w > f_a$

That is, focal length of lens in water will increase, but the nature of lens will remain unchanged.

Q. 17. For which colour the magnifying power of a simple microscope is highest? For which colour it is lowest?

Ans. It is highest for violet and lowest for red colour since $M = 1 + \frac{D}{f}$ and $f_V < f_R$

Q. 18. A telescope has been adjusted for relaxed eye. You are asked to adjust it for least distance of distinct vision, then how will you change the distance between two lenses? [*HOTS*]

Ans. For relaxed eye, $L = f_0 + f_e$

For least distance of distinct vision

$$L' = f_0 + u_e, \; u_e < f_e$$

Therefore, $L' < L$, that is, the distance will be decreased.

Q. 19. Will the focal length of a lens for red light be more, same or less than that for blue light? [*HOTS*] [*NCERT Exemplar*]

Ans. As the refractive index for red is less than that for blue $\frac{1}{f} \propto n - 1$, parallel beams of light incident on a lens will be bent more towards the axis for blue light compared to red. Thus the focal length for red light will be more than that for blue.

Q. 20. State the condition under which a large magnification can be achieved in an astronomical telescope. [*CBSE 2019 (55/3/1)*]

Ans. $F_O >> F_e$

Focal length of objective must be much greater than focal length of eyepiece **1**

[*CBSE Marking Scheme 2019 (55/3/1)*]

Q. 21. An unsymmetrical double convex thin lens forms the image of a point object on its axis. Will the position of the image change if the lens is reversed? [*HOTS*] [*NCERT Exemplar*]

Ans. No, the reversibility of the lens makes equation.

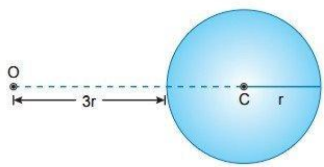
For convex lens, $\frac{1}{v}-\frac{1}{u}=\frac{1}{f}=(n-1)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)=-(n-1)\left(\frac{1}{R_2}-\frac{1}{R_1}\right)$

On reversing the lens, values of R_1 and R_2 are reversed and so their signs. Hence, for a given position of object (u), position of image (v) remains unaffected.

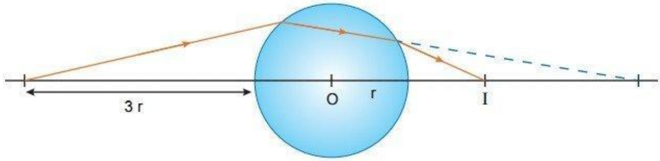
Very Short Answer Questions

Each of the following questions are of 2 marks.

Q. 1. A point object is placed at O in front of a glass sphere as shown in figure. Show the formation of image by the sphere. [*CBSE 2022 (55/3/1), (55/3/3), Term-2*]



Ans.



Q. 2. For paraxial rays, show that the focal length of a spherical mirror is one-half of its radius of curvature. [*CBSE 2019 (55/3/1)*]

Ans. According to the law of reflection,

Angle of incidence (i) = Angle of reflection (r)

$\therefore \quad \angle ABC = \angle FBC$

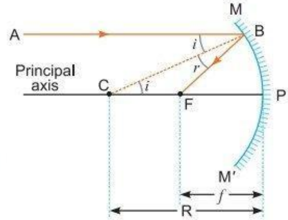
But $\quad \angle ABC = \angle BCF$ (alternate angles)

$\therefore \quad \angle FBC = \angle BCF$

Triangle BCF is isosceles. Hence, $CF = FB$ ...(*i*)

If aperture of mirror is small, then point B is very near to P, so

$\therefore \quad FB = FP$ ...(*ii*)



From equations (*i*) and (*ii*), $CF = FP$

$$\therefore \quad FP = \frac{FP + CF}{2} = \frac{PC}{2}$$

or $$f = \frac{R}{2}$$

Thus, the focal length of a spherical mirror (concave mirror) is half of its radius of curvature.

Q. 3. The focal length of and equiconcave lens is $\frac{3}{4}$ times of radius of curvature of its surfaces. Find the refractive index of the material of the lens. Under what condition will this lens behave as a converging lens? [*CBSE 2020 (55/2/2)*]

Ans. Using lens maker's formula,

$$\frac{1}{f} = (\mu - 1)\left[\frac{1}{R_1} - \frac{1}{R_2}\right]$$ ½

Given, $f = \frac{3}{4} R,\ R_1 = -R,\ R_2 = R$

$$\Rightarrow \quad -\frac{4}{3} = (\mu - 1)\left[\frac{1}{R_1} - \frac{1}{R_2}\right]$$ ½

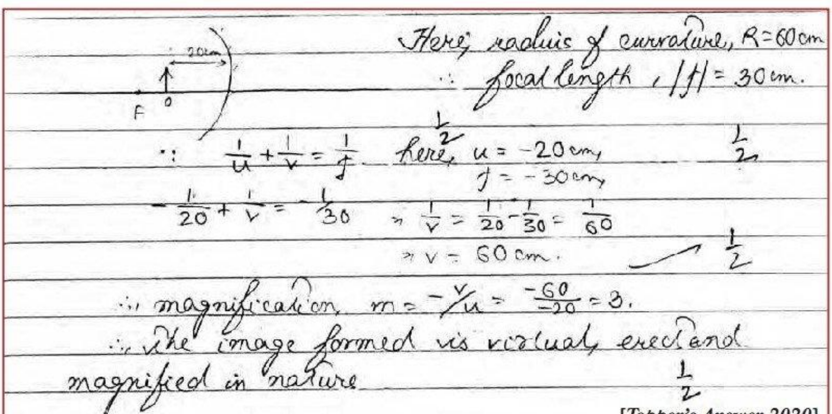
$$\Rightarrow \quad \mu = 1 + \frac{2}{3} = \frac{5}{3}$$ ½

If the lens is immersed in a medium of refractive index greater than 5/3, it will behave like a converging lens. ½

[*CBSE Marking Scheme 2020 (55/2/2)*]

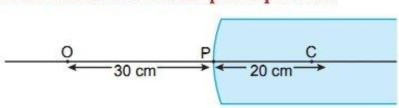
Q. 4. An object is kept 20 cm in front of a concave mirror of radius of curvature 60 cm. Find the nature and position of the image formed. [*CBSE 2020 (55/2/1)*]

Ans.



[*Topper's Answer 2020*]

Q. 5. A spherical convex surface of radius of curvature 20 cm, made of glass (n = 1.5) is placed in air. Find the position of the image formed, if a point object is placed at 30 cm in front of the convex surface on the principal axis. [*CBSE Sample Paper 2018*]



Ans. Here, $R = +20$ cm, $n_1 = 1.0$, $n_2 = 1.5$, $u = -30$ cm

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

$$\frac{1.5}{v} - \frac{1.0}{-30} = \frac{1.5-1.0}{20}$$

$$\Rightarrow \quad \frac{1.5}{v} + \frac{1}{30} = \frac{0.5}{20} = \frac{1}{40}$$

$$\Rightarrow \quad \frac{1.5}{v} = \frac{1}{40} - \frac{1}{30} = \frac{3-4}{120}$$

$$\Rightarrow \quad \frac{1.5}{v} = \frac{-1}{120}$$

$$\therefore \quad v = \mathbf{-180.0\ cm}$$

Q. 6. An angular magnification of 30X 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 Sample Paper-2022, Term-2*]

Ans. $m_o = 30$, $f_o = 1.25$ cm, $f_e = 5$ cm

when image is formed at least distance of distinct vision,

$$D = 25 \text{ cm}$$

Angular magnification of eyepiece

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

Total angular magnification, $m = m_o m_e$

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

As the objective lens forms the real image,

$$m_o = \frac{v_o}{u_o} = -5 \quad \Rightarrow \quad v_o = -5u_o$$

Using lens equation, $u_o = -1.5$ cm, $v_o = -5 \times (-1.5)\text{cm} = +7.5$ cm

Given $v_e = -D = -25$ cm, $f_e = +5$ cm, $u_e = ?$

Using again lens equation, $u_e = \frac{25}{6} = 4.17$ cm

Thus, object is to be placed at 1.5 cm from the objective and separation between the two lenses should be

$$L = v_o + |u_e| = \mathbf{11.67\ cm}$$

Q. 7. 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

(*i*) the telescope is in normal adjustment, [*CBSE Sample Paper-2022, Term-2*]

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

Ans. (*i*) In normal adjustment;

Magnifying power,

$$m = \frac{f_o}{f_e} = \left(\frac{140}{5}\right) = \mathbf{28}$$

(*ii*) When the final image is formed at the least distance of distinct vision (25 cm):

$$m = \frac{f_o}{f_e}\left(1 + \frac{f_e}{D}\right) = (28 \times 1.2) = \mathbf{33.6}$$

Q. 8. 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 (55/1/1)*]

Ans. We know that

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

According to question $P = -5$ D,

$$n_2 = 1.5, n_1 = 1.4$$

Also, lens is equiconcave $R_1 = -R, R_2 = R$

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

$\Rightarrow$ $$-5 = -\frac{0.1}{1.4} \times \frac{2}{R} \quad \Rightarrow \quad 5 = \frac{1}{14} \times \frac{2}{R}$$

$$\Rightarrow \frac{1}{R} = 35 \;\Rightarrow\; R = \frac{1}{35}\text{ m} = \frac{100}{35}\text{ cm} = \frac{20}{7}\text{ cm} = \mathbf{2.86\ cm}$$

Q. 9. 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. [*CBSE Sample Paper 2021*]

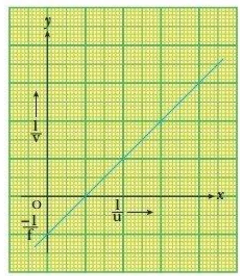
Ans. Characteristics of the images formed:

(*i*) Virtual and enlarged image

(*ii*) Same side of the object

We know that,

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



As both image and object lie on the same side, both v and u are negative,

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

Comparing with $y = mx + c$, the graph is shown.

Q. 10. An astronomical telescope has an angular magnification of magnitude 5 for distant objects. The separation between the objective and an eye piece is 36 cm and the final image is formed at infinity. Calculate the focal length of the objective and the focal length of the eye piece? [*CBSE Sample Paper 2018*]

Ans. Magnification $m = f_0/f_e = 5$

$$f_0 = 5f_e$$

Now, length of the tube, $L = f_0 + f_e$

$$36 = 5f_e + f_e$$

$$6f_e = 36 \text{ cm}$$

$$f_e = \mathbf{6\ cm}$$

$\therefore$ $$f_0 = 5 \times 6 = \mathbf{30\ cm}$$

Q. 11. The focal lengths of the objective and the eye-piece of a compound microscope are 1.0 cm and 2.5 cm respectively. Find the tube length of the microscope for obtaining a magnification of 300. [*CBSE 2023 (55/2/1)*]

Ans. Here, $f_0 = 1.0$ cm, $f_e = 2.5$ cm, $m = 300$, $D = 25$ cm,

Magnifying power,

$$|m| = \frac{L}{f_0} \cdot \frac{D}{f_e} \text{ (when image at infinity)}$$

$$\Rightarrow \qquad 300 = \frac{L}{1.0} \cdot \frac{25}{2.5}$$

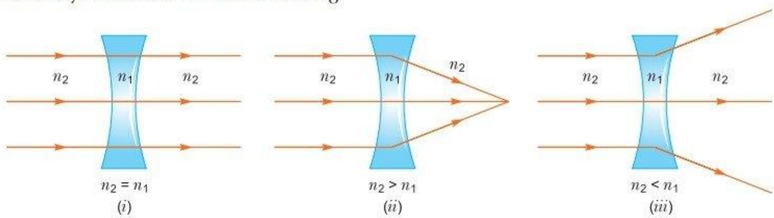
$$\therefore \qquad L = \mathbf{30\ cm}$$

Q. 12. The refractive index of a material of a concave lens is n_1. It is immersed in a medium of refractive index n_2. A parallel beam of light is incident on the lens. Trace the path of emergent rays when (i) $n_2 = n_1$ (ii) $n_2 > n_1$ (iii) $n_2 < n_1$.

Ans. From lens maker's formula, $\frac{1}{f} = \left(\frac{n_1}{n_2} - 1\right)\left(-\frac{1}{R_2} - \frac{1}{R_2}\right)$

(i) for $n_1 = n_2 \Rightarrow f = \infty$ (ii) for $n_1 < n_2 \Rightarrow f > 0$ (iii) for $n_1 > n_2 \Rightarrow f < 0$

The path of rays in three cases is shown in fig.



Q. 13. A convex lens made of a material of refractive index n_1 is kept in a medium of refractive index n_2. Parallel rays of light are incident on the lens. Complete the path of rays of light emerging from the convex lens if: (i) $n_1 > n_2$ (ii) $n_1 = n_2$ (iii) $n_1 < n_2$.

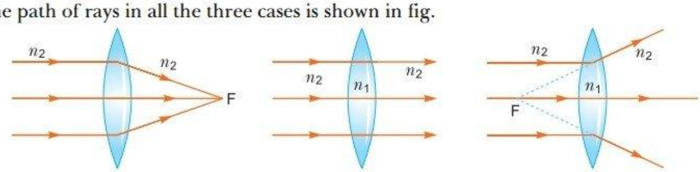
Ans. From lens maker's formula, $\frac{1}{f} = \left(\frac{n_1}{n_2} - 1\right)\left(\frac{1}{R_2} + \frac{1}{R_2}\right)$

In case (i) $n_1 > n_2$, the lens behaves as convergent lens.

In case (ii) $n_1 = n_2$, the lens behaves as a plane plate.

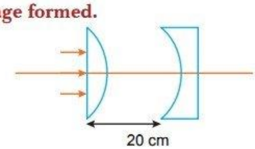
In case (iii) $n_1 < n_2$, the lens behaves as a divergent lens.

The path of rays in all the three cases is shown in fig.



(i) $n_1 > n_2$ (ii) $n_1 = n_2$ (iii) $n_1 < n_2$

Q. 14. 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 (55/2/1)]**



Ans. From lens maker's formula, $\frac{1}{f} = (1.5 - 1)\left(\frac{1}{\infty} - \frac{1}{(-15)}\right)$

we get, $f = 30$ cm

Again, $\frac{1}{f} = (1.5 - 1)\left(\frac{1}{(-15)} - \frac{1}{\infty}\right)$

We get, $f = -30$ cm

Using lens formula, $\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$

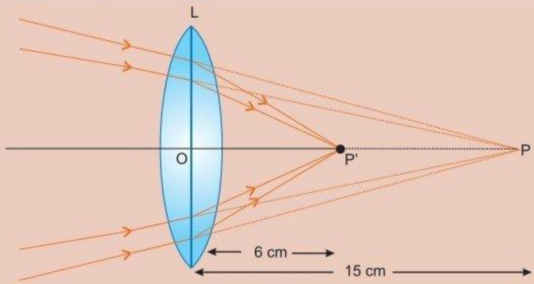
$\Rightarrow \quad -\frac{1}{30} = \frac{1}{v} - \frac{1}{10} \qquad (\because u = 10)$

$\Rightarrow \quad \frac{1}{v} = \frac{1}{10} - \frac{1}{30} = \frac{3-1}{30} = \frac{2}{30} = \frac{1}{15}$

$\therefore \quad v =$ **15 cm**

Q. 15. A beam of light converges at a point P. Now a convex lens is placed in the path of the convergent beam at 15 cm from P. At what point does a beam converge if the convex lens has a focal length 10 cm? *[CBSE 2019 (55/4/1)]*

Ans.



½

Using lens formula,

$$\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$$ ½

Here $u = +15$ cm; $f = +10$ cm ½

$\Rightarrow \quad \frac{1}{v} - \frac{1}{f} + \frac{1}{u} = \frac{1}{10} + \frac{1}{15}$

$\therefore \quad v = 6$ cm ½

[CBSE Marking Scheme 2019 (55/4/1)]

Q. 16. A small pin fixed on a table top is viewed from above from a distance of 50 cm. By what distance the pin appear to be raised if it is viewed from the same point through a 15 cm thick glass slab held parallel to the table? Refractive index of glass = 1.5. Does the answer depend on the location of the slab? *[NCERT]*

Ans. Apparent thickness of slab $= \frac{\text{Real thickness}}{\text{Refractive index}} = \frac{H}{n}$

Displacement of pin, $x = \left(H - \frac{H}{n}\right) = H\left(1 - \frac{1}{n}\right)$

Here, $H = 15$ cm, $n = 1.5$,

$\therefore \quad x = H\left(1 - \frac{1}{n}\right) = 15\left(\frac{1.5-1}{1.5}\right)$ cm $=$ **5 cm**

Thus the pin appears to be raised by 5 cm.

The answer does not depend upon the location of slab.

Q. 17. (*i*) State the condition under which a large magnification can be achieved in an astronomical telescope. *[CBSE 2019 (55/3/1)]*

(*ii*) Give two reasons to explain why a reflecting telescope is preferred over a refracting telescope. *[CBSE (F) 2017]*

Ans. (*i*) (*a*) When final image is formed at least distance of distinct vision, magnification

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

(*b*) Magnification in normal adjustment,

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

Clearly, for large magnification

$$f_o >> f_e$$

(*ii*) Reflecting telescope is preferred over refracting telescope because

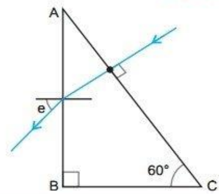
(*a*) No chromatic aberration, because mirror is used.

(*b*) Spherical aberration can be removed by using a parabolic mirror.

(*c*) Image is bright because no loss of energy due to reflection.

(*d*) Large mirror can provide easier mechanical support. (*any two*)

Q. 18. Calculate the angle of emergence (*e*) of the ray of light incident normally on the face *AC* of a glass prism *ABC* of refractive index $\sqrt{3}$. How will the angle of emergence change qualitatively, if the ray of light emerges from the prism into a liquid of refractive index 1.3 instead of air? **[*CBSE 2020 (55/5/1)*]**



Ans. Applying Snell's law at face *AB*, we get

$$\Rightarrow \sqrt{3}\sin 30 = 1.\sin e$$ ½

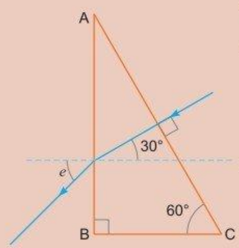
$$\Rightarrow \sqrt{3}\times\frac{1}{2} = \sin e$$ ½

$$\Rightarrow \frac{\sqrt{3}}{2} = \sin e$$

$$\Rightarrow \sin 60 = \sin e$$

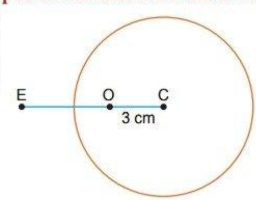
$$\therefore e = 60°$$ ½

When the medium (the air) in which prism is kept is replaced with a liquid of refractive index 1.3 the angle of emergence would derease. It is because bending in the ray of light will be lesser. ½



[*CBSE Making Scheme 2020 (55/5/1)*]

Q. 19. A solid glass sphere of radius 6.0 em has a small air bubble trapped at a distance 3.0 cm from its center *C* as shown in the figure. The refractive index of the material of the sphere is 1.5. Find the apparent position of this bubble when seen through the surface of the sphere from an outside point *E* in air. **[*CBSE 2023 (55/1/1/)*]**



Ans. Here, $R = 6$ cm, $u = 6 - 3 = 3$ cm, $n_1 = 1.5$. $n_2 = 1$

From the relation, $\frac{n_2}{v} - \frac{n_1}{u} = \frac{n_2 - n_1}{R}$

$$\frac{1}{v} - \frac{1.5}{3} = \frac{1-1.5}{-6}$$

$$\frac{1}{v} = \frac{0.5}{6} + \frac{1.5}{3} = \frac{0.5-3}{6} = -\frac{2.5}{6}$$

$$\therefore \quad v = -\frac{6}{2.5} = \mathbf{2.4\ cm}$$

Q. 20. **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 (55/1/2)*]

Ans.

Refractive index of prism = 1.6 = $\frac{8}{5}$ – n_1

Refractive index of surrounding medium = $\frac{4\sqrt{2}}{5}$ – n_2

Refractive index of prism w.r.t surroundings = $n_{12} = \frac{n_1}{n_2}$

$$\mu = \frac{8 \times 5}{5 \times 4\sqrt{2}} = \sqrt{2}$$

So, using the relation,

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

A = angle of prism = 60°, δ_{min} = angle of minimum deviation

we get,

$$\sqrt{2} = \frac{\sin\left(\frac{60+\delta_{min}}{2}\right)}{\sin 30°}$$

$$\frac{1}{\sqrt{2}} = \sin\left(\frac{60+\delta_{min}}{2}\right)$$

$$\frac{60+\delta_{min}}{2} = \sin^{-1}\frac{1}{\sqrt{2}} = 45°$$

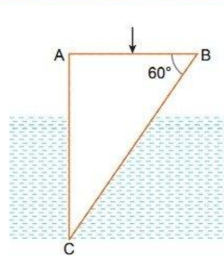
$$60° + \delta_{min} = 90°$$

$$\delta_{min} = 30°$$

Hence, angle of minimum deviation of prism = 30°

[*Topper's Answer 2019*]

Q. 21. **(*a*) A ray of light is incident normally on the face *AB* of a right-angled glass prism of refractive index $_a n_g$ = 1.5. The prism is partly immersed in a liquid of unknown refractive index. Find the value of refractive index of the liquid so that the ray grazes along the face *BC* after refraction through the prism.**



(*b*) Trace the path of the rays if it were incident normally on the face *AC*.

[*CBSE Ajmer 2015*]

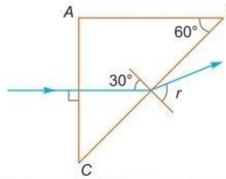
Ans. (*a*) From Snell's law,

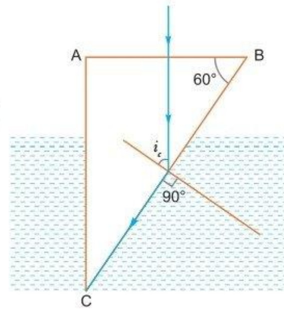
$$_a n_g \sin i_c = {_a n_l} \sin 90°$$

$$1.5 \times \sin 60^\circ = {}_a n_l$$

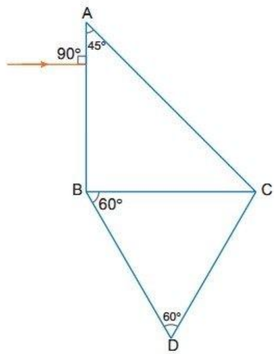
$$\therefore \quad {}_a n_l = 1.5 \times \frac{\sqrt{3}}{2} = \mathbf{1.3}$$

(*b*) The ray strikes at an angle of $30^\circ < i_c$. So, the ray of light deviates apart from the normal, as it moves from denser to rarer medium.





Q. 22. Two prisms *ABC* and *DBC* are arranged as shown in figure.

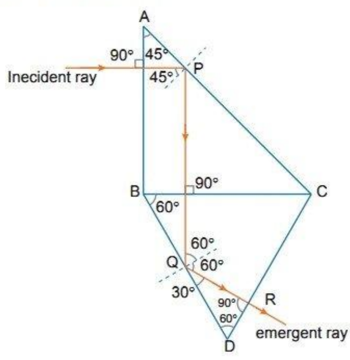


The critical angles for the two prisms with respect to air are 41.1° and 45° respectively. Trace the path of the ray through the combination. **[*CBSE 2022 (55/3/1), Term-2*]**

Ans. For surface *AC* : at point *P*, $i > i_c$ (*i.e.*, $i_{c_1} = 41.1^\circ$); hence ray will suffer total internal reflection.

For surface *BD* : at point *Q*; again $i > i_c$ (*i.e.*, $i_{c_2} = 45^\circ$); hence ray will suffer total internal reflection.

For surface *DC* : ray will be normal to *DC*.



Q. 23. 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 (AI) 2017*]**

Ans. Angle of prism, $A = 60°$ (Since prism is an equilateral glass prism)

We are given that

$$i = \frac{3}{4}A = \frac{3}{4} \times 60°$$

$\therefore$ $i = 45°$

At minimum deviation,

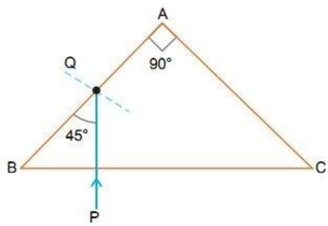
$$r = \frac{A}{2} = 30°$$

$\therefore$ $$n = \frac{\sin i}{\sin r} = \frac{\sin 45°}{\sin 30°} = \frac{\frac{1}{\sqrt{2}}}{\frac{1}{2}} = \frac{2}{\sqrt{2}} = \sqrt{2}$$

$\therefore$ Speed of light in the prism is given by

$$v = \frac{c}{n} = \frac{3 \times 10^8}{\sqrt{2}} = \mathbf{2.1 \times 10^8\ m/s}$$

Q. 24. A ray of light *PQ* enters an isosceles right angled prism *ABC* of refractive index 1.5 as shown in figure. **[*CBSE 2020 (55/4/1)*]**



(*i*) Trace the path of the ray through the prism.

(*ii*) What will be the effect on the path of the ray if the refractive index of the prism is 1.4?

Ans. (*i*) $n = 1.5$

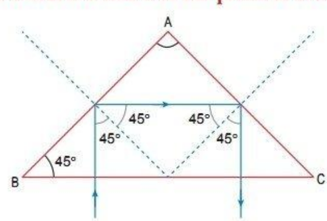
$$i_c = \sin^{-1}\left(\frac{1}{\mu}\right)$$

$$= \sin^{-1}\left(\frac{2}{3}\right) = \sin^{-1}(0.66) = 41°$$

Here, $i = 45°$

Since $i > i_c$

Hence the ray will suffer total interval reflection



(*ii*) If $n = 1.4$

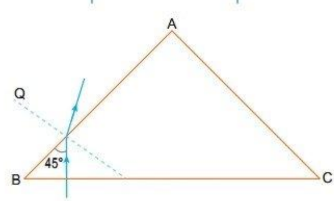
$$i_c = \sin^{-1}\left(\frac{1}{1.4}\right)$$

$$= 45.58°$$

Here $i = 45°$

Since $i < i_c$

Hence the ray will get refracted.



Short Answer Questions

Each of the following questions are of 3 marks.

Q. 1. (*i*) What is total internal reflection? Under what conditions does it occur?

[*CBSE 2022 (55/2/1), Term–2*]

(*ii*) Find a relation between critical angle and refractive index.

(*iii*) Name one phenomenon which is based on total internal reflection.

[*CBSE (East) 2016, 2019 (55/1/1)*]

Ans. (*i*) When a ray of light travels from an optically denser medium into a rarer medium at an angle greater than the critical angle, it reflects back into the denser medium. This phenomenon is called total internal reflection.

Conditions for total internal reflection:

(*a*) Light must travel from denser medium to rarer medium.

(*b*) Angle of incidence in denser medium must be greater than critical angle.

(*ii*) $\frac{1}{n} = \frac{\sin i}{\sin r}$, for total internal reflection to occur $i \geq i_c$; at critical angle, angle of refraction, $r = 90°$ hence $\frac{1}{n} = \frac{\sin i_c}{\sin 90^o} \Rightarrow n = \frac{1}{\sin i_c}$

(*iii*) (*a*) Mirage (*b*) Optical fibre (*c*) Sparkling of diamond (*d*) Shinning of air bubbles in water (*e*) Totally reflecting prism. (*any one*)

Q. 2. (*i*) Name the phenomenon on which the working of an optical fibre is based.

[*CBSE 2022 (55/1/1), Term–2*]

(*ii*) What are the necessary conditions for this phenomenon to occur?

[*CBSE 2022 (55/3/1), Term–2*]

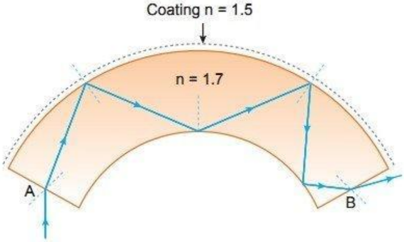
(*iii*) Draw a labelled diagram of an optical fibre and show how light propagates through the optical fibre using this phenomenon. [*CBSE 2019, CBSE 2022 (55/1/1), (55/2/3), Term–2*]

Ans. (*i*) Working of an optical fibre is based on total internal reflection.

(*ii*) (*a*) Rays of light have to travel from optically denser medium to optically rarer medium and

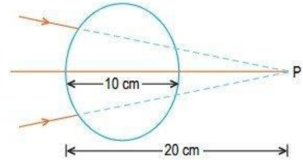
(*b*) Angle of incidence in the denser medium should be greater than critical angle.

(*iii*)



Q. 3. A converging beam of light travelling in air converges at a point *P* as shown in the figure. When a glass sphere of refractive index 1.5 is introduced in between the path of the beam, calculate the new position of the image. Also draw the ray diagram for the image formed.

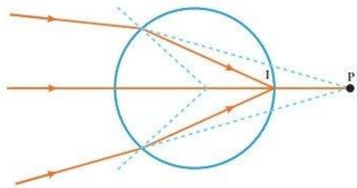
[*CBSE 2019 (55/3/1)*]



Ans. Given, $u = 20$ cm

$n_1 = 1$

$R = \frac{10}{2} = 5$ cm



As the light passes from rare to denser medium, so

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

$$\frac{1.5}{v} - \frac{1}{20} = \frac{1.5-1}{5}$$

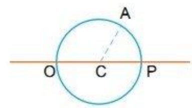
$$\frac{1.5}{v} = \frac{1}{10} + \frac{1}{20}$$

$$\frac{1.5}{v} = \frac{2+1}{20}$$

$$v = \mathbf{+10\ cm}$$

Thus, the image is formed at the other end (I) of the diameter.

Q. 4. A point 'O' marked on the surface of a glass sphere of diameter 20cm is viewed through glass from the position directly opposite to the point O. If the refractive index of the glass is 1.5, find the position of the image formed. Also, draw the ray diagram for the image formed. Also, draw the ray diagram for the formation of the image. *[CBSE 2019 (55/3/1)]*



Ans. The mark O on the surface of glass sphere acts as object. The incident ray OA is in glass and refracted ray AB is in air. I is the image of O.

Thus, $n_1 = 1$, $n_2 = 1.5$

$u = -20$ cm (Minus sign is taken for refraction at concave surface)

As light passes from denser to rarer medium, so

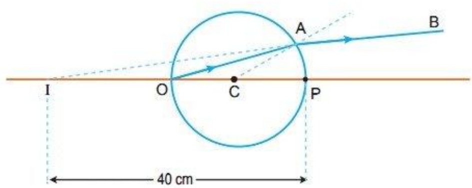
$$\frac{n_1}{v} - \frac{n_2}{u} = \frac{n_1 - n_2}{R}$$

$$\frac{1}{v} + \frac{1.5}{20} = \frac{1-1.5}{-10}$$

$$\frac{1}{v} = \frac{1}{20} - \frac{3}{40}$$

$$\frac{1}{v} = \frac{2-3}{40} = \frac{-1}{40}$$

$$v = \mathbf{-40\ cm}$$



Negative sign shows that the image is virtual. It is formed on the same side of the refracting surface as the object at a distance of 40 cm from the pole P.

Q. 5. Use the mirror equation to show that

(*a*) an object placed between f and $2f$ of a concave mirror produces a real image beyond $2f$. *[CBSE Delhi 2015, (F) 2017, 2019 (55/3/3)]*

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

(*c*) an object placed between the pole and focus of a concave mirror produces a virtual and enlarged image. *[NCERT] [CBSE (AI) 2011]*

Ans. (*a*) Mirror equation is $\frac{1}{f} = \frac{1}{v} + \frac{1}{u}$ *or* $\frac{1}{v} = \frac{1}{f} - \frac{1}{u}$

For a concave mirror, f is negative, *i.e.*, $f < 0$.

For a real object (on the left of mirror), $u < 0$

$$\therefore \qquad 2f < u < f \text{ or } \frac{1}{2f} > \frac{1}{u} > \frac{1}{f}$$

$$\text{or} \qquad -\frac{1}{2f} < -\frac{1}{u} < -\frac{1}{f} \text{ or } \frac{1}{f} - \frac{1}{2f} < \frac{1}{f} - \frac{1}{u} < \frac{1}{f} - \frac{1}{f}$$

$$\text{or} \qquad \frac{1}{2f} < -\frac{1}{v} < 0 \quad i.e., \frac{1}{v} \text{ is negative.}$$

This implies that v is negative.

Also from above inequality $2f > v$

or $\qquad |2f| < |v| \qquad$ ($\because$ $2f$ and v are negative)

Hence, the real image is formed beyond $2f$.

(*b*) For a convex mirror, f is positive, *i.e.*, $f > 0$.

For a real object on the left, u is negative

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

As u is negative and f is positive; $\frac{1}{v}$ must be positive, so v must be positive *i. e.* , image lies behind the mirror. Hence, image is virtual whatever the value of u may be.

(*c*) Using mirror formula, $\frac{1}{v} = \frac{1}{f} - \frac{1}{u}$ ...(*i*)

For a concave mirror, f is negative *i.e.*, $f < 0$

As u is also negative, so $f < u < 0$

This implies, $\qquad \frac{1}{f} - \frac{1}{u} > 0$

Then from (*i*) $\frac{1}{v} > 0$ or v is positive.

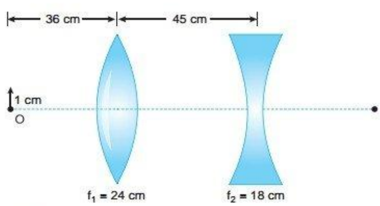
i.e., image is on the right and hence **virtual**.

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

As u is negative and f is positive, magnification $m = \frac{|f|}{|f| - |u|} > 1$ *i.e.*, image is enlarged.

Q. 6. Two thin lenses L_1 and L_2, L_1 being a convex lens of focal length 24 cm and L_2 a concave lens of focal length 18 cm are placed coaxially at a separation of 45 cm. A 1 cm tall object is placed in front of the lens L_1 at a distance of 36 cm. Find the location and height of the image formed by the combination. **[*CBSE 2023 (55/4/1)*]**

Ans.



Here, $u_1 = -36$ cm, $f_1 = 24$

Image formed by first lens, L_1.

Using lens formula,

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

$$\Rightarrow \qquad \frac{1}{v_1} = \frac{1}{f_1} + \frac{1}{u_1} = \frac{1}{24} + \frac{1}{(-36)} = \frac{3-2}{72} = \frac{1}{72}$$

$\therefore \quad v_1 = 72$ cm

Hence, Image formed by convex lens is real and inverted but it acts as virtual object for lens, L_2.

Now, $u_2 = 72 - 45 = 27$ cm

Again using lens formula,

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

$$\Rightarrow \quad \frac{1}{v_2} = \frac{1}{f_2} + \frac{1}{u_2} = \frac{1}{(-18)} + \frac{1}{(27)}\text{s}$$

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

$\therefore \quad$ $v_2 =$ **–54 cm**

Hence, final image will form at 54 cm from the left side of concave lens.

Final distance, $v'_2 = -54 - (-45) = -9$ cm (to the left of convex lens)

So, magnification,

$$m = \frac{h_2}{h_1} = \frac{v'_2}{u}$$

$$\Rightarrow \quad \frac{h_2}{1} = \frac{-9}{-36} = \frac{1}{4}$$

$\therefore \quad h_2 = \frac{1}{4}$ cm = **0.25 cm.**

Q. 7. The image of a small electric bulb fixed on the wall of a room is to be obtained on the opposite wall 3 m away by means of a large convex lens. What is the maximum possible focal length of the lens required for the purpose? [*NCERT*]

Ans. For a fixed distance D between object and image for its real image

$$D = |u| + |v| \quad \ldots(i)$$

$$x = v - u \quad \ldots(ii)$$

From equation (*i*) and (*ii*),

$$v = \frac{D+x}{2} \qquad u = \frac{D-x}{2}$$

Sign convention: u is negative and v is positive.

$$\frac{1}{f} = \frac{1}{v} + \frac{1}{u} = \frac{2}{D+x} + \frac{2}{D-x} = \frac{4D}{D^2 - x^2}$$

$$\Rightarrow \quad f = \frac{D^2 - x^2}{4D}$$

where x is the separation between two positions of lens.

For maximum f, $x = 0$

$$\therefore \quad f_{max} = \frac{D}{4}$$

Given $D = 3$ m

$f = \frac{3}{4}$ m = **0.75 m**

Q. 8. A thin equiconvex lens of radius of curvature R made of material of refractive index μ_1 is kept coaxially, in contact with an equiconcave lens of the same radius of curvature and refractive index μ_2 ($>\mu_1$). Find: [*CBSE 2022 (55/1/1), Term–2*]

(*i*) the ratio of their powers, and

(*ii*) the power of the combination and its nature.

Ans. (*i*) From Lens maker's formula, $= \frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$

$$P_1 = P_{Convex} = (\mu - 1)\left(\frac{1}{R_1} - (\frac{1}{R_2})\right) \quad ½$$

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

$$P_2 = P_{Convex} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

$$= (\mu - 1)\left(\frac{2}{R}\right)$$ ½

$$\therefore \frac{P_1}{P_2} = \frac{(\mu_1 - 1)}{(\mu_2 - 1)} = \frac{(\mu_1 - 1)}{(1 - \mu_2)}$$ ½

(*ii*) For combination of lenses, $P = P_1 + P_2$

$$= (\mu_1 - 1)\left(\frac{2}{R}\right) + (-(\mu_2 - 1))\left(\frac{2}{R}\right)$$ ½

$$= \frac{2(\mu_1 - \mu_2)}{R}$$

As $\mu_2 > \mu_1$, P is negative ½

$\therefore$ Nature is diverging. ½

[*CBSE Making Scheme-2022 (55/1/1), Term–2*]

Q. 9. What are optical fibres? Mention their one practical application.

[*CBSE Delhi 2011, Guwahati 2015*]

Ans. **Optical Fibre:** An optical fibre is a device based on total internal reflection by which a light signal may be transmitted from one place to another with a negligible loss of energy. It is a very long and thin pipe of quartz ($n = 1.7$) of thickness nearly $\approx 10^{-4}$ m coated all around with a material of refractive index 1.5. A large number of such fibres held together form a *light pipe* and are used for communication of light signals. When a light ray is incident on one end at a small angle of incidence, it suffers refraction from air to quartz and strikes the quartz-coating interface at an angle more than the critical angle and so suffers total internal reflection and strikes the opposite face again at an angle greater than critical angle and so again suffers total internal reflection. Thus the ray within the fibre suffers multiple total internal reflections and finally strikes the other end at an angle less than critical angle for quartz-air interface and emerges in air.

As there is no loss of energy in total internal reflection, the light signal is transmitted by this device without any appreciable loss of energy.

Application : Optical fibre is used to transmit light signal to distant places.

For diagram, Refer to Question 2 (*iii*), Short Answer Question.

Q. 10. 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? [*CBSE Sample Paper-2022, Term–2*]

Ans. Given, ${}^a\mu_g = 1.5$

Focal length of the given convex lens when it is placed in air is

$f = +20$ cm

Refractive index of the given medium with respect to air is

${}^a\mu_m = 1.25$

New focal length of the given convex lens when placed in a medium is f'

$$\frac{1}{f} = ({}^a\mu_g - 1)\left[\left(\frac{1}{R_1}\right) + \left(\frac{1}{R_2}\right)\right] \quad ...(i)$$

$$\frac{1}{f'} = ({}^m\mu_g - 1)\left[\left(\frac{1}{R_1}\right) + \left(\frac{1}{R_2}\right)\right] \quad ...(ii)$$

Dividing (*i*) by (*ii*), we get

$$\frac{f'}{f} = \frac{({}^{a}\mu_g - 1)}{({}^{m}\mu_g - 1)} = \frac{(1.5-1)}{(1.2-1)} = \frac{0.5}{0.2} = \frac{5}{2} = 2.5$$

$$f' = 2.5f = (2.5 \times 20) \text{ cm} = +50 \text{ cm as } {}^{m}\mu_g = \frac{\mu_g}{\mu_m} = \frac{1.5}{1.25} = 1.2$$

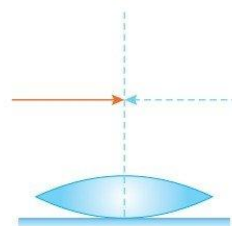
New focal length is positive.

The significance of the positive sign of the focal length is that given convex lens is still converging in the given medium.

Q. 11. A symmetric biconvex 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 is 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. Let n_l denote the refractive index of the liquid. When the image of the needle coincides with the lens itself; its distance from the lens, equals the relevant focal length.

With liquid layer present, the given set up, is equivalent to a combination of the given (convex) lens and a concave plane/plano concave 'liquid lens'.



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

and $$\frac{1}{f} = \left(\frac{1}{f_1} + \frac{1}{f_2}\right)$$

As per the given data, we then have

$$\frac{1}{f_2} = \frac{1}{y} = (1.5-1)\left(\frac{1}{R} - \frac{1}{(-R)}\right) = \frac{1}{R}$$

$$\therefore \quad \frac{1}{x} = (n_l - 1)\left(-\frac{1}{R}\right) + \frac{1}{y} = \frac{-n_l}{y} + \frac{2}{y}$$

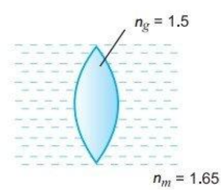
$$\therefore \quad \frac{n_l}{y} = \frac{2}{y} - \frac{1}{x} = \left(\frac{2x-y}{xy}\right)$$

or $$\boldsymbol{n_l = \left(\frac{2x-y}{x}\right)}$$

Q. 12. A biconvex lens of glass of refractive index 1.5 having focal length 20 cm is placed in a medium of refractive index 1.65. Find its focal length. What should be the value of the refractive index of the medium in which the lens should be placed so that it acts as a plane sheet of glass? [*CBSE Bhubaneshwar 2015*]

Ans. From lens maker's formula, when lens in a medium

$$\frac{1}{f_m} = \left(\frac{n_g}{n_m} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \quad \ldots(i)$$



When lens in air $$\frac{1}{f_a} = (n_g - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \quad \ldots(ii)$$

From equation (*i*) and (*ii*), we get

$$\frac{f_a}{f_m} = \frac{\left(\frac{n_g}{n_m} - 1\right)}{(n_g - 1)}$$

$$\frac{20 \text{ cm}}{f_m} = \frac{\left(\frac{1.5}{1.65} - 1\right)}{(1.5-1)}$$

$$\Rightarrow \quad f_m = \frac{20 \times (1.5-1)}{\left(\frac{1.5}{1.65}-1\right)} = \frac{20 \times 0.5 \times 1.65}{-0.15} = \mathbf{-110\ cm}$$

If lens in the medium behave as a plane sheet of glass. Then $f_m = \infty$

$$\frac{1}{\infty} = \left(\frac{n_g}{n_m}-1\right)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)$$

$$\Rightarrow \left(\frac{n_g}{n_m}-1\right) = 0 \ \Rightarrow n_g = n_m = \mathbf{1.5}$$

The refractive index of the medium must be 1.5.

Q. 13. A point source in air is kept 24 cm in front of a concave spherical glass surface ($_a\mu_g = 1.5$) and radius of curvature 60 cm. Find the nature of the image formed and its distance from the point source. *[CBSE 2022 (55/1/1), Term–2]*

Ans. Relation for concave spherical surface,

$$\Rightarrow \quad \frac{\mu_1}{-u} + \frac{\mu}{v} = \frac{\mu-1}{R} \qquad \frac{1}{2}$$

$$\Rightarrow \quad \frac{1}{-u} + \frac{\mu}{v} = \frac{\mu-1}{R} \qquad \frac{1}{2}$$

$$\Rightarrow \quad \frac{1}{-(-24)} + \frac{1.5}{v} = \frac{1.5-1}{-60} \qquad \frac{1}{2}$$

$\therefore \quad v = -30$ cm

Distance of image from point source = –24 –(–30) = 60 cm ½

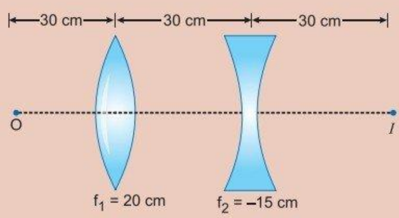
Nature of image = Virtual image 1

[CBSE Marking Scheme 2022 (55/1/1), Term–2]

Q. 14. A convex lens of focal length 20 cm and a concave lens of focal length 15 cm are kept 30cm apart with their principal axes coincident. When an object is placed 30 cm in front of the convex lens, calculate the position of the final image formed by the combination. Would this result change if the object were placed 30 cm in front of the concave lens? Give reason. *[CBSE 2019 (55/5/1)]*

Ans. For Image formed by convex lens,

Using Lens Formula



$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u} \qquad \frac{1}{2}$$

$$\Rightarrow \quad \frac{1}{20} = \frac{1}{v} + \frac{1}{30}$$

$$\therefore \quad v = \frac{20 \times 30}{30-20} = 60 \text{ cm} \qquad 1$$

Again, for concave lens = + 30 cm

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

$$\Rightarrow \quad \frac{1}{-15} = \frac{1}{v} - \frac{1}{30}$$

$$\therefore \quad v = \frac{15 \times 30}{15-30} = -30 \text{ cm} \qquad 1$$

No, the result will not change from principle of reversibility. ½

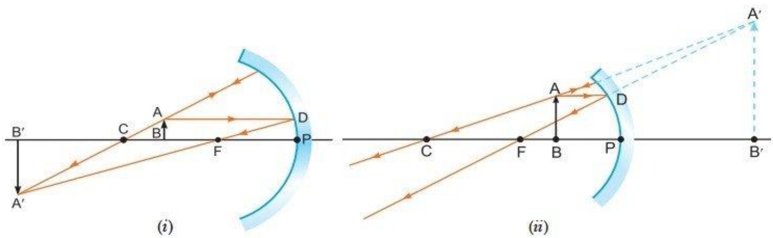
[CBSE Marking Scheme 2019 (55/5/1)]

Q. 15. An object is placed in front of a concave mirror of focal length of 12 cm. There are two possible positions of the object for which the image formed is three times the size of the object.

(a) Draw the ray diagram for the each case, and

(b) Find the distance between the two positions of the object. [CBSE 2020 (55/4/2)]

Ans. (a) Concave mirror forms magnified image for the following positions of object.



(i) (ii)

(b) Given, $f = -12$ cm

If $m = -3$ (Real and inverted)

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

$v = 3u$

Using mirror formula,

$$\frac{1}{v} + \frac{1}{u} = \frac{1}{f} \quad \Rightarrow \frac{1}{3u} + \frac{1}{u} = \frac{1}{f}$$

$$\Rightarrow \quad \frac{4}{3u} + \frac{1}{u} = \frac{1}{f} \quad \Rightarrow \frac{4}{3u} = \frac{1}{f}$$

$$\therefore \quad u = \frac{4f}{3} = \frac{4}{3} \times -12 \text{ cm} = -16 \text{ cm.}$$

If $m = +3$ (Virtual and errect)

Again using mirror formula,

$$\frac{1}{v} + \frac{1}{u} = \frac{1}{f} \quad \Rightarrow \quad \frac{-1}{3u} + \frac{1}{u} = \frac{1}{f}$$

$$\Rightarrow \quad \frac{2}{3u} = \frac{1}{f} \quad \Rightarrow \quad u = \frac{2}{3} \times f = \frac{2}{3} \times (-12)$$

$$= -8 \text{ cm}$$

Distance between two positions of object $= (16 - 8)$ cm $=$ **8 cm**

Q. 16. A concave mirror forms a real image of an object kept at a distance 9 cm from it. If the object is taken away from the mirror by 6 cm, the image size reduces to $\frac{1}{4}$ th of its previous size. Find the focal length of the mirror. [CBSE 2020 (55/4/3)]

Ans. From Given, $u_1 = -9$ cm, $u_2 = -(9 + 6)$ cm $= -15$ cm

From magnification, $m = \frac{f}{f - u} = \frac{h_i}{h_0}$

$$(h_i)_2 = \frac{1}{4}(h_i)_1 \text{ (Given)}$$

$$\Rightarrow \quad \frac{f}{f - u_2} = \left(\frac{f}{f - u_1}\right)\frac{1}{4}$$

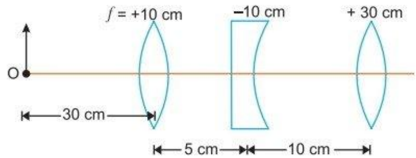
$$\Rightarrow \quad \frac{f}{f-(-15)}=\frac{f}{[f-(-9)]}\frac{1}{4}$$

$$\Rightarrow \quad f+15=4\,(f+9)$$

$$\Rightarrow \quad 3f=15-4\times 9=15-36$$

$$\therefore \quad f=\frac{-21}{3}=\mathbf{-7\ cm}$$

Q. 17. Find the position of the image formed of an object 'O' by the lens combination given in the figure. *[2019 (55/4/1)]*



Ans. For first lens, $u_1 = -30$ cm, $f_1 = +10$ cm

$\therefore$ From lens formula, $\frac{1}{f_1}=\frac{1}{v_1}-\frac{1}{u_1}$

$$\Rightarrow \quad \frac{1}{v_1}=\frac{1}{f_1}+\frac{1}{u_1}=\frac{1}{10}-\frac{1}{30}=\frac{3-1}{30}$$

$$\Rightarrow \quad v_1 = 15 \text{ cm}$$

The image formed by the first lens serves as the object for the second. This is at a distance of (15 – 5) cm = 10 cm to the right of the second lens. Though the image is real, it serves as a virtual object for the second lens, which means that the rays appear to come from it for the second lens.

For second lens, $f_2 = -10$ cm, $u_2 = 15 - 5 = +10$ cm

$$\therefore \quad \frac{1}{v_2}=\frac{1}{f_2}+\frac{1}{u_2}=-\frac{1}{10}+\frac{1}{10} \quad \Rightarrow \quad v_2=\infty$$

The virtual image is formed at an infinite distance to the left of the second lens. This acts as an object for the third lens.

For third lens, $f_3 = +30$ cm, $u_3 = \infty$

From lens formula, $\frac{1}{v_2}=\frac{1}{f_3}+\frac{1}{u_3}=\frac{1}{30}+\frac{1}{\infty}$

$$\therefore \quad v_3 = \mathbf{30\ cm}$$

The final image is formed at a distance 30 cm to the right of third lens.

Q. 18. (*i*) A screen is placed at a distance of 100 cm from an object. The image of the object is formed on the screen by a convex lens for two different locations of the lens separated by 20 cm. Calculate the focal length of the lens used.

(*ii*) A converging lens is kept coaxially in contact with a diverging lens - both the lenses being of equal focal length. What is the focal length of the combination? *[CBSE (North) 2016]*

Ans. (*i*) For first position of the lens, we have

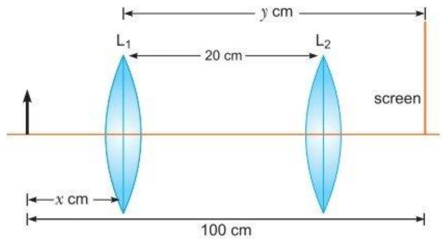
$$\frac{1}{f}=\frac{1}{y}-\frac{1}{(-x)} \quad \Rightarrow \quad \frac{1}{f}=\frac{1}{y}+\frac{1}{x} \qquad ...(i)$$

For second position of lens, we have

$$\frac{1}{f}=\frac{1}{y-20}-\frac{1}{[-(x+20)]}$$

$$\frac{1}{f}=\frac{1}{y-20}+\frac{1}{x+20} \qquad ...(ii)$$

From (*i*) and (*ii*), we have



$$\frac{1}{y}+\frac{1}{x}=\frac{1}{(y-20)}+\frac{1}{(x+20)}$$

$$\frac{x+y}{xy}=\frac{(x+20)+(y-20)}{(y-20)(x+20)}$$

$$\frac{x+y}{xy}=\frac{x+y}{(y-20)(x+20)}$$

$\therefore$ $xy = (y - 20)(x + 20)$

$\Rightarrow$ $xy = xy - 20x + 20y - 400$

$\Rightarrow$ $20x - 20y = -400$

$\therefore$ $x - y = -20$

Also, $x + y = 100$

On solving, we have

$x = 40$ cm and $y = 60$ cm

$$\therefore \quad \frac{1}{f}=\frac{1}{60}-\frac{1}{-40}=\frac{5}{120} \quad \Rightarrow f = \mathbf{24cm}$$

(*ii*) Let focal length of the combination be f.

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

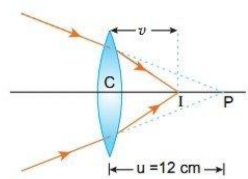
$$\Rightarrow \quad \frac{1}{f}=\frac{1}{f}+\left(-\frac{1}{f}\right)$$

$$\Rightarrow \quad \frac{1}{f}=0 \Rightarrow f = \textbf{infinite.}$$

Q. 19. A beam of light converges to a point *P*. A lens is placed in the path of the convergent beam 12 cm from *P*. At what point does the beam converge if the lens is (*a*) a convex lens of focal length 20 cm, (*b*) a concave lens of focal length 16 cm? [*NCERT*]

Ans. (*a*) Point *P* acts as a virtual object for convex lens.

Given $u = +12$ cm, $f = +20$ cm



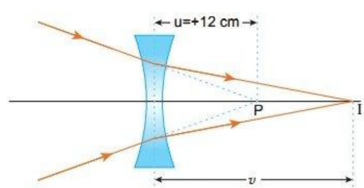
$$\therefore \quad \frac{1}{f}=\frac{1}{v}-\frac{1}{u} \text{ gives } \frac{1}{v}=\frac{1}{f}+\frac{1}{u}=\frac{1}{20}+\frac{1}{12}$$

$$=\frac{3+5}{60}$$

$$\Rightarrow \quad v=\frac{60}{8}= \mathbf{7.5\ cm}$$

This implies that the image is formed to the right of the lens and is real.

(*b*) In this case, $u = +12$ cm, $f = -16$ cm,



$$\therefore \quad \frac{1}{f}=\frac{1}{v}-\frac{1}{u} \text{ gives } \frac{1}{v}=\frac{1}{f}+\frac{1}{u}$$

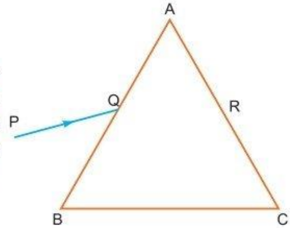
$$=-\frac{1}{16}+\frac{1}{12}=\frac{-3+4}{48}$$

$$v = \mathbf{48\ cm}$$

This shows that the image is formed at a distance of 48 cm to the right of concave lens and is real.

Q. 20. A ray PQ incident on the face AB of a prism ABC, as shown in the figure, emerges from the face AC such that $AQ = AR$. Draw the ray diagram showing the passage of the ray through the prism. If the angle of the prism is 60° and refractive index of the material of the prism is $\sqrt{3}$, determine the values of angle of incidence and angle of deviation.

[*CBSE Panchkula 2015*]



Ans. Here, $\angle A = 60°$ and $n = \sqrt{3}$

We have, $i + e = A + \delta$

Since QR is parallel to BC hence this is the case of minimum deviation.

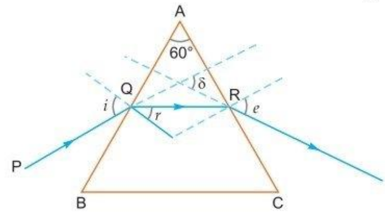
$$i = e$$

$$2i = 60 + \delta \quad \ldots(i)$$

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

$$n = \frac{\sin i}{\sin r} \Rightarrow \sqrt{3} = \frac{\sin i}{\sin 30°}$$

$$\sin i = \frac{\sqrt{3}}{2} \Rightarrow \angle i = \mathbf{60°}$$

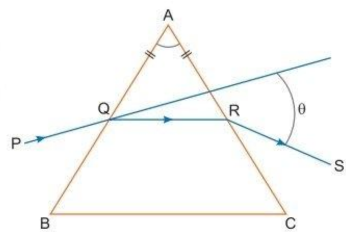


Substitute in (*i*), we have

$$120 = 60 + \delta \Rightarrow \delta = \mathbf{60°}$$

Q. 21. A ray PQ incident on the refracting face BA is refracted in the prism BAC as shown in the figure and emerges from the other refracting face AC as RS such that $AQ = AR$. If the angle of prism $A = 60°$ and refractive index of material of prism is $\sqrt{3}$, calculate angle θ.

[*CBSE North 2016*]



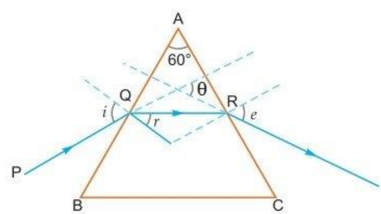
Ans. Given, $AQ = AR$, we have

$$QR || BC$$

At the minimum deviation, the refracted ray inside the prism becomes parallel to its base.

∴ θ is the angle of minimum deviation.

$$n = \frac{\sin\left(\frac{A+\theta}{2}\right)}{\sin\left(\frac{A}{2}\right)} \Rightarrow \sqrt{3} = \frac{\sin\left(\frac{60° + \theta}{2}\right)}{\sin 30°}$$



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

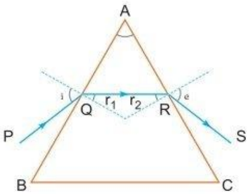
$$\Rightarrow \frac{60° + \theta}{2} = 60° \Rightarrow \theta = \mathbf{60°}$$

Q. 22. Figure shows a ray of light passing through a prism. If the refracted ray QR is parallel to the base BC, show that

(*i*) $r_1 = r_2 = A/2$,

(*ii*) angle of minimum deviation, $D_m = 2i - A$.

[*CBSE (F) 2014*]



Ans. (*i*) We know that

$$r_1 + r_2 = A$$

Since QR is parallel to BC

So, $r_1 = r_2$ and $i = e$

Therefore, $2r_1$ or $2r_2 = A \Rightarrow r_1 = r_2 = A/2$

(*ii*) D_m = Deviation at the first face + Deviation of the second face

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

$$= 2i - A \qquad (\because i = e)$$

Q. 23. What is the difference in the construction of an astronomical telescope and a compound microscope? The focal lengths of the objective and eyepiece of a compound microscope are 1.25 cm and 5.0 cm, respectively. Find the position of the object relative to the objective in order to obtain an angular magnification of 30 when the final image is formed at the near point. **[CBSE 2020 (55/2/1)]**

Ans.

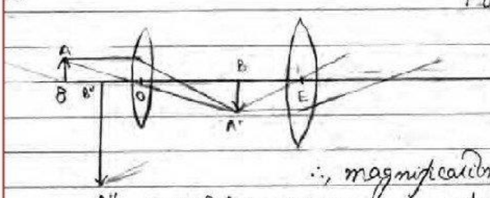
• The differences in the construction of an astronomical telescope and compound microscope.

In ~~a~~ compound microscope, the objective is of smaller aperture and smaller focal length than the eyepiece, but in an astronomical telescope, objective is larger than eyepiece and has a large focal length.

••

Focal length of objective, $f_o = 1.25$ cm

f_e = Focal length of eyepiece = 5.00 cm.



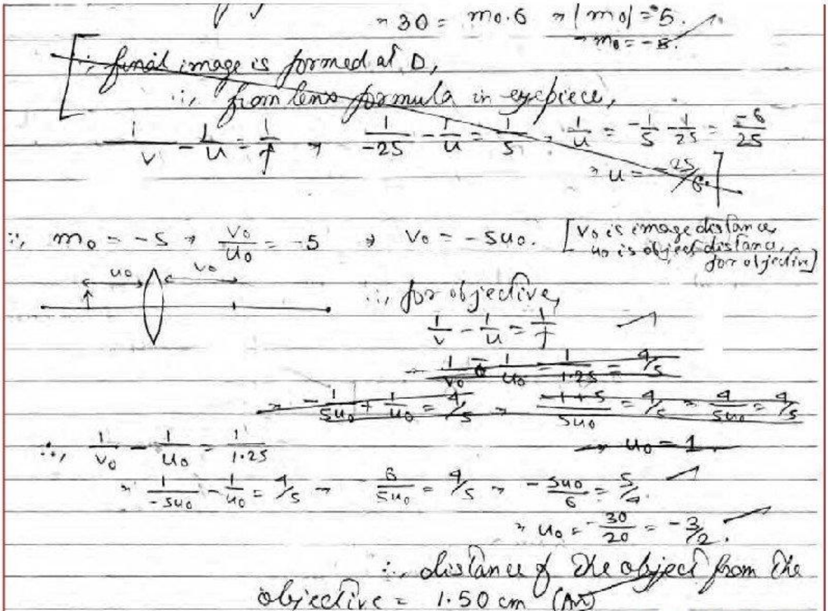
∴ magnification for image at near point $D = 25$ cm : $m = -\frac{L}{f_o}\left(1 + \frac{D}{f_e}\right)$

where, L is tube length.

∵ magnification by eyepiece $= 1 + D/f_e$,

here, 'm' by eyepiece $(m_e) = 1 + \frac{25}{5} = 1 + 5 = 6.$

∴ Total magnification $m = m_o \cdot m_e$



$\Rightarrow 30 = m_o \cdot 6 \Rightarrow |m_o| = 5.$

~~$\Rightarrow m_o = -5.$~~

~~[∴ final image is formed at D,~~
~~∴ from lens formula in eyepiece,~~
~~$\frac{1}{v} - \frac{1}{u} = \frac{1}{f} \Rightarrow \frac{1}{-25} - \frac{1}{u} = \frac{1}{5} \Rightarrow \frac{1}{u} = -\frac{1}{5} - \frac{1}{25} = \frac{-6}{25}$~~
~~$\Rightarrow u = -\frac{25}{6}$]~~

∴ $m_o = -5 \Rightarrow \frac{v_o}{u_o} = -5 \Rightarrow v_o = -5u_o.$ [v_o is image distance, u_o is object distance, for objective]

∴ for objective,
$\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$

~~$\Rightarrow \frac{1}{v_o} - \frac{1}{u_o} = \frac{1}{1.25} = \frac{4}{5}$~~
~~$\Rightarrow -\frac{1}{5u_o} + \frac{1}{u_o} = \frac{4}{5} \Rightarrow \frac{-1+5}{5u_o} = \frac{4}{5} \Rightarrow \frac{4}{5u_o} = \frac{4}{5}$~~
~~$\Rightarrow u_o = 1.$~~

∴ $\frac{1}{v_o} - \frac{1}{u_o} = \frac{1}{1.25}$

$\Rightarrow \frac{1}{-5u_o} - \frac{1}{u_o} = \frac{4}{5} \Rightarrow \frac{6}{5u_o} = \frac{4}{5} \Rightarrow -\frac{5u_o}{6} = \frac{5}{4}.$

$\Rightarrow u_o = -\frac{30}{20} = -\frac{3}{2}.$

∴ distance of the object from the objective = 1.50 cm (Ans)

[*Topper's Answer 2020*]

Q. 24. The total magnification produced by a compound microscope is 20. The magnification produced by the eye piece is 5. The microscope is focussed on a certain object. The distance between the objective and eyepiece is observed to be 14 cm. If least distance of distinct vision is 20 cm, calculate the focal length of the objective and the eye piece. **[*CBSE Delhi 2014*]**

Ans. Here, $M = -20$, $m_e = 5$, $v_e = -20$ cm

For eyepiece, $m_e = \frac{v_e}{u_e}$

$$\Rightarrow \quad 5 = \frac{-20}{u_e} \quad \Rightarrow \quad u_e = \frac{-20}{5} = -4 \text{ cm}$$

Using lens formula,

$$\frac{1}{v_e} - \frac{1}{u_e} = \frac{1}{f_e} \Rightarrow -\frac{1}{20} + \frac{1}{4} = \frac{1}{f_e}$$

$$\Rightarrow \quad \frac{-1+5}{20} = \frac{1}{f_e} \quad \Rightarrow \quad f_e = \mathbf{5\ cm}$$

Now, total magnification

$$M = m_e \times m_o$$

$$-20 = 5 \times m_o \quad \Rightarrow \quad m_o = -4$$

Also $\quad |v_o| + |u_e| = 14$

$$|v_o| + |-4| = 14$$

$$v_o = 14 - 4 = 10 \text{ cm}$$

$$m_o = 1 - \frac{v_o}{f_o} \quad \Rightarrow \quad -4 = 1 - \frac{10}{f_o}$$

$$-5 = -\frac{10}{f_0} \quad \Rightarrow \quad f_o = \mathbf{2\ cm.}$$

Q. 25. 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 adjustment?

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

Ans. If the telescope is in normal adjustment, *i.e.*, the final image is at infinity.

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

Since $f_o = 150$ cm, $f_e = 5$ cm

$$\therefore \quad M = \frac{150}{5} = \mathbf{30}$$

If tall tower is at distance 3 km from the objective lens of focal length 150 cm. It will form its image at distance v_o So,

Using Lens formula,

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

$$\Rightarrow \quad \frac{1}{150\text{ cm}} = \frac{1}{v_o} - \frac{1}{(-3\text{ km})}$$

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

$$\therefore \quad v_o = \frac{3000 \times 1.5}{3000 - 1.5} = \frac{4500}{2998.5} = 1.5\text{ m}$$

$$\text{Magnification,} \quad m_o = \frac{I}{O} = \frac{h_i}{h_o} = \frac{v_o}{u_o}$$

$$\Rightarrow \quad \frac{h_i}{100\text{ m}} = \frac{1.5\text{ m}}{3\text{ km}} = \frac{1.5}{3000}$$

$$\Rightarrow \quad h_i = \frac{1.5 \times 100}{3000} = \frac{1}{20}\text{ m}$$

$$\therefore \quad h_i = \mathbf{0.05\ m}$$

Q. 26. An amateur astronomer wishes to estimate roughly the size of the sun using his crude telescope consisting of an objective lens of focal length 200 cm and an eyepiece of focal length 10 cm. By adjusting the distance of the eyepiece from the objective, he obtains an image of the sun on a screen 40 cm behind the eyepiece. The diameter of the sun's image is measured to be 6.0 cm. Estimate the sun's size, given that the average earth-sun distance is 1.5×10^{11} m. **[*CBSE 2019 (55/5/1)*]**

Ans. For eyepiece.

Given, $v_e = 40$ cm, $f_e = 10$ cm

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

$$\text{or} \quad \frac{1}{u_e} = \frac{1}{v_e} - \frac{1}{f_e} = \frac{1}{40} - \frac{1}{10} \quad \Rightarrow \quad u_e = \frac{-40}{3}\text{ cm}$$

Magnification produced by eye piece is

$$m_e = \frac{v_e}{|u_e|} = \frac{40}{40/3} = 3$$

Diameter of the image formed by the objective is

$$d = 6/3 = 2\text{ cm}$$

If D be the diameter of the sun then the angle subtended by it on the objective will be

$$a = \frac{D}{1.5 \times 10^{11}} \text{rad}$$

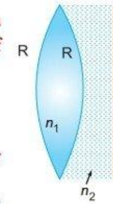
Angle subtended by the image at the objective

= angle subtended by the sun

$$\therefore \quad \alpha = \frac{\text{Size of image}}{f_0} = \frac{2}{200} = \frac{1}{100} \text{rad}$$

$$\therefore \quad \frac{D}{1.5 \times 10^{11}} = \frac{1}{100} \Rightarrow D = \mathbf{1.5 \times 10^9\ m}$$

Q. 27. A biconvex lens with its two faces of equal radius of curvature R is made of a transparent medium of refractive index n_1. It is kept in contact with a medium of refractive index n_2 as shown in the figure.



(a) Find the equivalent focal length of the combination.

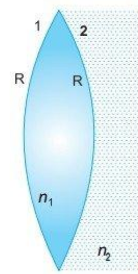
(b) Obtain the condition when this combination acts as a diverging lens.

(c) Draw the ray diagram for the case $n_1 > (n_2 + 1)/2$, when the object is kept far away from the lens. Point out the nature of the image formed by the system.

[*CBSE Patna 2015*] [*HOTS*]

Ans. (a) If refraction occurs at first surface

$$\frac{n_1}{v_1} - \frac{1}{u} = \frac{(n_1 - 1)}{R} \quad ...(i)$$



If refraction occurs at second surface, and the image of the first surface acts as an object

$$\frac{n_2}{v} - \frac{n_1}{v_1} = \frac{n_2 - n_1}{-R} \quad ...(ii)$$

On adding equation (i) and (ii), we get

$$\frac{n_2}{v} - \frac{1}{u} = \frac{2n_1 - n_2 - 1}{R}$$

If rays are coming from infinity, *i.e.*, $u = -\infty$ then $v = f$

$$\frac{n_2}{f} + \frac{1}{\infty} = \frac{2n_1 - n_2 - 1}{R} \Rightarrow f = \frac{n_2 R}{2n_1 - n_2 - 1}$$

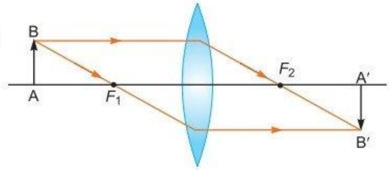
(b) If the combination behave as a diverging system then $f < 0$. This is possible only when

$$2n_1 - n_2 - 1 < 0$$

$$\Rightarrow \quad 2n_1 < n_2 + 1$$

$$\Rightarrow \quad n_1 < \frac{(n_2 + 1)}{2}$$

(c) If the combination behaves as a converging lens then $f > 0$. It is possible only when



$$2n_1 - n_2 - 1 > 0$$

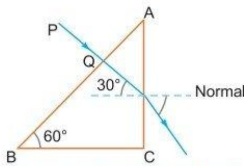
$$\Rightarrow \quad 2n_1 - > n_2 + 1$$

$$\Rightarrow \quad n_1 > \frac{(n_2 + 1)}{2}$$

Nature of the image formed is real.

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

And, applying Snell's law at face AC,



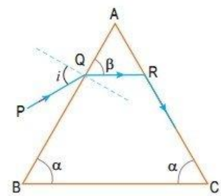
$$\sin 30° \times \frac{3}{2} = \sin r \times 1$$

$$\Rightarrow \quad \sin r = \frac{1}{2} \times \frac{3}{2} \quad \Rightarrow \quad r = \sin^{-1}\left(\frac{3}{4}\right) = \sin^{-1}(0.75) = 48.6°$$

And, clearly $r > i$, as ray passes from denser to rarer medium.

Q. 31. 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 suffers total internal reflection. **[*CBSE 2019 (55/2/2)*]**

Ans. For minimum deviation



$$r_1 + r_2 = A; \qquad r_1 = r_2$$

Also, $(90 - \beta) + (90 - \beta) = A$

$\Rightarrow \quad 180 - 2\beta = A$

$\Rightarrow \quad 2\beta = 180 - A$

$\Rightarrow \quad 2\beta = 2\alpha$

$\Rightarrow \quad \beta = \alpha$

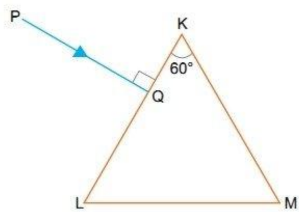
We have, $r_1 + r_2 = A$

$\Rightarrow \quad r_1 + i_c = A \qquad$ (Take $r_2 = i_c$)

$\Rightarrow \quad i_c = A - r_1$

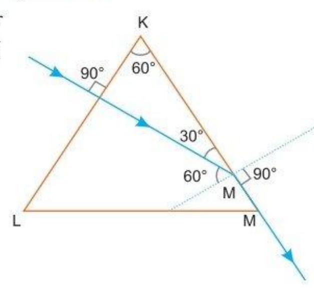
$\therefore \quad i_c = A - (90 - \beta)$

Q. 32. 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 (55/2/1)*]**



Ans. When light ray incident on face KL, it is pass undeviated, because it is normal to the surface and incident on face KM. The angle of incidence for face KM is equal to 60°.

$$\frac{\sin 60°}{\sin r} = \frac{n_2}{n_1} \qquad \left[\begin{array}{l} n_2 = \text{Second medium} = \text{air} \\ n_1 = \text{Glass medium} = 2/\sqrt{3} \end{array}\right.$$



$$\frac{\sin 60°}{\sin r} = \frac{1}{2/\sqrt{3}} = \frac{\sqrt{3}}{2}$$

$$\Rightarrow \quad \sin r = \frac{\sin 60°}{\frac{\sqrt{3}}{2}} = 1$$

$$\sin r = 1 \quad \Rightarrow \quad r = 90°$$

Angle of emergence = **90°**

Angle of deviation = **30°**

Long Answer Questions

Each of the following questions are of 5 marks.

Q. 1. An object is placed in front of a concave mirror. It is observed that a virtual image is formed. Draw the ray diagram to show the image formation and hence derive the mirror equation $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$. **[*CBSE 2020 (55/1/1)*]**

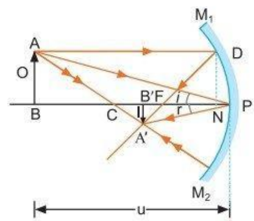
OR

(*i*) Derive the mirror formula. What is the corresponding formula for a thin lens?

(*ii*) Draw a ray diagram to show the image formation by a concave mirror when the object is kept between its focus and the pole. Using this diagram, derive the magnification formula for the image formed. **[*CBSE Delhi 2011*]**

Ans. (*i*) **Mirror Formula:** M_1M_2 is a concave mirror having pole P, focus F and centre of curvature C.

An object AB is placed in front of mirror with point B on the principal axis. The image formed by mirror is $A'B'$. The perpendicular dropped from point of incidence D on principal axis is DN



In ΔABC and $\Delta A'B'C$

$\angle ABC = \angle A'B'C$ (each equal to 90°)

$\angle ACB = \angle A'CB'$ (opposite angles)

Both triangles are similar.

$$\therefore \frac{AB}{A'B'} = \frac{BC}{B'C} \quad ...(i)$$

Now in ΔDNF and $\Delta A'B'F$

$\angle DNF = \angle A'B'F$ (each equal to 90°)

$\angle DFN = \angle A'FB'$ (opposite angles)

$\therefore$ Both triangles are similar

$$\frac{DN}{A'B'} = \frac{FN}{B'F} \text{ or } \frac{AB}{A'B'} = \frac{FN}{B'F} (\because AB = DN) \quad ...(ii)$$

Comparing (*i*) and (*ii*), we get

$$\frac{BC}{B'C} = \frac{FN}{B'F} \quad ...(iii)$$

If aperture of mirror is very small, the point N will be very near to P, so $FN = FP$

$$\therefore \frac{BC}{B'C} = \frac{FP}{B'F} \text{ or } \frac{PB-PC}{PC-PB'} = \frac{FP}{PB'-PF} \quad ...(iv)$$

By sign convention

Distance of object from mirror $PB = -u$

Distance of image from mirror $PB' = -v$

Focal length of mirror $PF = -f$

Radius of curvature of mirror $PC = -R = -2f$

Substituting these values in (*iv*), we get

$$\frac{-u-(-2f)}{-2f-(-v)} = \frac{-f}{-v-(-f)}$$

$$\frac{-u+2f}{-2f+v}=\frac{-f}{-v+f}$$

$\Rightarrow\ 2f^2 - vf = -uf + uv + 2f^2 - 2vf \quad$ or $\quad vf + uf = uv$

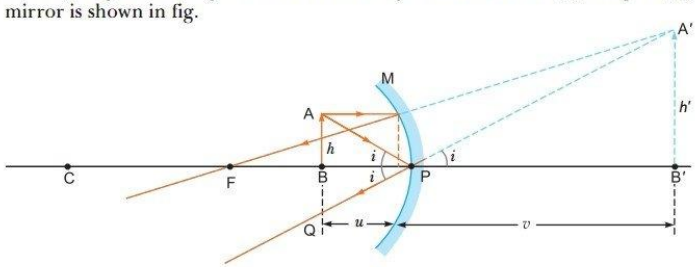
Dividing both sides by uvf we get

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

The corresponding formula for thin lens is

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

(ii) The ray diagram of image formation for an object between focus (F) and pole (P) of a concave mirror is shown in fig.



Magnification: $m = \dfrac{\text{Size of image } (A'B')}{\text{Size of object } (AB)}$

From fig. $\angle APB = \angle BPQ = i$

Also, $\angle BPQ = \angle A'PB' = i$

In $\Delta\ APB, \tan i = \dfrac{AB}{BP}$ ...(*i*)

In $\Delta\ A'PB', \tan i = \dfrac{A'B'}{B'P}$ ...(*ii*)

From (*i*) and (*ii*),

$$\frac{AB}{BP}=\frac{A'B'}{B'P}$$

$\Rightarrow$ Magnification, $m = \dfrac{A'B'}{AB} = \dfrac{B'P}{BP}$

or $m = \dfrac{v}{-u}$ or $\mathbf{m = -\dfrac{v}{u}}$

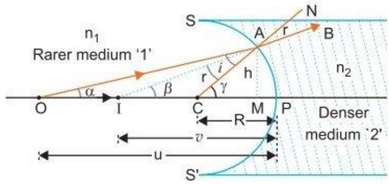
Q. 2. With the help of a ray diagram, show the formation of image of a point object due to refraction of light at a spherical surface separating two media of refractive indices n_1 and n_2 ($n_2 > n_1$) respectively. Using this diagram, derive the relation

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

Write the sign conventions used. What happens to the focal length of convex lens when it is immersed in water?

Ans. Formula for Refraction at Spherical Surface

Concave Spherical Surface: Let SPS' be a spherical refracting surface, which separates media '1' and '2'. Medium '1' is rarer and medium '2' is denser. The refractive indices of media '1' and '2' are n_1 and n_2 respectively ($n_1 < n_2$). Let P be the pole and C the centre of curvature and PC the principal axis of spherical refracting surface.



O is a point-object on the principal axis. An incident ray OA, after refraction at A on the spherical surface bends towards the normal CAN and moves along AB. Another incident ray OP falls on the surface normally and hence passes undeviated after refraction. These two rays, when produced backward meet at point I on principal axis. Thus I is the virtual image of O.

Let angle of incidence of ray OA be i and angle of refraction be r *i.e.*,

$$\angle OAC = i \quad \text{and} \quad \angle NAB = r$$

Let $\angle AOP = \alpha$, $\angle AIP = \beta$ and $\angle ACP = \gamma$

In triangle OAC $\quad \gamma = \alpha + i$ or $i = \gamma - \alpha$ ...(*i*)

In triangle AIC, $\quad \gamma = \beta + r$ or $r = \gamma - \beta$ ...(*ii*)

From Snell's law $\quad \dfrac{\sin i}{\sin r} = \dfrac{n_2}{n_1}$ ...(*iii*)

If point A is very near to P, then angles i, r, α, β, γ will be very small, therefore $\sin i = i$ and $\sin r = r$

Substituting values of i and r from *(i)* and *(ii)* we get

$$\frac{\gamma - \alpha}{\gamma - \beta} = \frac{n_2}{n_1} \quad \text{or} \quad n_1(\gamma - \alpha) = n_2(\gamma - \beta) \qquad \text{...(iv)}$$

The length of perpendicular AM dropped from A on the principal axis is h *i.e.*, $AM = h$. As angles α, β and γ are very small, therefore

$$\tan\alpha = \alpha, \quad \tan\beta = \beta, \quad \tan\gamma = \gamma$$

Substituting these values in equation *(iv)*

$$n_1(\tan\gamma - \tan\alpha) = n_2(\tan\gamma - \tan\beta) \qquad \text{...(v)}$$

As point A is very close to P, point M is coincident with P

$$\tan\alpha = \frac{\text{Perpendicular}}{\text{Base}} = \frac{AM}{MO} = \frac{h}{PO}$$

$$\tan\beta = \frac{AM}{MI} = \frac{h}{PI}, \quad \tan\gamma = \frac{AM}{MC} = \frac{h}{PC}$$

Substituting this value in *(v)*, we get

$$n_1\left(\frac{h}{PC} - \frac{h}{PO}\right) = n_2\left(\frac{h}{PC} - \frac{h}{PI}\right)$$

or

$$\frac{n_1}{PC} - \frac{n_1}{PO} = \frac{n_2}{PC} - \frac{n_2}{PI} \qquad \text{...(vi)}$$

Let u, v and R be the distances of object O, image I and centre of curvature C from pole P. By sign convention PO, PI and PC are negative, *i.e.*, $u = -PO$, $v = -PI$ and $R = -PC$

Substituting these values in (*vi*), we get

$$\frac{n_1}{(-R)} - \frac{n_1}{(-u)} = \frac{n_2}{(-R)} - \frac{n_2}{(-v)} \quad \text{or} \quad \frac{n_1}{R} - \frac{n_1}{u} = \frac{n_2}{R} - \frac{n_2}{v}$$

or

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

Sign Conventions:

(*i*) All the distances are measured from optical centre (*P*) of the lens.

(*ii*) Distances measured in the direction of incident ray of light are taken positive and vice-versa.

As we know

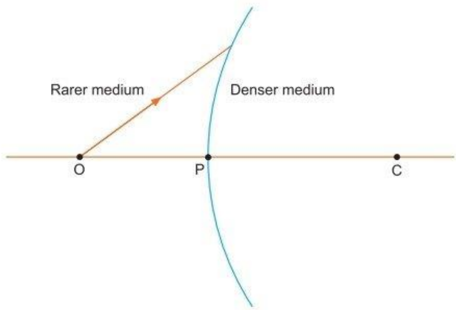
$$\frac{1}{f} = (n-1)\left[\frac{1}{R_1} - \frac{1}{R_2}\right]$$

When convex lens is immersed in water, refractive index n decreases and hence focal length will increase *i.e.*, the focal length of a convex lens increases when it is immersed in water.

Q. 3. A spherical surface of radius of curvature *R*, separates a rarer and a denser medium as shown in the figure.

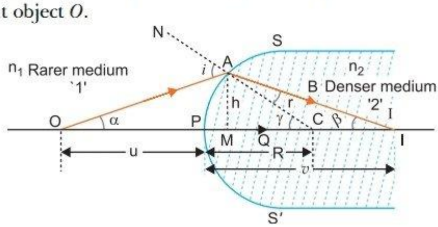
Complete the path of the incident ray of light, showing the formation of a real image. Hence derive the relation connecting object distance '*u*', image distance '*v*', radius of curvature *R* and the refractive indices n_1 and n_2 of two media. **[*CBSE 2023 (55/1/1)*]**

Briefly explain, how the focal length of a convex lens changes, with increase in wavelength of incident light.



[***CBSE Delhi 2014; Central 2016; (F) 2017; Sample Paper 2016***]

Ans. Relation of object and image distances of a convex spherical surface: Let *SPS′* be the convex spherical refracting surface, separating the two media of refractive indices n_1 and n_2 respectively ($n_1 < n_2$) *i.e.*, medium '1' is rarer and medium '2' is denser. Let *P* be the pole, *C* the centre of curvature and *PC* the principal axis of convex refracting surface. *O* is a distant point object on the principal axis. The ray *OA* starting from *O* is incident on point *A* of the spherical surface, *CAN* is normal at point *A* of the surface. Due to going from rarer to denser medium the ray *OA* deviates along the normal *CAN* and is refracted along the direction *AB*. The another ray *OP* starting from *O* is incident normally on the spherical surface and passes undeviated after refraction along *PQ*. Both the rays *AB* and *PQ* meet at point *I* on the principal axis, *i.e.*, *I* is the real image of point object *O*.



Let i be the angle of incidence of ray *OA* and r the angle of refraction in the denser medium *i.e.*, $\angle OAN = i$ and $\angle CAI = r$. Let $\angle AOP = \alpha$, $\angle AIP = \beta$ and $\angle ACP = \gamma$

In triangle *OAC*, $i = \gamma + \alpha$ ...(*i*)

In triangle AIC, $\gamma = \beta + r$ or $r = \gamma - \beta$ ...(ii)

From Snell's law
$$\frac{\sin i}{\sin r} = \frac{n_2}{n_1} \quad ...(iii)$$

If point A is very close to P, then angles i, r, α, β and γ will be very small, therefore
$$\sin i = i \quad \text{and} \quad \sin r = r$$

From equation *(iii)*,
$$\frac{i}{r} = \frac{n_2}{n_1}$$

Substituting values of i and r from *(i)* and *(ii)*, we get
$$\frac{\gamma + \alpha}{\gamma - \beta} = \frac{n_2}{n_1} \text{ or } n_1(\gamma + \alpha) = n_2(\gamma - \beta) \quad ...(iv)$$

Let h be the height of perpendicular drawn from A on principal axis *i.e.*, $AM = h$. As α, β and γ are very small angles.
$$\tan \alpha = \alpha, \tan \beta = \beta \text{ and } \tan \gamma = \gamma$$

Substituting these values in *(iv)*
$$n_1(\tan \gamma + \tan \alpha) = n_2(\tan \gamma - \tan \beta) \quad ...(v)$$

As point A is very close to point P, point M is coincident with P.

From figure
$$\tan \alpha = \frac{AM}{OM} = \frac{h}{OP}$$
$$\tan \beta = \frac{AM}{MI} = \frac{h}{PI}$$
$$\tan \gamma = \frac{AM}{MC} = \frac{h}{PC}$$

Substituting these values in *(v)*, we get
$$n_1\left(\frac{h}{PC} + \frac{h}{OP}\right) = n_2\left(\frac{h}{PC} - \frac{h}{PI}\right)$$

or
$$n_1\left(\frac{1}{PC} + \frac{1}{OP}\right) = n_2\left(\frac{1}{PC} - \frac{1}{PI}\right) \quad ...(vi)$$

If the distances of object O, image I, centre of curvature C from the pole be u, v and R respectively, then by sign convention PO is negative while PC and PI are positive. Thus,
$$u = -PO, \qquad v = +PI, \qquad R = +PC$$

Substituting these values in *(vi)*, we get
$$n_1\left(\frac{1}{R} - \frac{1}{u}\right) = n_2\left(\frac{1}{R} - \frac{1}{v}\right)$$

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

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

The focal length of a convex lens is given by
$$\frac{1}{f} = (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

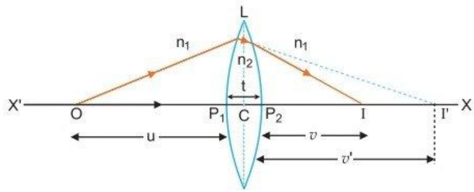
According to Cauchy's formula
$$n = a + \frac{b}{\lambda^2} + \frac{c}{\lambda^4} + ...$$

Then n varies inversely as λ.

When wavelength increases, the refractive index n decreases; so focal length of lens increases with increase of wavelength.

Q. 4. Draw a ray diagram for 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 for a double convex lens. State the assumptions made and sign convention used. [*CBSE (F) 2013, (Central) 2016, 2020 (55/2/1)*]

Ans. Lens Maker's Formula: Suppose L is a thin lens. The refractive index of the material of lens is n_2 and it is placed in a medium of refractive index n_1. The optical centre of lens is C and $X'X$ is the principal axis. The radii of curvature of the surfaces of the lens are R_1 and R_2 and their poles are P_1 and P_2 The thickness of lens is t, which is very small. O is a point object on the principal axis of the lens. The distance of O from pole P_1 is u. The first refracting surface forms the image of O at I' at a distance v' from P_1. From the refraction formula at spherical surface



$$\frac{n_2}{v'} - \frac{n_1}{u} = \frac{n_2 - n_1}{R_1} \quad ...(i)$$

The image I' acts as a virtual object for second surface and after refraction at second surface, the final image is formed at I. The distance of I from pole P_2 of second surface is v. The distance of virtual object (I') from pole P_2 is $(v' - t)$.

For refraction at second surface, the ray is going from second medium (refractive index n_2) to first medium (refractive index n_1), therefore from refraction formula at spherical surface

$$\frac{n_1}{v} - \frac{n_2}{(v' - t)} = \frac{n_1 - n_2}{R_2} \quad ...(ii)$$

For a thin lens t is negligible as compared to v' therefore from (*ii*)

$$\frac{n_1}{v} - \frac{n_2}{v'} = -\frac{n_2 - n_1}{R_2} \quad ...(iii)$$

Adding equations (*i*) and (*iii*), we get

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

or

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

i.e.

$$\frac{1}{v} - \frac{1}{u} = ({}_1n_2 - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \quad ...(iv)$$

where ${}_1n_2 = \frac{n_2}{n_1}$ is refractive index of second medium (*i.e.*, medium of lens) with respect to first medium.

If the object O is at infinity, the image will be formed at second focus *i.e.*,

if $u = \infty$, $v = f_2 = f$

Therefore from equation (*iv*),

$$\frac{1}{f}-\frac{1}{\infty}=({}_1n_2-1)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)$$

i.e.,

$$\frac{1}{f}=({}_1n_2-1)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)$$

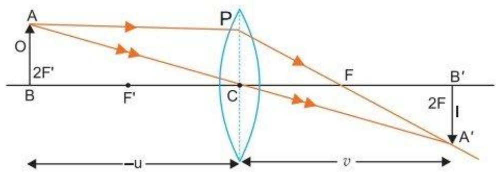
This formula is called ***Lens-Maker's formula.***

If first medium is air and refractive index of material of lens be n, then ${}_1n_2 = n$, therefore the modified above equation may be written as

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

Q. 5. Draw a ray diagram to show the formation of real image of the same size as that of the object placed in front of a converging lens. Using this ray diagram establish the relation between u, v and f for this lens.

Ans. **Thin Lens Formula:** Suppose an object AB of finite size is placed normally on the principal axis of a thin convex lens (fig.). A ray AP starting from A parallel to the principal axis, after refraction through the lens, passes through the second focus F. Another ray AC directed towards the optical centre C of the lens, goes straight undeviated. Both the rays meet at A' Thus A' is the real image of A. The perpendicular $A'B'$ dropped from A' on the principal axis is the whole image of AB.



Let distance of object AB from lens $= u$

Distance of image $A'B'$ from lens $= v$

Focal length of lens $= f$. We can see that triangles ABC and $A'B'C'$ are similar

$$\frac{AB}{A'B'}=\frac{CB}{CB'} \quad ...(i)$$

Similarly triangles PCF and $A'B'F$ are similar

$$\frac{PC}{A'B'}=\frac{CF}{FB'}$$

But $PC = AB$

$$\frac{AB}{A'B'}=\frac{CF}{FB'} \quad ...(ii)$$

From (*i*) and (*ii*), we get $\frac{CB}{CB'}=\frac{CF}{FB'}$ ...(*iii*)

From sign convention, $CB = -u$, $CB' = v$, $CF = f$

and $FB' = CB' - CF = v - f$

Substituting this value in (*iii*), we get, $-\frac{u}{v}=\frac{f}{v-f}$

or $-u(v-f)=\frac{1}{f}vf$ or $-uv+uf=vf$

Dividing throughout by uvf, we get $\frac{1}{f}=\frac{1}{v}-\frac{1}{u}$

Q. 6. Derive the lens formula $\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$ for a thin concave lens, using the necessary ray diagram.

Ans. The formation of image by a concave lens '*L*' is shown in fig. *AB* is object and *A′ B′* is the image. Triangles *ABO* and *A′ B′ O* are similar

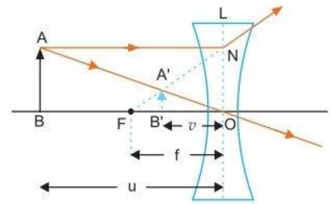
$$\frac{AB}{A'B'} = \frac{OB}{OB'} \qquad \ldots(i)$$

Also triangles *NOF* and *A′ B′ F* are similar

$$\frac{NO}{A'B'} = \frac{OF}{FB'}$$

But $NO = AB$

$$\frac{AB}{A'B'} = \frac{OF}{FB'} \qquad \ldots(ii)$$



Comparing equation (*i*) and (*ii*)

$$\frac{OB}{OB'} = \frac{OF}{FB'} \Rightarrow \frac{OB}{OB'} = \frac{OF}{OF - OB'}$$

Using sign conventions of coordinate geometry

$$OB = -u, \ OB' = -v, \ OF = -f$$

$$\frac{-u}{-v} = \frac{-f}{-f+v} \Rightarrow uf - uv = vf$$

$$\Rightarrow \qquad uv = uf - vf$$

Dividing throughout by *uvf*, we get

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

This is the required lens formula.

Q. 7. Define power of a lens. Write its units. Deduce the relation $\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2}$ for two thin lenses kept in contact coaxially. ***[CBSE (F) 2012, 2019 (55/4/3), 2020 (55/4/1)]***

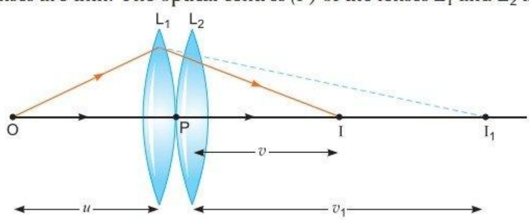
Ans. Power of lens: It is the reciprocal of focal length of a lens.

$$P = \frac{1}{f} \ (f \text{ is in metre})$$

Unit of power of a lens is Diopter.

An object is placed at point *O*. The lens L_1 produces an image at I_1 which serves as a virtual object for lens L_2 which produces final image at *I*.

Given, the lenses are thin. The optical centres (*P*) of the lenses L_1 and L_2 is co-incident.



For lens L_1, we have

$$\frac{1}{v_1} - \frac{1}{u} = \frac{1}{f_1} \qquad \ldots(i)$$

For lens L_2, we have $\frac{1}{v} - \frac{1}{v_1} = \frac{1}{f_2}$ ...(*ii*)

Adding equations *(i)* and *(ii)*, we have

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

$$\frac{1}{v}-\frac{1}{u}=\frac{1}{f_1}+\frac{1}{f_2} \quad ...(iii)$$

If two lenses are considered as equivalent to a single lens of focal length f, then

$$\frac{1}{v}-\frac{1}{u}=\frac{1}{f} \quad ...(iv)$$

From equation *(iii)* and equation *(iv)*, we can write

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

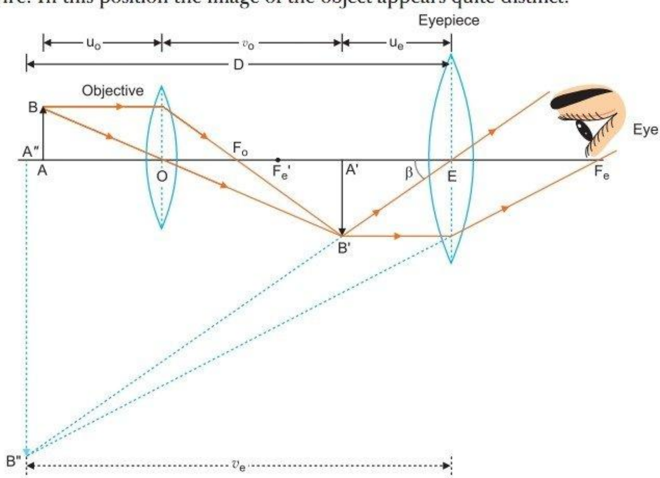
Q. 8. *(a)* **Draw the labelled ray diagram for the formation of image by a compound microscope. Derive an expression for its total magnification (or magnifying power), when the final image is formed at the near point.** [*CBSE Sample paper 2022, Term-2*] [*CBSE 2019 (55/5/1)*]
Why both objective and eyepiece of a compound microscope must have short focal lengths?

(b) **Draw a ray diagram showing the image formation by a compound microscope. Hence obtain expression for total magnification when the image is formed at infinity.**

[*CBSE Delhi 2013*]

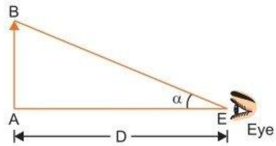
Ans. *(a)* **Compound Microscope:** It consists of a long cylindrical tube, containing at one end a convex lens of small aperture and small focal length. This is called the objective lens *(O)*. At the other end of the tube another co-axial smaller and wide tube is fitted, which carries a convex lens *(E)* at its outer end. This lens is towards the eye and is called the eye-piece. The focal length and aperture of eyepiece are somewhat larger than those of objective lens. Cross-wires are mounted at a definite distance before the eyepiece. The entire tube can be moved forward and backward by the rack and pinion arrangement.

Adjustment: First of all the eyepiece is displaced backward and forward to focus it on cross-wires. Now the object is placed just in front of the objective lens and the entire tube is moved by rack and pinion arrangement until there is no parallax between image of object and cross wire. In this position the image of the object appears quite distinct.



Working : Suppose a small object AB is placed slightly away from the first focus F_0' of the objective lens. The objective lens forms the real, inverted and magnified image $A'B'$ which acts as an object for eyepiece. The eyepiece is so adjusted that the image $A'B'$ lies between the first focus F_e' and the eyepiece E. The eyepiece forms its image $A''B''$ which is virtual, erect and magnified. Thus the final image $A''B''$ formed by the microscope is inverted and magnified and its position is outside the objective and eyepiece towards objective lens.

Magnifying power of a microscope is defined as the ratio of angle (β) subtended by final image on the eye to the angle (α) subtended by the object on eye, when the object is placed at the least distance of distinct vision, *i.e.*,



Magnifying power $M = \frac{\beta}{\alpha}$.

As object is very small, angles α and β are very small and so $\tan\alpha = \alpha$ and $\tan\beta = \beta$. By definition the object AB is placed at the least distance of distinct vision.

$$\alpha = \tan\alpha = \frac{AB}{EA}$$

By sign convention $EA = -D$, $\therefore$ $\alpha = \frac{AB}{-D}$

and from figure $\beta = \tan\beta = \frac{A'B'}{EA'}$

If u_e is distance of image $A'B'$ from eye-piece E, then by sign convention, $EA' = -u_e$

and so, $\beta = \frac{A'B'}{(-u_e)}$

Hence magnifying power $M = \frac{\beta}{\alpha} = \frac{A'B'/(-u_e)}{AB/(-D)} = \frac{A'B'}{AB}.\frac{D}{u_e}$

By sign conventions, magnification of objective lens

$$\frac{A'B'}{AB} = \frac{v_0}{(-u_0)}$$

$$M = -\frac{v_0}{u_0}.\frac{D}{u_e}$$

Using lens formula $\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$ for eye-lens, (*i.e.*, using $f = f_e$, $v = v_e$, $u = -u_e$), we get

$$\frac{1}{f_e} = \frac{1}{-v_e} - \frac{1}{(-u_e)} \quad \text{or} \quad \frac{1}{u_e} = \frac{1}{f_e} + \frac{1}{v_e}$$

Magnifying power $M = -\frac{v_0}{u_0}D\left(\frac{1}{f_e} + \frac{1}{v_e}\right)$

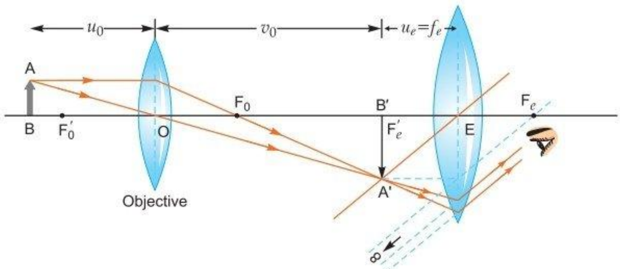
or $M = -\frac{v_0}{u_0}\left(\frac{D}{f_e} + \frac{D}{v_e}\right)$

When final image is formed at the distance of distinct vision, $v_e = D$

Magnification, $M = -\frac{v_0}{u_0}\left(1 + \frac{D}{f_e}\right)$

For greater magnification of a compound microscope, f_e should be small. As $f_0 < fe$, so f_0 is small. Hence, for greater magnification both f_0 and f_e should be small with f_0 to be smaller of the two.

(b) If image $A'B'$ is exactly at the focus of the eyepiece, then image $A''B''$ is formed at infinity.



If the object AB is very close to the focus of the objective lens of focal length f_o, then magnification M_o by the objective lens

$$M_o = \frac{L}{f_0}$$

where L is tube length (or distance between lenses L_o and L_e)

Magnification M_e by the eyepiece

$$M_e = \frac{D}{f_e}$$

where D = Least distance of distinct vision

Total magnification, $m = M_o M_e = \left(\frac{L}{f_o}\right)\left(\frac{D}{f_e}\right)$

Q. 9. Explain with the help of a labelled ray diagram, how is image formed in an astronomical telescope. Derive an expression for its magnifying power.

[*CBSE (F) 2014, 2019 (55/1/1) 2020 (55/1/1), 2023 (55/4/1)*]

OR

Draw a ray diagram showing the image formation of a distant object by a refracting telescope. Define its magnifying power and write the two important factors considered to increase the magnifying power.

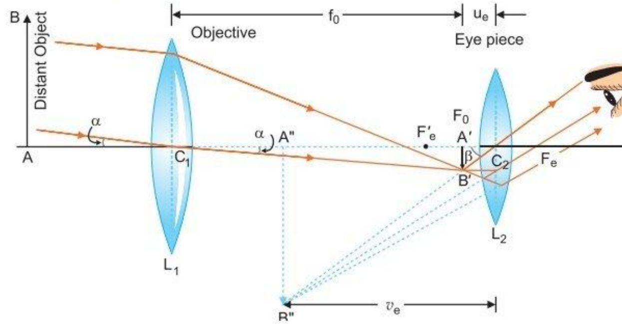
Describe briefly the two main limitations and explain how far these can be minimised in a reflecting telescope. **[*CBSE (F) 2015, 2023 (55/2/1)*]**

Ans. Astronomical (Refracting) Telescope:

Construction: It consists of two co-axial cylindrical tubes, out of which one tube is long and wide, while the other tube is small and narrow. The narrow tube may be moved in and out of the wide tube by rack and pinion arrangement. At one end of wide tube an achromatic convex lens L_1 is placed, which faces the object and is so called ***objective (lens).*** The focal length and aperture of this lens are kept large. The large aperture of objective is taken that it may collect sufficient light to form a bright image of a distant object. The narrow tube is towards eye and carries an achromatic convex lens L_2 of small focal length and small aperture on its outer end. This is called **eye-lens or eyepiece.** The small aperture of eye-lens is taken so that the whole light refracted by it may reach the eye. Cross-wires are fitted at a definite distance from the eye-lens.

Due to large focal length of objective lens and small focal length of eye lens, the final image subtends a large angle at the eye and hence the object appears large. The distance between the two lenses may be arranged by displacing narrow tube in or out of wide tube by means of rack and pinion arrangement.

Adjustment: First of all the eyepiece is moved backward and forward in the narrow tube and focused on the cross-wires. Then the objective lens is directed towards the object and narrow tube is displaced in or out of wide tube until the image of object is formed on cross-wires and there is no parallax between the image and cross-wires. In this position a clear image of the object is seen. As the image is formed by refraction of light through both the lenses, this telescope is called the ***refracting telescope.***



Working: Suppose AB is an object whose end A is on the axis of telescope. The objective lens (L_1) forms the image $A'B'$ of the object AB at its second principal focus F_0 This image is real, inverted and diminished. This image $A'B'$ acts as an object for the eye-piece L_2 and lies between first focus F_e and optical centre C_2 of lens L_2. Therefore eye-piece forms its image $A''B''$ which is virtual, erect and magnified.

Thus the final image $A''B''$ of object AB formed by the telescope is magnified, inverted and lies between objective and eyepiece.

Magnifying Power: The magnifying power of a telescope is measured by the ratio of angle (β) subtended by final image on the eye to the angle (α) subtended by object on the eye, *i.e.*,

$$\text{Magnifying power } M = \frac{\beta}{\alpha}$$

As α and β are very small angles, therefore, from figure.

The angle subtended by final image $A''B''$ on eye

$$\beta = \text{angle subtended by image } A'B' \text{ on eye}$$

$$= \tan\beta = \frac{A'B'}{C_2A'}$$

As the object is very far (at infinity) from the telescope, the angle subtended by object at eye is same as the angle subtended by object on objective lens.

$$\alpha = \tan\alpha = \frac{A'B'}{C_1A'}$$

$$M = \frac{\beta}{\alpha} = \frac{A'B'/C_2A'}{A'B'/C_1A'} = \frac{C_1A'}{C_2A'}$$

If the focal lengths of objective and eye-piece be f_o, and f_e, distance of image $A'B'$ from eye-piece be u_e, then by sign convention

$$C_1 A' = +f_0, \; C_2 A' = -u_e$$

$$M = -\frac{f_0}{u_e}$$

If v_e is the distance of $A''B''$ from eye-piece, then by sign convention, f_e is positive, u_e and v_e both are negative. Hence by lens formula $\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$, we have

$$\frac{1}{f_e} = \frac{1}{-v_e} - \frac{1}{(-u_e)} \text{ or } \frac{1}{u_e} = \frac{1}{f_e} + \frac{1}{v_e}$$

Substituting this value in (*i*), we get

$$M = -f_0\left(\frac{1}{f_e} + \frac{1}{v_e}\right)$$

This is the general formula for magnifying power. In this formula only numerical values of f_0, f_e and v_e are to be used because signs have already been used.

Length of Telescope: The distance between objective and eye-piece is called the length (L) of the telescope. Obviously

$$L = L_1L_2 = C_1C_2 = f_o + u_e$$

Now there arise two cases:

(*i*) **When the final image is formed at minimum distance (D) of distinct vision :** then $v_e = D$

$$M = -f_0\left(\frac{1}{f_e} + \frac{1}{D}\right) = -\frac{f_0}{f_e}\left(1 + \frac{f_e}{D}\right)$$

Length of telescope $L = f_o + u_e$

(*ii*) **In normal adjustment position, the final image is formed at infinity :** For relaxed eye, the final image is formed at infinity. In this state, the image $A'B'$ formed by objective lens should be at first the principal focus of eyepiece, *i.e.*,

$$u_e = f_o \text{ and } v_e = \infty$$

$\therefore$ Magnifying power, $M = -f_o\left(\frac{1}{f_e} + \frac{1}{\infty}\right) = -\frac{f_o}{f_e}$

Length of telescope $= f_0 + f_e$.

For large magnifying power, f_o should be large and f_e should be small.

For high resolution of the telescope, diameter of the objective should be large.

Factors for increasing the magnifying power

1. Increasing focal length of objective
2. Decreasing focal length of eye piece

Limitations

1. Suffers from chromatic aberration
2. Suffers from spherical aberration
3. Small magnifying power
4. Small resolving power

Q. 10. **(*i*) Draw a labelled ray diagram to obtain the real image formed by an astronomical telescope in normal adjustment position. Define its magnifying power.**

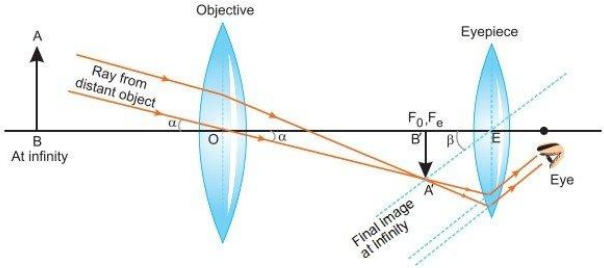
[*CBSE Sample paper-2022, Term-2*] [*CBSE 2019 (55/1/2)*]

(*ii*) You are given three lenses of power 0.5 D, 4 D and 10 D to design a telescope.

(*a*) Which lenses should be used as objective and eyepiece? Justify your answer.

(*b*) Why is the aperture of the objective preferred to be large? **[*CBSE (Central) 2016*]**

Ans. (*i*)



Definition: It is the ratio of the angle (β) subtended at the eye by the final image, to the angle (α) subtended by the object on the eye, *i.e.*, $M = \frac{\beta}{\alpha}$

(*ii*) (*a*) Objective = 0.5 D

Eye lens = 10 D

This choice would give higher magnification as

$$M = \frac{f_0}{f_e} = \frac{P_e}{P_0}$$

(*b*) The aperture of the objective lens is preferred to be large that it may collect sufficient light to form a brighter image of a distant object.

Q. 11. **(*a*) State two main considerations taken into account while choosing the objective of astronomical telescope.**

(*b*) Draw a ray diagram of reflecting type telescope. State its magnifying power.

(*c*) State the advantages of reflecting type telescope over the refracting type.

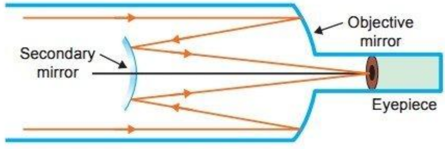
[*CBSE Sample Paper 2021*]

Ans. (*a*) The main considerations taken into account while choosing the objective of astronomical telescope is:

(*i*) The aperture of objective lens is kept large so, that it may collect sufficient light to form a bright image of a distant object.

(*ii*) The focal length of objective is kept large so that the final image subtends a large angle at the eye and the object appears large.

(*b*)



If f_0 and f_e are the focal lengths of objective and eyepiece respectively, then magnifying power when the image is formed at the least distance of distinct vision,

$$m = \frac{f_0}{f_e}\left(1 + \frac{f_e}{D}\right)$$

Magnifying power when image is formed at infinity,

$$m = \frac{f_0}{f_e}$$

(*c*) The advantages of reflecting type telescope over refractive type telescope:

(*i*) No chromatic aberration, because mirror is used.

(*ii*) Easy mechanical support (less mechanical support is required, because mirror weighs much less than a lens of equivalent optical quality)

(*iii*) Large gathering power

(*iv*) Large magnifying power

(*v*) Large resolving power

(*vi*) Spherical aberration can be removed by using parabolic mirror

Q. 12. Draw a graph to show the angle of deviation δ with the variation of angle of incidence *i* for a monochromatic ray of light passing through a prism of refracting angle *A*. Deduce the relation

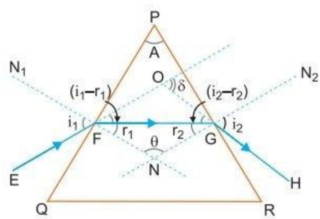
$$n = \frac{\sin\left(\frac{A + \delta_m}{2}\right)}{\sin\left(\frac{A}{2}\right)}$$

[*CBSE Delhi 2011, 2016; (F) 2011, 2017; Sample Paper 2016, 2020(55/4/1)*]

OR

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). **[*CBSE 2023(55/3/1)*]**

Ans. Graph of deviation in δ with variation in angle of incidence *i* : The homogeneous transparent medium (such as glass) enclosed by two plane refracting surfaces is called a prism. The angle between the refracting surfaces is called the refracting angle or angle of prism. The section cut by a plane perpendicular to the refracting surfaces is called the principal section of the prism.



Let *PQR* be the principal section of the prism. The refracting angle of the prism is *A*.

A ray of monochromatic light *EF* is incident on face *PQ* at angle of incidence i_1 The refractive index of material of prism for this ray is *n*. This ray enters from rarer to denser medium and so is deviated towards the normal FN_1 and gets refracted along the direction *FG*. The angle of refraction for this face is r_1 The refracted ray *FG* becomes incident on face *PR* and is refracted away from the normal GN_2 and emerges in the direction *GH*. The angle of incidence on this face is r_2 (into prism) and angle of refraction (into air) is i_2. The incident ray *EF* and emergent ray *GH* when produced meet at *O*. The angle between these two rays is called angle of deviation 'δ'.

$$\angle OFG = i_1 - r_1 \quad \text{and} \quad \angle OGF = i_2 - r_2$$

In $\Delta\, FOG$, δ is exterior angle

$$\delta = \angle OFG + \angle OGF = (i_1 - r_1) + (i_2 - r_2)$$

$$= (i_1 + i_2) - (r_1 + r_2) \qquad ...(i)$$

The normals FN_1 and GN_2 on faces PQ and PR respectively, when produced meet at N. Let $\angle FNG = \theta$ In $\Delta\, FGN$, $\quad r_1 + r_2 + \theta = 180°$ ...(*ii*)

In quadrilateral $PFNG$, $\angle PFN = 90°$, $\angle PGN = 90°$

$$A + 90° + \theta + 90° = 360° \text{ or } A + \theta = 180° \qquad ...(iii)$$

Comparing (*ii*) and (*iii*), $\quad r_1 + r_2 = A$ ...(*iv*)

Substituting this value in (*i*), we get

$$\delta = i_1 + i_2 - A \qquad ...(v)$$

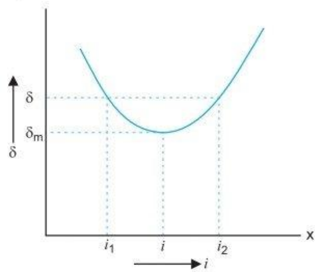
or

$$i_1 + i_2 = A + \delta \qquad ...(vi)$$

From Snell's law, $n = \dfrac{\sin i_1}{\sin r_1} = \dfrac{\sin i_2}{\sin r_2}$ ...(*vii*)

Minimum Deviation: From equation (*v*), it is clear that the angle of deviation depends upon the angle of incidence i_1 As the path of light is reversible, therefore if angle of incidence be i_2 then angle of emergence will be i_1 Thus for two angles of incidence

i_1 and i_2 there will be one angle of deviation.



If we determine experimentally, the angles of deviation corresponding to different angles of incidence and then plot i (*on* X-axis) and δ (on Y-axis), we get a curve as shown in figure. Clearly if angle of incidence is gradually increased, from a small value, the angle of deviation first decreases, becomes minimum for a particular angle of incidence and then begins to increase. Obviously for one angle of deviation (δ) there are two angles of incidences i_1 and i_2, but ***for one and only one particular value of angle of incidence (i), the angle of deviation is the minimum.*** This minimum angle of deviation is represented by δ_m. For minimum deviation i_1 and i_2 become coincident, *i.e.*, $i_1 = i_2 = i$ (say)

So from (*vii*) $\quad r_1 = r_2 = r$ (say)

Hence from (*iv*) and (*vi*), we get $\quad r + r = A \Rightarrow r = A/2$

and

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

Hence, from Snell's law, $n = \dfrac{\sin i}{\sin r} = \dfrac{\sin\left(\dfrac{A + \delta_m}{2}\right)}{\sin\left(\dfrac{A}{2}\right)}$

Questions for Practice

1. **Choose and write the correct option in the following questions.**

   (*i*) An astronomical telescope has objective and eyepiece of focal length 40 cm and 4 cm respectively. To view an object 200 cm away from the objective, the lenses must be separated by a distance

   (*a*) 50.0 cm (*b*) 54.0 cm (*c*) 37.3 cm (*d*) 46.0

   (*ii*) The angle of incidence for a ray of light at a refracting surface of a prism is 45°. The angle of prism is 60°. If they ray suffers minimum deviation through the prism, the angle of minimum deviation and refractive index of the material of the prism respectively, are.

   (*a*) $45°; \sqrt{2}$ (*b*) $30°; \frac{1}{\sqrt{2}}$ (*c*) $45°; \frac{1}{\sqrt{2}}$ (*d*) $30°; \sqrt{2}$

   (*iii*) 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

   (*iv*) Light wave enters from medium 1 to medium 2. Its velocity in 2nd medium is double from 1st. For total internal reflection the angle of incidence must be greater than

   (*a*) 30° (*b*) 60° (*c*) 45° (*d*) 90°

   (*v*) A thin glass (refractive index 1.5) lens has optical power of – 5 D in air. Its optical power in a liquid medium with refractive index 1.6 will be

   (*a*) 1 D (*b*) –1 D (*c*) 25 D (*d*) 0.625 D

2. ***In the following questions, a statement of Assertion (A) is followed by a statement of Reason (R). Choose the correct answer out of the following choices.***

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

   Assertion(*A*) : If a convex lens is kept in water, its convergence power decreases.

   Reason (*R*) : The refractive index of convex lens relative to water is less than that relative to air.

3. 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 lens? Give reason.

4. How does the angle of minimum deviation of a glass prism vary, if the incident violet light is replaced by red light? Give reason.

5. (*a*) State the conditions for total internal reflection to take place.

   (*b*) Suspended by a thread in the liquid is gradually lowered till it touches the bottom. The apparent depth is determined corresponding to different positions of the coin.

   (*i*) Plot a graph showing variation of the apparent depth with the real depth of the coin.
   (*ii*) What is the physical significance of the slope of the graph? [*CBSE 2022 (55/2/1), Term-2*]

6. For the same angle of incidence the angles of refraction in three different media *A*, *B* and *C* are 15°, 25° and 35° respectively. In which medium the velocity of light is minimum?

7. Two monochromatic rays of light are incident normally on the face *AB* of an isosceles right-angled prism *ABC*. The refractive indices of the glass prism for the two rays '1' and '2' are respectively 1.3 and 1.5. Trace the path of these rays after entering through the prism. Explain briefly.

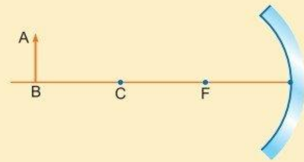
8. The radii of curvature of the two surfaces of a concave lens are 20 cm each. Find the refractive index of the material of the lens if its power is –5.0 D. [*CBSE 2023 (55/3/1)*]

9. A biconvex lens has a focal length $\frac{2}{3}$ times the radius of curvature of either surface. Calculate the refractive index of lens material.

10. 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?

11. A 1.8 m tall person stands in front of a convex lens of focal length 1 m, at a distance of 5 m. Find the position and height of the image formed. [*CBSE 2023 (55/3/1)*]

12. An object *AB* is kept in front of a concave mirror as shown in the figure. [*CBSE (AI) 2012*]



(*i*) Complete the ray diagram showing the image formation of the object.

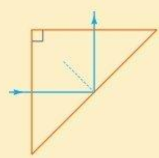
(*ii*) How will the position and intensity of the image be affected if the lower half of the mirror's reflecting surface is painted black?

13. A converging and a diverging lens of equal focal lengths are placed co-axially in contact. Find the power and the focal length of the combination. [*CBSE (AI) 2010*]

14. An object is kept in front of a concave mirror of focal length 15 cm. The image formed is real and three times the size of the object. Calculate the distance of the object from the mirror. [*CBSE 2019 (55/4/1)*]

15. The radii of curvature of both the surfaces of a lens are equal. If one of the surfaces is made plane by grinding, then will the focal length of lens change? Will the power change? [*CBSE Guwahati 2015*]

16. A ray of light incident normally on one face of a right isosceles prism is totally reflected as shown in figure. What must be minimum value of refractive index glass? Give relevant calculations. [*CBSE Delhi 2016*]



17. A small bulb is placed at the bottom of a tank containing water to a depth of 80 cm. What is the area of the surface of water through which light from the bulb can emerge out? Refractive index of water is $\frac{4}{3}$. [*NCERT*]

18. How is the working of a telescope different from that of a microscope? [*CBSE Delhi 2012, 2019 (55/2/3)*]

19. 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 (AI) 2017*]

20. Draw a ray diagram to show the image formation of a distant object by a refracting telescope. Write the expression for its angular magnification in terms of the focal lengths of the lenses used. State the important considerations required to achieve large resolution and their consequent limitations.

21. (*a*) Plot a graph for angle of deviation as a function of angle of incidence for a triangular prism.

(*b*) Derive the relation for the refractive index of the prism in terms of the angle of minimum deviation and angle of prism.

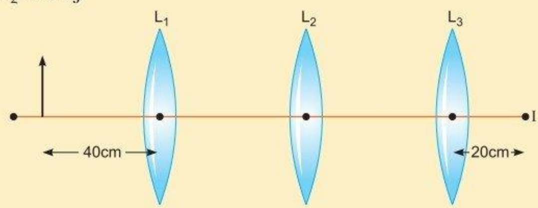
22. An optical instrument uses a lens of 100 D for the objective lens and 50 D for its eye piece. When the tube length is kept at 20 cm, the final image is formed at infinity.

(*a*) Identify the optical instrument.

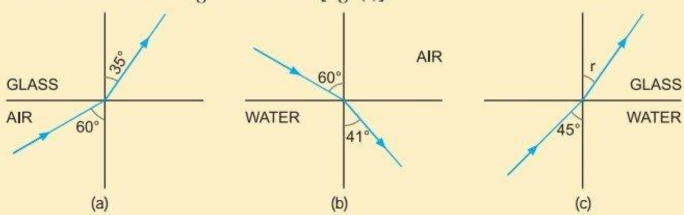
(*b*) Calculate the magnification produced by the instrument. **[*CBSE 2020 (55/5/1)*]**

23. Two objects *P* and *Q* when placed at different positions in front of a concave mirror of focal length 20 cm, form real images of equal size. Size of object *P* is three times size of object *Q*. If the distance of *P* is 50 cm from the mirror, find the distance of *Q* from the mirror. **[*CBSE 2020 (55/4/1)*]**

24. You are given three lenses L_1, L_2 and L_3 each of focal length 20 cm. An object is kept at 40 cm in front of L_1, as shown. The final real image is formed at the focus '*I*' of L_3. Find the separations between L_1, L_2 and L_3. **[*CBSE (AI) 2012*]**



25. Fig. (*a*) and (*b*) show refraction of an incident ray in air at 60° with the normal to a glass-air and water-air interface, respectively. Predict the angle (*r*) of refraction of an incident ray in water at 45° with the normal to a water-glass interface [fig. (*c*)]. **[*NCERT*]**



26. An angular magnification of 30X is desired using an objective of focal length 1.25 cm and an eye-piece of focal length 5 cm. How would you set up the compound microscope? **[*NCERT*] [*CBSE Sample Paper 2018*]**

27. A small telescope has an objective lens of focal length 144 cm and an eye piece of focal length 6.0 cm. What is the magnifying power of the telescope? What is the separation between the objective and the eye-piece? **[*NCERT*]**

28. An object of size 3.0 cm is placed 14 cm in front of a concave lens of focal length 21 cm. Describe the image produced by the lens. What happens if the object is moved farther from the lens? **[*NCERT*]**

29. (*a*) Calculate the distance of an object of height *h* from a concave mirror of radius of curvature 20 cm, so as to obtain a real image of magnification 2. Find the location of image also.

(*b*) Using mirror formula, explain why does a convex mirror always produce a virtual image. **[*CBSE Delhi 2016*]**

30. (*a*) A mobile phone lies along the principal axis of a concave mirror. Show, with the help of a suitable diagram, the formation of its image. Explain why magnification is not uniform.

(*b*) Suppose the lower half of the concave mirror's reflecting surface is covered with an opaque material. What effect this will have on the image of the object? Explain. **[*CBSE Delhi 2014*]**

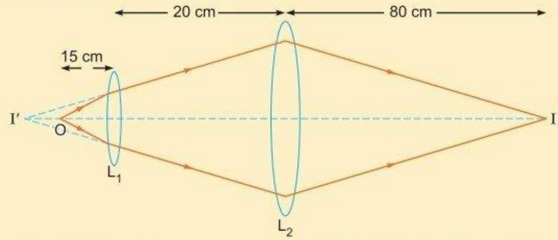
31. A convex lens made up of glass of refractive index 1.5 is dipped, in turn, in (*i*) a medium of refractive index 1.65, (*ii*) a medium of refractive index 1.33.

(*a*) Will it behave as a converging or a diverging lens in the two cases?

(*b*) How will its focal length change in the two media? **[*CBSE (AI) 2011*]**

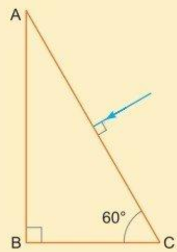
32. A converging lens has a focal length of 20 cm in air. It is made of a material of refractive index 1.6. If it is immersed in a liquid of refractive index 1.3, find its new focal length. [*CBSE (F) 2017*]

33. In the following diagram, an object '*O*' is placed 15 cm in front of a convex lens L_1 of focal length 20 cm and the final image is formed at '*I*' at a distance of 80 cm from the second lens L_2. Find the focal length of the L_2. [*CBSE (F) 2016*]



34. An object is placed 40 cm from a convex lens of focal length 30 cm. If a concave lens of focal length 50 cm is introduced between the convex lens and the image formed such that it is 20 cm from the convex lens, find the change in the position of the image. [*CBSE Chennai 2015*] [*HOTS*]

35. Trace the path of a ray of light passing through a glass prism (*ABC*) as shown in the figure. If the refractive index of glass is $\sqrt{3}$, find out of the value of the angle of emergence from the prism. [*CBSE (F) 2012*] [*HOTS*]



Answers

1. (*i*) (*b*) (*ii*) (*d*) (*iii*) (*b*) (*iv*) (*a*) (*v*) (*d*)

2. (*a*) **8.** $\frac{3}{2}$ **9.** $\frac{7}{4}$ **10.** 100 cm **11.** 1.25 m, – 0.45 m

13. infinite **14.** –20 cm **16.** $\sqrt{2}$ **17.** 2.6 m^2 **19.** 22 cm **22.** (*b*) 312.5

23. – 30 cm **24.** 60 cm (between L_2 and L_3)

25. (*a*) 1.51 (*b*) 1.32 (*c*) 38° **26.** 11.67 **27.** –24, 150 cm **28.** –8.4 cm, 1.8 cm

29. (*a*) –15 cm, –30 cm **32.** 52 cm **33.** – 40 cm **34.** 200 cm **35.** 60°