CHAPTER-9

Ray Optics and Optical Instruments

ASSIGNMENT-1

1-Mark Questions

Q1. Which of the following does not change during the refraction of light?
frequency, velocity or wavelength of light

Q2. State Snell's law of refraction?

Q3. Define refractive index of the material?

Q4. Which mirror is used as driver's mirror?

Q5. Define principal focus of a mirror?

Q6. Show the variation of u and v in the case of a concave mirror?

Q7. Write the relation between the object distance (u), image distance (v) and focal length (f) of a concave mirror?

Q8. If the wavelength (colour) of incident light on a concave mirror is changed, how will the focal length of the mirror change?

Q9. State the laws of reflection of light?

Q10. Light travelling in a medium with the velocity 3×10^8m/s is refracted into a second medium in which it travels with a velocity 2×10^8m/s. What is a refractive index of the second medium?

Q11. Light a wavelength 5000 $°A$ in air enters a medium of refractive index 1.4 what will be its frequency in the medium?

Q12. What is the ratio of velocity of two light waves travelling in vacuum and having wavelength 4000$°A$ and 8000$°A$?

Q13. Can absolute refractive index of any material be less than one. Why?

Q14. State the principle of an optical fibre?

Q15. What do you mean by critical angle?

Q16. Write the relation between critical angle and refractive index?

Q17. What is the main use of optical fibres?

Q18. Calculate the speed of light in a medium whose critical angle is 30 °?

Q19. State the thin lens formula?

Q20. Define power of a lens and write its SI unit?

MULTIPLE CHOICE QUESTIONS

Q21. Which of the following is not due to total internal reflection?

a) Brilliance of diamond
b) Working of optical fibre
c) Difference between apparent and real depth of a pond
d) Mirage on hot summer days

Q22. An object is placed at the focus of the convex mirror. If its focal length is 20cm, the distance of image from the mirror is

a) 10cm
b) 20cm
c) 40cm
d) None of the above

Q23. An object is placed at the focus of a concave mirror. If the focal length of the mirror is 20cm, then the distance of image from the pole is

a) 10cm
b) 20cm
c) 40cm
d) Infinity

Q24. The relation between angle of incidence i , angle of prism A and angle of minimum deviation d_m for a triangular prism is

a) A+d_m = i
b) A+d_m = 2i
c) $A + \frac{d_m}{2}$ =i
d) 2A+d_m = i

Q25. The critical angle for total internal reflection from a medium to vacuum is 30°. The velocity of light in the medium is

a) 3×10^8m/s
b) 1.5×10^8m/s
c) 6×10^8m/s
d) $\sqrt{3} \times 10^8$m/s

Q26. A beam of light passes from air to glass. How does the speed of light vary

a) decreases
b) increases
c) remains unchanged
d) it may decrease or increase, depending on the colour

Q27. A convex length of focal length is put in contact with a concave lens of same focal length. The equivalent focal length of the combination is

a) zero
b) f
c) 2f
d) Infinity

Q28. Half of the lens is wrapped in black paper. How will it change the image

a) Size of image is halved

b) Intensity of image is halved
c) There is no change in the size of image or intensity
d) Both size and intensity of the image are changed.

Q29. Which of the following produces virtual as well as real image.
a) Concave lens and Convex mirror
b) Convex Mirror and Convex lens
c) Convex lens and Concave mirror
d) Concave mirror and Concave lens

Q30. What is the nature of the graph between $\frac{1}{u}$ and $\frac{1}{v}$ for a convex lens where u is the distance of the object and v is that of the image?
a) Straight line b) Parabola c) Ellipse d) Hyperbola

Q31. A ray of light passes through a plane glass slab of thickness t and refractive index μ = 1.5, The angle between the incident ray and the emergent ray will be
a) 0º b) 30º c) 45º d) 60º

Q32. A convex lens of power 4D and a concave lens of power 3D are placed in contact. What is the equivalent power of the combination?
a) 7D b) $\frac{4}{3}$D c) 1D d) $\frac{3}{4}$D

Q33. A lens behaves as a diverging lens in air (n=1) and a converging lens in water (n=1.3). The refractive index μ of the material of the lens is
a) $1 < n < 1.3$
b) $n > 1.3$
c) $n < 1.0$
b) $n = \frac{1+1.3}{2}$

Q34. For using a convex lens as a magnifying glass, where should we place the object?
a) At the principal focus
b) Nearer to the lens
c) At $\frac{f}{2}$, where f = focal length
d) Anywhere

Q35. A lens of power 3.5D is placed is contact with a lens of power -2.5D. The combination will behave like
a) A convergent lens of focal length 100cm
b) A divergent lens of focal length 100cm
c) A convergent lens of focal length 200cm
d) A divergent lens of focal length 200cm

ASSERTION AND REASON

Directions: These questions consist of two statements, each printed as Assertion and Reason. While answering these questions, you are required to choose any one of the following four responses.

(a) If both Assertion and Reason are correct and the Reason is a correct explanation of the Assertion.

(b) If both Assertion and Reason are correct but Reason is not a correct explanation of the Assertion.

(c) If the Assertion is correct but Reason is incorrect.

(d) If both the Assertion and Reason are incorrect.

Q36. Assertion: Plane mirror may form real image

Reason: Plane mirror forms virtual image, if object is real.

Q37. Assertion: The focal length of the convex mirror will increase, if the mirror is placed in water.

Reason: The focal length of a convex mirror of radius R is equal to f = R/2.

Q38. Assertion: The image formed by a concave mirror is certainly real if the object is virtual.

Reason: The image formed by a concave mirror is certainly virtual if the object is real.

Q39.**Assertion:** If the rays are diverging after emerging from a lens; the lens must be concave.

Reason: The convex lens can give diverging rays.

Q40. **Assertion:** The optical instruments are used to increase the size of the image of the object.

Reason: The optical instruments are used to increase the visual angle.

Q41. **Assertion:** The resolving power of a telescope is more if the diameter of the objective lens is more.

Reason: Objective lens of large diameter collects more light.

Q42. **Assertion:** The focal length of an equiconvex lens of radius of curvature R made of material of refractive index n = 1.5, is R.

Reason: The focal length of the lens will be R/2.

Q43. **Assertion (A):** The maximum intensity in interference pattern is four times the intensity due to each slit.

Reason (R): Intensity is directly proportional to square of amplitude.

Q44. **Assertion (A):** Diffraction is common in sound but not common in light waves.

Reason (R): Wavelength of light is more than the wavelength of sound.

Q45. **Assertion (A):** Interference obeys the law of conservation of energy.

Reason (R): The energy is redistributed in case of interference.

2 MARKS QUESTIONS

Q46. A concave mirror is placed in water. Will there be any change in its focal length? Give reason?

Q47. An object under water appears to be at a lesser depth than in reality, why?

Q48. The refractive index of the material of a concave lens is n. It is immersed in a medium of refractive index n_1. A parallel beam of light is incident on the lens. Trace the path of emergent rays in each of the following cases:

i) $n_1 > n$ ii) $n_1 < n$ iii) $n_1 = n$

Q49. An air bubble is formed inside water. Does it act as a converging lens or a diverging lens? Explain.

Q50. An equi-convex lens of radius of curvature R is cut into two equal parts by a vertical plane, so it becomes a Plano convex lens. If f is the focal length of the equi-convex lens, then what will be focal length of Plano convex lens?

Q51. An object is kept in front of a concave mirror as shown in figure. Complete the ray diagram showing the image formation of the object.

How will the position and intensity of the image be affected if the lower half of the mirrors reflecting surface is painted black?

Q52. A spherical convex surface of radius of curvature 20cm made of glass of refractive index 1.5 is placed in air. Find the position of the image formed if a point object is placed 30cm in front of a convex surface on the principal axis?

Q53. The radii of curvature of the faces of a double convex lens are 10cm and 15cm. If the focal length of the lens is 12cm, find the refractive index of the material of the lens?

Q54. An object is kept in front of a concave mirror of focal length 15cm. Calculate the refractive index of the material of the lens?

Q55. State the condition under which a large magnification can be achieved in an astronomical telescope?

THREE MARKS QUESTIONS

Q56. State the condition for total internal reflection of light to take place at an interface separating two transparent media. Hence derive the expression for the critical angle in terms of the speeds of light in two media. (CBSE D 2000)

Q57. (i) What is total internal reflection? Under what conditions does it occur?

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

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

Q58. (i) Name the phenomenon on which the working of an optical fiber is based.

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

(iii) Draw a labelled diagram of an optical fiber and show how light propagates through the optical fiber using this phenomenon.

Q59.What are optical fibers? Mention their one practical application.

Q60.Write the basic assumptions in the derivation of lens maker's formula. Hence derive this expression. (CBSE OD 20)

Q61. Using the ray diagram for a system of two lenses of focal lengths f1 and f2 in contact with each other, show that two lens system can be regarded as equivalent to a single lens of focal length f, where $\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2}$ Also write the relation for the equivalent power of the lens combination.

(CBSE 17, 19, 20)

Q62. Draw a graph to show the variation of the angle of deviation δ with that of the angle of incidence i for a monochromatic ray of light passing through a glass prism of refracting angle A. Hence deduce the relation:

$$n = \frac{sin(\frac{\delta m+A}{2})}{sin(\frac{A}{2})}$$

(CBSE D 17C)

Q63. A concave lens made of material of refractive index 'n_2'is held in a reference medium of refractive index 'n_1'. Trace the path of parallel beam of light passing through the lens when:

(i) $n_1 = n_2$ (ii) $n_1 < n_2$ (iii) $n_1 > n_2$ (CBSE OD 2000, 03C)

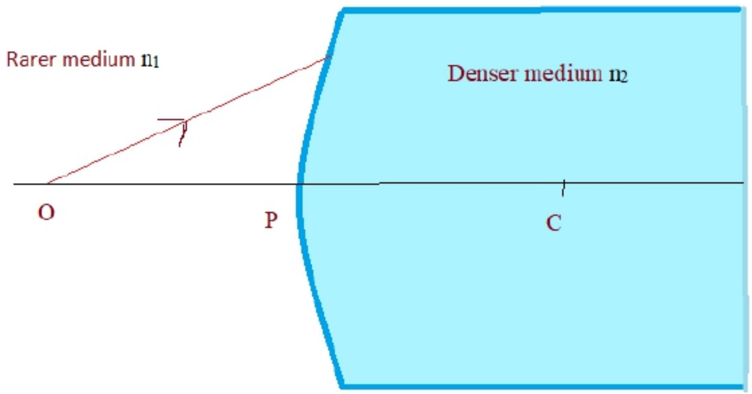
5 MARKS QUESTIONS

Q64. (a) Draw a ray diagram to show image formation when the concave mirror produces a real, inverted and magnified image of the object.

(b) Obtain the mirror formula and write the expression for the linear magnification.

(c) Explain two advantages of a reflecting telescope over a refracting telescope. (CBSE 18)

Q65. (a)A spherical surface of radius of curvature, separates a rarer and a denser medium as shown in 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 the two media.



(b)Briefly explain, how the focal length of a convex lens changes, with increase in wavelength of incident light. (CBSEOD 04; D 16C)

Q66.Derive expression for the Lens Maker's formula $\frac{1}{f} = (n-1)\left[\frac{1}{R_1} - \frac{1}{R_2}\right]$ where the symbols have usual meanings. State the assumptions used and the convention of signs.

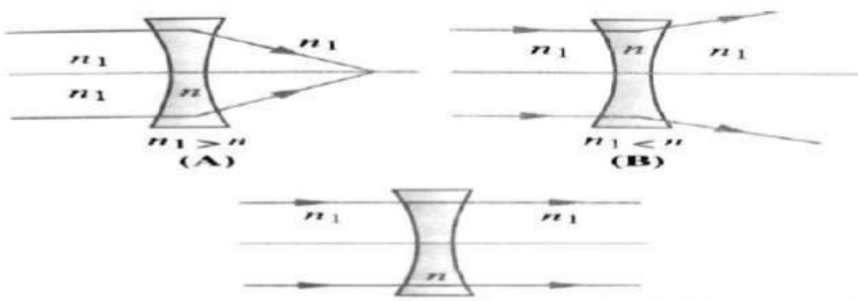
Q67. Trace the path of a monochromatic ray of light through a prism of refracting angle 'A'. Draw a graph to show the variation of angle of deviation 'δ' with the variation of angle of incidence 'i'.Deduce the relation $n = \frac{\sin\left(\frac{\delta m + A}{2}\right)}{\sin\left(A/2\right)}$ (CBSE F 08; D 16)

ANSWERS TO QUESTIONS OF 2 MARKS

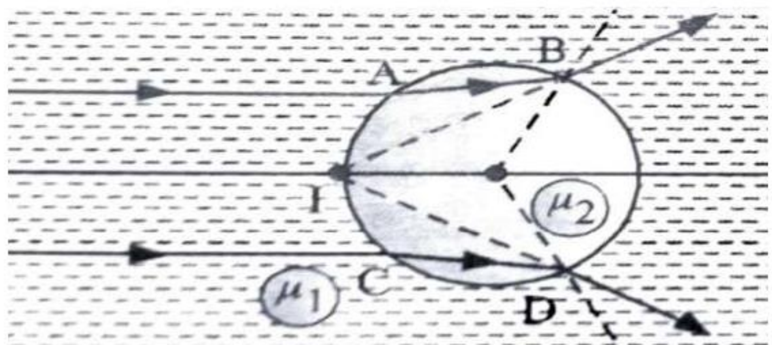
46. Focal length of a mirror f=$\frac{R}{2}$ where R is the radius of curvature of the mirror. Hence focal length doesn't depends on the medium in which it is immersed. So focal length remains the same.

47. This is due to refraction of light. Refractive index n = $\frac{\text{real depth}}{\text{apparent depth}}$. Since n>1, apparent depth is less than the real depth.

48.



49. A ray of light parallel to the principal axis, incident on the air bubble, bends away from the normal as it goes from denser to rarer medium. The refracted ray AB, suffers refraction at B and it bends toward the normal. The refracted rays at B and D when produced backwards, meets the principal axis at I, giving a virtual image. The air bubble diverges the rays of light, so it behaves like a diverging lens.



50.$\frac{1}{f}$=(n−1)$(\frac{1}{R_1} - \frac{1}{R_2})$

For equi-convex lens R_1 = +R and R_2=-R

$\frac{1}{f}$=$(n-1)(\frac{1}{R} + \frac{1}{R})$

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

For plano convex lens R_1 = +R and R_2= ∞

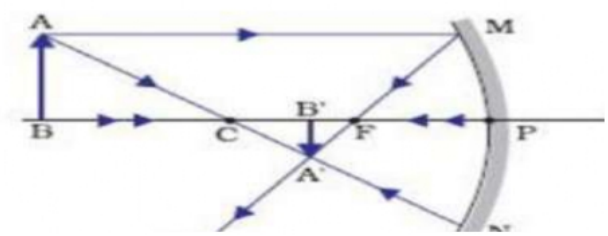
$\frac{1}{f^1}$=$(n-1)(\frac{1}{R})$

=$(n-1)R = 2f$

Focal length become two times.

51. Image formed will be real, inverted and diminished between C and F

There will be no change in the position of the image, but its intensity will be reduced.



52.R=20cm,n1=1,n2=1.5 ,u= -30cm

$$\frac{n2}{v} - \frac{n_1}{u} = \frac{n_2 - n\mu_1}{R}$$

$$\frac{1.5}{v} - \frac{1}{-30} = \frac{1.5 - 1}{20}$$

$$\frac{1.5}{v} = \frac{-1}{120} v = -180cm$$

53.Given m=3 and f=-15cm m=$\frac{v}{u}$ $v = 3u$

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

u=-20cm

54. $R_1 = +10cm \quad R_2 = -15cm$,$f = 12cm$

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

$\frac{1}{12}$=$(n-1)(\frac{1}{10} - \frac{1}{-15})$

$(n-1) = 0.5$

$n = 1 + 0.5 = 1.5$

55. Angular magnification M=$-\frac{f_o}{f_e}\left(1 + \frac{f_e}{D}\right)$ when the final image is formed at least distance of distinct vision

M $= -\frac{f_o}{f_e}$ in normal adjustment

ANSWERS OF THREE MARKS QUESTIONS

56. 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

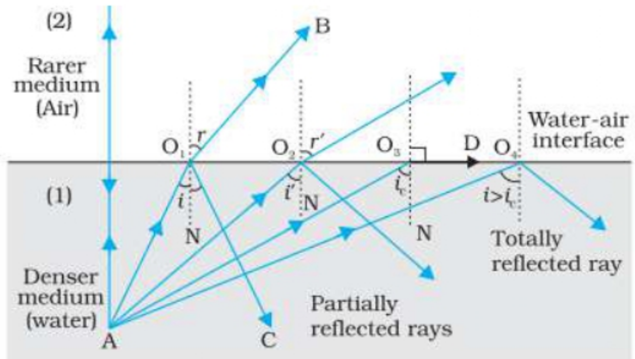


FIGURE Refraction and internal reflection of rays from a point A in the denser medium (water) incident at different angles at the interface with a rarer medium (air).

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$n_{21} = \frac{\sin i}{\sin r}$ (as per the figure above)

for total internal reflection to occur $i \geq i_c$;

at critical angle i_c; angle of refraction, $r = 90^0$

hence $n_{21} = \frac{\sin i_c}{\sin 90^0} = \sin i_c$

$$n_{21} = \frac{1}{n_{12}}$$

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

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

Thus, refractive index of denser medium with respect to the rarer medium is equal to $1/_{\sin i_c}$

57. (i) When a ray of light travels from an optically denser medium into rarer medium at an angle greater than the critical angle, it reflects back into the denser medium. This phenomenon I 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

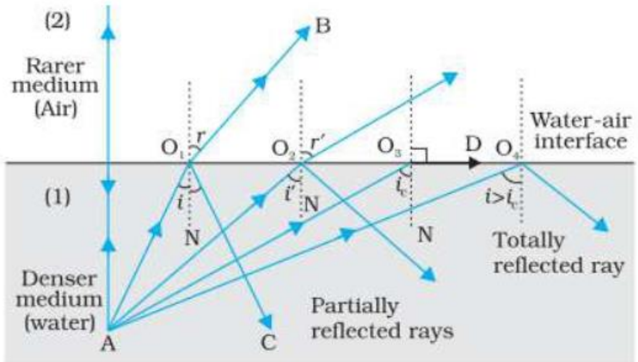

FIGURE Refraction and internal reflection of rays from a point A in the denser medium (water) incident at different angles at the interface with a rarer medium (air).

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$n_{21} = \frac{sin\, i}{sin\, r}$ (as per the figure above)

for total internal reflection to occur $i \geq i_c$;

at critical angle i_c; angle of refraction, $r = 90^0$

hence $n_{21} = \frac{sin\, i_c}{sin\, 90^0} = sin\, i_c$

$$n_{21} = \frac{1}{n_{12}}$$

$$\frac{1}{n_{12}} = sin\, i_c$$

$$n_{12} = \frac{1}{sin\, i_c}$$

Thus, refractive index of denser medium with respect to the rarer medium is equal to $^1/_{sin\, i_c}$

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

58. (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

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

(iii)

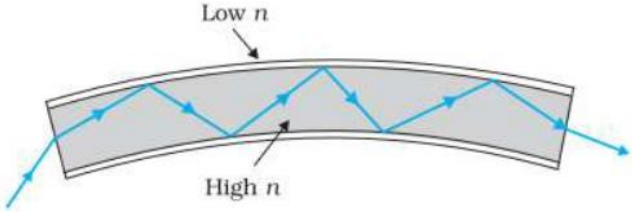

FIGURE Light undergoes successive total internal reflections as it moves through an optical fibre.

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59. 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 from a light pipe and are used for communication of light signals. When a light ray is incident on one 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 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 (i)to transmit light signal to distant places (ii) in endoscopy.

60. Refer question 3 of section A 5 marks questions.

61.

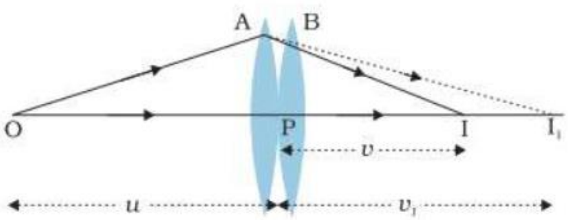

FIGURE Image formation by a combination of two thin lenses in contact.

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Consider two lenses A and B of focal length f_1 and f_2 placed in contact with each other. Let the object be placed at a point O beyond the focus of the first lens A. The first lens produces an image at I_1. Since image I_1 is real, it serves as a virtual object for the second lens B, producing the final image at I.

For the image formed by the first lens A, we get

$$\frac{1}{v_1} - \frac{1}{u} = \frac{1}{f_1} \text{ ... . } (1)$$

For the image formed by the second lens B, we get

$$\frac{1}{v} - \frac{1}{v_1} = \frac{1}{f_2} \text{ ... ... } (2)$$

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

$$\frac{1}{v} - \frac{1}{u} = \frac{1}{f_1} + \frac{1}{f_2} \text{ ... ... } (3)$$

If the two lens-system is regarded as equivalent to a single lens of focal length f we get

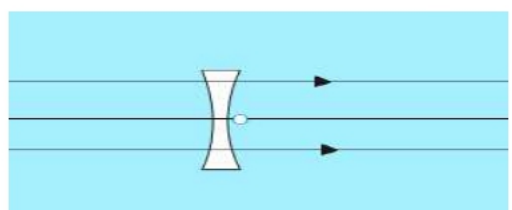
$$\frac{1}{v} - \frac{1}{u} = \frac{1}{f} \text{ ... ... } (4)$$

From (3) and (4)

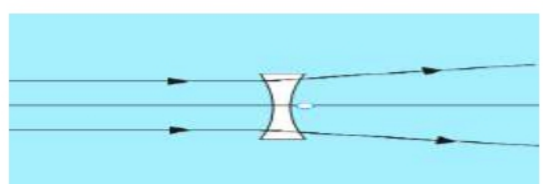
$$\frac{1}{f_1} + \frac{1}{f_2} = \frac{1}{f}$$

62. Refer question 4 of section A 5 marks questions.

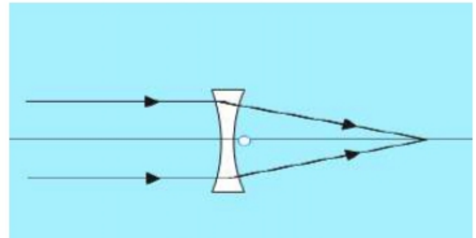
63. (i) $n_1 = n_2$



(ii) $n_1 < n_2$

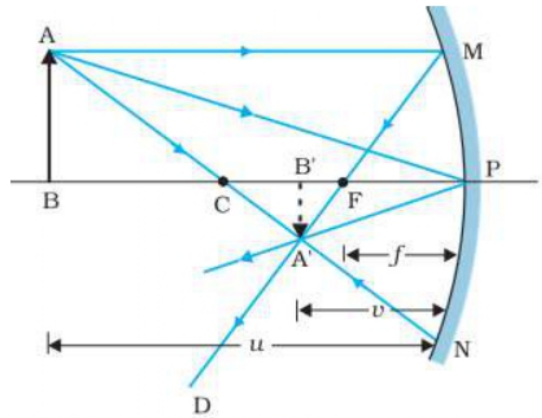


(iii) $n_1 > n_2$



SOLUTION OF 5 MARKS QUESTIONS

64. (a) Ray diagram:



Ray diagram for image formation by concave mirror

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(b) The two right- angled triangles $A'B'F$ and MPF are similar.

$$\frac{B'A'}{PM} = \frac{B'F}{FP}$$

$$\frac{B'A'}{BA} = \frac{B'F}{FP} (\because PM = BA) \dots\dots\dots (1)$$

$$\angle APB = \angle A'PB'$$

The right triangles $A'B'P$ and ABP are also similar

$$\frac{B'A'}{BA} = \frac{B'P}{BP} \dots\dots (2)$$

Comparing eqs. (1) and (2)

$$\frac{B'F}{FP} = \frac{B'P}{BP}$$

$$\frac{B'P - FP}{FP} = \frac{B'P}{BP} \dots\dots. (3)$$

Taking the sign conventions, $B'P = -v, \quad FP = -f, \quad BP = -u$

Using these in equation (3)

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

$$\frac{v-f}{f} = \frac{v}{u} \quad \Rightarrow \quad \frac{v}{f} - 1 = \frac{v}{u} \quad \Rightarrow \quad \frac{1}{f} - \frac{1}{v} = \frac{1}{u} \dots\dots (dividing\ by\ v)$$

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

The above equation is mirror formula.

Linear magnification: $m = \frac{h'}{h}$

From eqn (2)

$$\frac{B'A'}{BA} = \frac{B'P}{BP} \qquad \therefore \frac{-h'}{h} = \frac{-v}{-u}$$

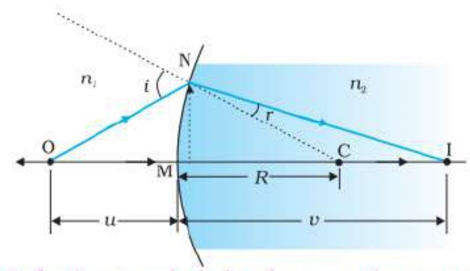
$$m = \frac{h'}{h} = -\frac{v}{u}$$

(c) The two advantages of reflecting telescope:

(i)There is no chromatic aberration in case of reflecting telescope as the objective is a mirror.

(ii) Spherical aberration is reduced in case of reflecting telescope by using mirror objective in the form of paraboloidal mirror.

65. The figure shows the geometry of image formation of image I of an object O on the principal axis of a spherical surface with centre of curvature C, and radius of curvature R.



Refraction at a spherical surface separating two media.
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Consider the aperture of surface to be small compared to other distances involved, so that the angle approximation can be made.

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

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

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

For ΔNOC*, 'i' is the exterior angle.*

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

$$\therefore i = \frac{MN}{OM} + \frac{MN}{MC} \dots\dots (1)$$

For $\Delta NCI, \angle NCM$ *is the exterior angle.*

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

$$\therefore r = \frac{MN}{MC} - \frac{MN}{MI} \dots\dots (2)$$

By Snell's law

$n_1 \sin i = n_2 \sin r$

$n_1 i = n_2 r \dots\dots \quad (for\ small\ angles)$

$$n_1\left(\frac{MN}{OM}+\frac{MN}{MC}\right) = n_2\left(\frac{MN}{MC}-\frac{MN}{MI}\right) \qquad \dots\dots (from\ (1)\&(2))$$

$$\frac{n_1}{OM}+\frac{n_1}{MC}=\frac{n_2}{MC}-\frac{n_2}{MI} \dots\dots\dots (dividing\ by\ MN)$$

$$\frac{n_1}{OM}+\frac{n_2}{MI}=\frac{n_2-n_1}{MC}$$

Applying the sign convention, $OM = -u, \quad MI = +v, \quad MC = +R$

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

$$\frac{n_2}{v}-\frac{n_1}{u}=\frac{n_2-n_1}{R} \dots\dots (3)$$

Equation (3) is the required equation.

(b) $n_{21} = \frac{\lambda_1}{\lambda_2} = \frac{n_2}{n_1}$

$for\ \lambda_2 > \lambda_1,\ n_2 < n_1$

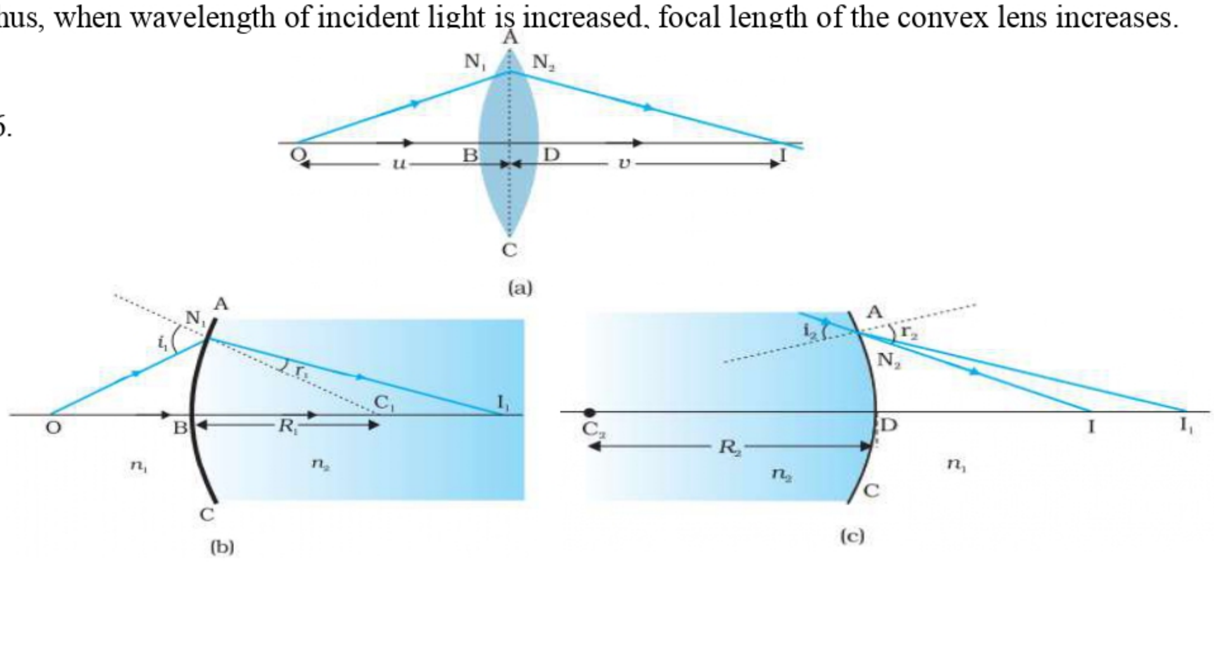
$According\ to\ Lens\ maker's\ equation \frac{1}{f} = (n-1)\left[\frac{1}{R_1}-\frac{1}{R_2}\right]$

$$\therefore f \propto \frac{1}{(n-1)}$$

$\therefore for\ \lambda_2 > \lambda_1,\ n_2 < n_1\ and\ f_2 > f_1$

Thus, when wavelength of incident light is increased, focal length of the convex lens increases.

66.



Fig(a) shows the geometry of image formation by a double convex lens. The image formation can be seen in terms of two steps:

(i) The first refracting surface forms the image I_1 of the object O (fig b)

(ii) The image I_1 acts as a virtual object for the second surface that forms the image at I (fig c)

Applying equation for refraction at a spherical surface to the first surface ABC,

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

Applying equation for refraction at a spherical surface to the second surface ADC,

$$\frac{n_2}{-DI_1}+\frac{n_1}{DI}=\frac{n_1-n_2}{-DC_2} \dots\dots (2)$$

For this case the refractive index of the medium on the right side of ADC is n_1 while on its left it is n_2. Further DI_1 is negative as the distance is measured against the direction of incident light.

Also for thin lens, $BI_1 = DI_1$

Equation (2) becomes

$$-\frac{n_2}{BI_1}+\frac{n_1}{DI}=\frac{n_2-n_1}{DC_2} \dots\dots (3)$$

Adding eqs (1) and (3)

$$\frac{n_1}{OB}+\frac{n_1}{DI}=(n_2-n_1)\left(\frac{1}{BC_1}+\frac{1}{DC_2}\right) \dots\dots (4)$$

Suppose the object is at infinity, $OB \to \infty \; and \; DI = f$

$$\frac{n_1}{f}=(n_2-n_1)\left(\frac{1}{BC_1}+\frac{1}{DC_2}\right) \dots\dots (5)$$

By the sign conventions, $BC_1 = +R_1 DC_2 = -R_2$

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

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

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

$$\frac{1}{f}=(n_{21}-1)\left(\frac{1}{R_1}-\frac{1}{R_2}\right) \dots\dots (6) \left(\because n_{21}=\frac{n_2}{n_1}\right)$$

Eqn (6) is Lens Maker's formula.

Assumptions made in the derivation of Lens Maker's formula

1. The lens used is thin so that the distances measured from its surfaces may be taken equal to those measured from its optical centre.
2. The object is a point object placed on the principal axis.
3. The aperture of the lens is small.
4. All the rays are paraxial.

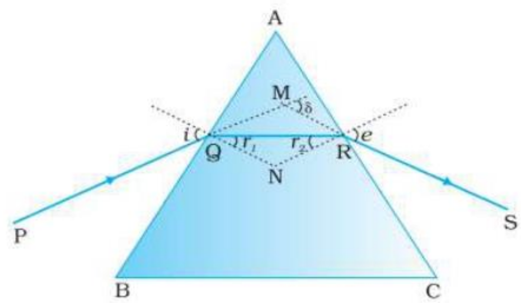


FIG: Light passing through the triangular prism
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New Cartesian sign convention for spherical lenses:

1. All distances are measured from the optical centre of the lens.
2. The distances measured in the direction of incident light are positive.
3. The distances measured in the opposite direction of incident light are negative.

67. Figure shows the passage of light through a triangular prism ABC. Ray PQ is incident on the face AB. The angle of incidence and angle of refraction are i and $r_1$respectively. The ray QR emerges from the face AC. The angle of incidence on this face is r_2 and angle of refraction or emergence is e.

The angle between the emergent ray RS and the direction of the incident ray is called the angle of deviation, δ

In □ AQNR, $\angle AQN + \angle ARN = 90^O + 90^O = 180^O$

$\angle A + \angle QNR = 180^O$ ..... (1)

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

Comparing (1) and (2) $r_1 + r_2 = A$ ... . (3)

In ΔMQR, $\delta = \angle MQR + \angle MRQ$ ..... (δ *is exterior angle*)

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

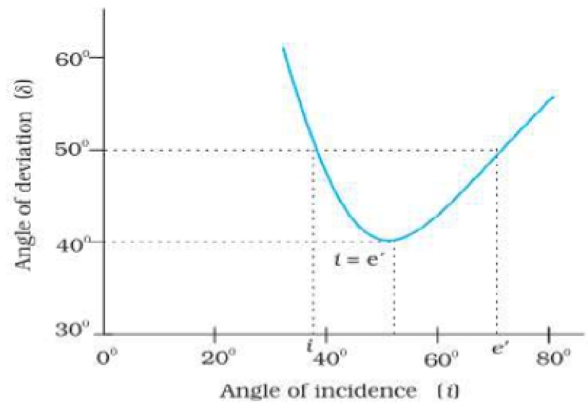
$\delta = i + e - A$ ... . (4)

Plot of angle of deviation (δ) versus angle of incidence (i) for a triangular prism:

At $\delta = \delta_m i = e \ \therefore r_1 = r_2$

$\therefore eqn\ (3) becomes\ 2r = A \quad \therefore r = \frac{A}{2}$

$Eqn\ (4)\ becomes\ \delta_m = 2i - A \quad \therefore i = \frac{A + \delta_m}{2\delta}$



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According to Snell's law

$$n_{21} = \frac{\sin i}{\sin r}$$

Substituting i and r in the above equation $\quad n_{21} = \frac{\sin\left(\frac{A+\delta m}{2}\right)}{\sin\left(\frac{A}{2}\right)}$