CHAPTER - 9

Ray Optics and Optical Instruments

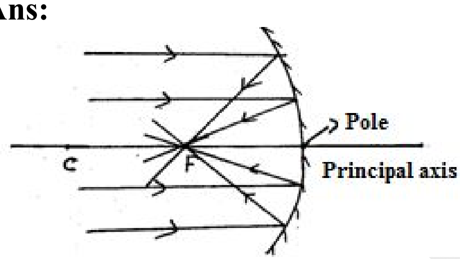
Phenomena of light

i) Rectilinear propagation of light
ii) Reflection
iii) Refraction
iv) Diffraction
v) Scattering
vi) Polarization
vii) Interference
viii) Colour vision
ix) Photoelectric effect

Spherical Mirrors (Reflection)

1. Define **principal focus of a concave mirror**.

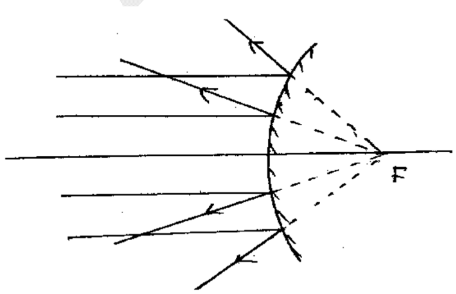
Ans:



The light rays which are coming parallel to the principal axis after reflection converge to a point on the principal axis. This point is called the principal focus of a concave mirror.

2. Define **principal focus of a convex mirror**.

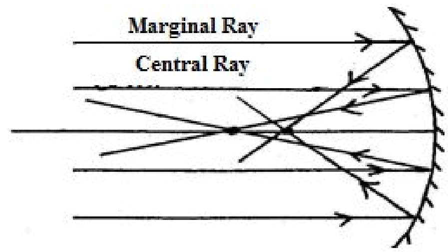
Ans:



The light rays which are coming parallel to the principal axis after reflection from the convex mirror appears to diverge from a point on the principal axis, on the other side of the mirror. This point is called the principal focus of the convex mirror.

3. What is **spherical aberration**?

Ans:



The marginal rays in mirrors of very large apertures are focussed relatively closer to the vertex (pole) as compared to the central rays, which converge at F. As a result of this the image formed is not sharp but fuzzy. The fuzzy formation of image which arises due to large aperture of mirror is called spherical aberration.

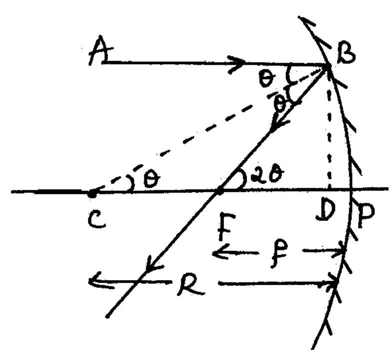
In other words, the inability of a spherical mirror of large aperture to focus the marginal rays and central rays at a single point is called spherical aberration.

4. How can you minimise spherical aberration?

Ans: - Spherical aberration can be minimised (i) by using stop for marginal rays so that only central rays are allowed to pass through or (ii) by using parabolidal mirrors.

5. Derive the **relation between R and f** for a spherical mirror.

Ans:



Let us consider a ray **AB** parallel to the principal axis is incident on a concave mirror at B which is very close to the pole 'P'. After reflection the ray passes through 'F'.

From ΔBCD,

$$\tan\theta = \frac{BD}{CD} \cdots\cdots\cdots (1)$$

From ΔBFD,

$$\tan 2\theta = \frac{BD}{FD} \cdots\cdots\cdots (2)$$

If θ is very small,

$\tan\theta \approx \theta$ and $\tan 2\theta \approx 2\theta$

$\therefore$ eqns (1) and (2) $\rightarrow$

$$\theta = \frac{BD}{CD} \text{ and}$$

$$2\theta = \frac{BD}{FD}$$

Now we have

$$\frac{BD}{FD} = 2\theta \Rightarrow \frac{\cancel{B}D}{FD} = 2 \times \frac{\cancel{B}D}{CD}$$

$$\Rightarrow \frac{1}{FD} = \frac{2}{CD}$$

$$\Rightarrow CD = 2FD \cdots\cdots\cdots (3)$$

But $FD \approx f$ and $CD \approx R$

$\therefore$ equ (3) $\rightarrow R = 2f$

$$\boxed{R = 2f}$$

6. Explain **new Cartesian sign convention.**

Ans: The main conventions in the new Cartesian sign convention are:

i) All distances are measured from the pole of the mirror.

ii) All distances measured in the direction of incident ray are taken as positive.

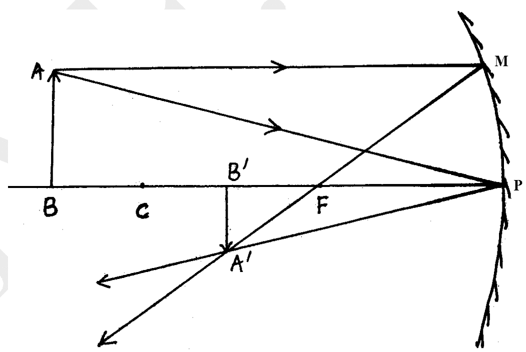
iii) All distances measured against the direction of incident ray are taken as negative.

iv) Heights measured perpendicular to the principal axis and upwards are taken as positive.

v) Heights measured perpendicular to the principal axis and downwards are taken as negative.

7. Derive the **mirror formula.**

Ans:



Let AB is a linear object placed on the principal axis of a concave mirror. $A'B'$ is the image of AB.

The two right triangle $\Delta A'B'F$ and ΔMPF are similar.

$$\therefore \frac{A'B'}{MP} = \frac{B'F}{PF}$$

But MP = AB

$$\therefore \frac{A'B'}{AB} = \frac{B'F}{PF} \cdots\cdots\cdots\cdots (1)$$

Also triangles $A'B'P$ and ABP are similar.

$$\therefore \frac{A'B'}{AB} = \frac{B'P}{BP} \cdots\cdots\cdots\cdots (2)$$

From equation (1) and (2)

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

$$\Rightarrow \frac{B'P-PF}{PF}=\frac{B'P}{BP}\ldots\ldots(3)$$

By applying new cartesian sign Convention,

$B'P=-v,\ PF=-f,\ BP=-u$

$\therefore \text{equ}(3)\rightarrow$

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

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

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

Dividing by 'v', we get

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

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

This is called mirror formula.

8. Define **linear magnification produced by a spherical mirror.**

Ans: It is the ratio of height of the image to the height of the object.

$$m=\frac{h_i}{h_o}$$

We can prove that,

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

<u>Significance of magnification 'm'</u>

- When 'm' is positive, the image is erect (virtual)
- When 'm' is negative, the image is inverted (real)
- For enlarged image, m>1
- For diminished image, m<1

9. What are the **applications** (uses) **of spherical mirrors**?

Ans: <u>Concave mirrors</u>

i. Used as reflectors of table lamps to direct light in a given area.
ii. Concave mirrors of large aperture are used in reflecting type astronomical telescopes.
Iii. Shaving mirrors are made slightly concave to get erect enlarged image of the face.

<u>Convex mirrors</u>

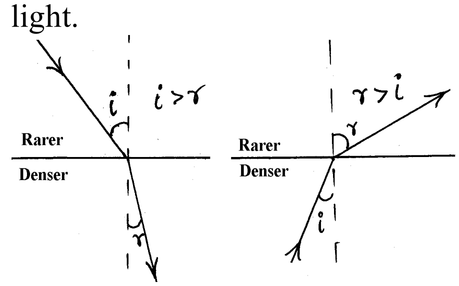
They are used in automobiles as rear view mirrors because of the two reasons:

i) A convex mirror always produces an erect image.
ii) The image is diminished in size, so that it gives a wide field of view.

<u>Refraction of Light</u>

10. What is **refraction**?

Ans: The direction of propagation of an obliquely incident ray of light that enters the other medium, changes at the interface of the two media. This phenomenon is called refraction of light.



11. State the **laws of refraction.**

Ans:

i) Incident ray, refracted ray, and the normal to the point of incidence lie in the same plane.

ii) Snell's law: - The ratio of the sine of the angle of incidence to the sine of the angle of refraction is a constant.

i.e., $\frac{\sin i}{\sin r} = \text{Constant}$

$$\frac{\sin i}{\sin r} = \frac{n_2}{n_1} = n_{21}$$

12. Define **Refractive Index (n)** of a medium

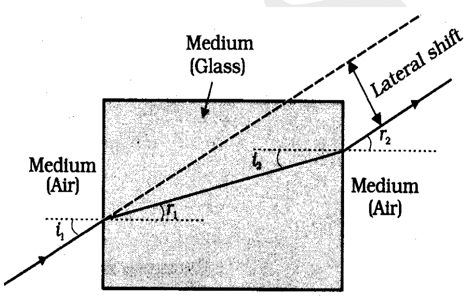
Ans: Refractive index of a medium is defined as the ratio of velocity of light vacuum to the velocity of light in the medium.

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

$n_{air} = 1$	$n_{glass} = 1.5$
$n_{water} = 1.33$	$n_{diamond} = 2.42$

13. Draw the **refraction through a glass slab** and show that the incident ray and emergent ray are parallel.

Ans: Let a glass slab of refractive index n_2 be placed in air of refractive index n_1



At the air- glass interface, we can write the Snell's law:

$$\frac{n_2}{n_1} = \frac{\sin i_1}{\sin r_1} \text{..........(1)}$$

At the glass-air interface, we can write the Snell's law:

$$\frac{n_1}{n_2} = \frac{\sin i_2}{\sin r_2}$$

Taking reciprocal, we get

$$\frac{n_2}{n_1} = \frac{\sin r_2}{\sin i_2} \text{..........(2)}$$

From equations (1) and (2),we get

$$\frac{\sin i_1}{\sin r_1} = \frac{\sin r_2}{\sin i_2} \text{..........(3)}$$

But from the figure, it is clear that $r_1 = i_2$

$$\therefore \text{eqn}(3) \rightarrow \sin i_1 = \sin r_2$$
$$\Rightarrow i_1 = r_2$$

i.e., angle of incidence = angle of emergence

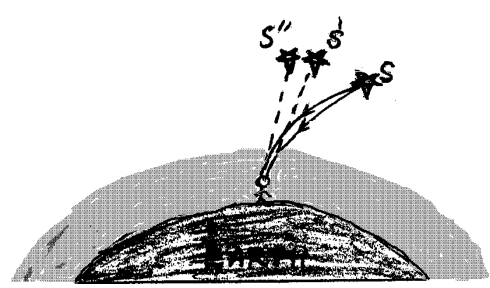
Or the incident ray and the emergent ray are parallel

APPLICATIONS OF REFRACTION

14. What are the applications of refraction?

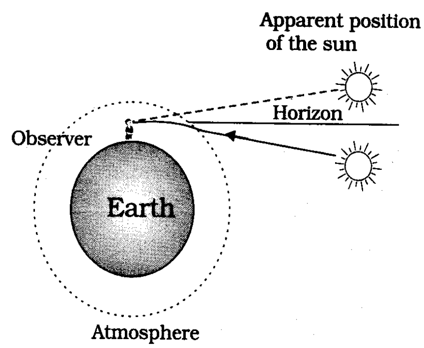
Ans:

i) Twinkling of stars



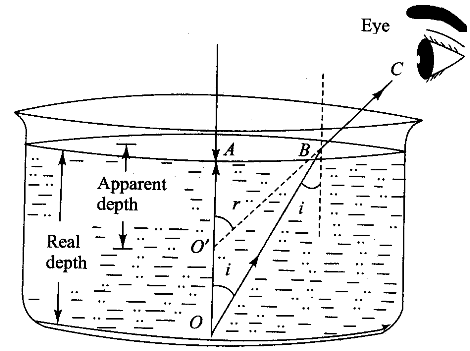
As we go up, the density of air in the atmosphere continuously decreases. Therefore, the light coming from the star is travelling from a rarer part of air to denser part. Therefore, it bends towards the normal. Thus we see the star at an apparent position. But the density of air in the atmosphere continuously changes. Therefore the apparent position also continuously changes. Thus the star appears to be twinkling.

ii) Early sunrise and delayed sunset



As we go up, the density of air in the atmosphere continuously decreases. Therefore the light coming from the sun is travelling from a rarer medium to denser medium. Therefore it bends towards the normal. Thus we see the sun at an apparent position raised above the horizon. This is the reason for early sunrise and delayed sunset.

iii) Apparent depth



If an object in a denser medium is viewed from a rarer medium the image appears to be raised towards the surface.

Refractive index,

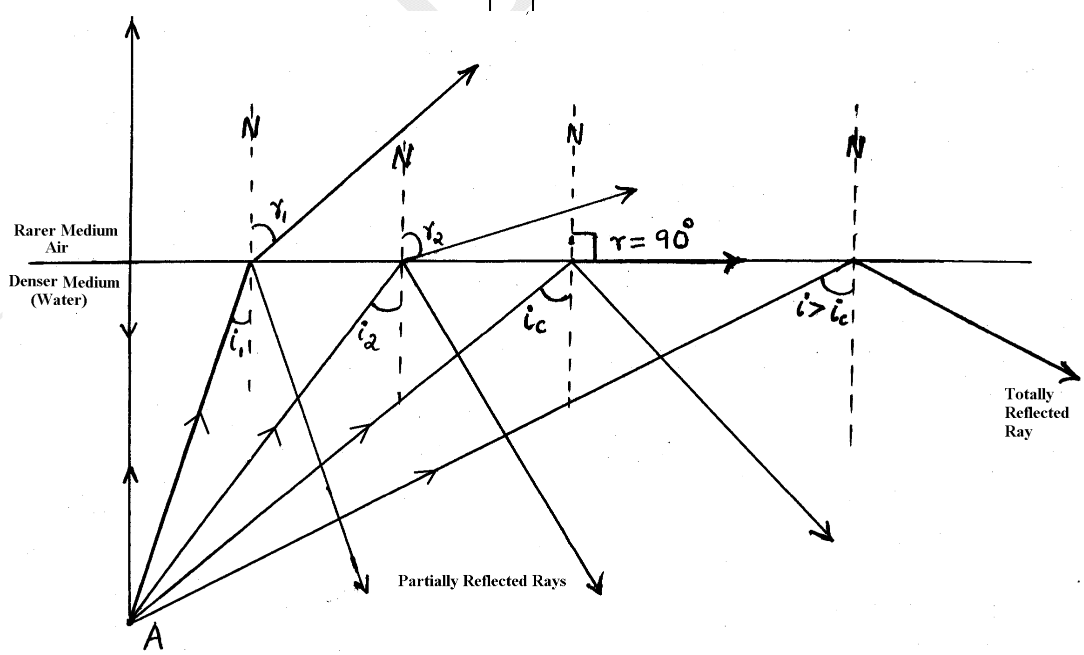
$$n_{21} = \frac{\text{Real depth}}{\text{Apparent depth}}$$

$$\text{Apparent depth} = \frac{\text{Real depth}}{n_{21}}$$

Total Internal Reflection (TIR)

15. Explain total internal reflection?

Ans:



When a ray of light is incident on the surface separating two media, a part of light is reflected and the other part is transmitted (refracted). When light travel from a denser medium to a rarer medium, the refracted ray bends away from the normal. As the angle of incidence increases, the angle of refraction also increases. For a particular angle of incidence the angle of refraction becomes 90^0. If the angle of incidence is further increased the ray gets totally reflected into the same medium. This phenomenon is called total internal reflection.

16. Define **total internal reflection.**

Ans: When light travels from a denser medium to a rarer medium, if the angle of incidence is greater than the critical angle it gets totally reflected in to the same medium. This phenomenon is called total internal reflection.

17. What are the necessary **conditions for total internal reflection** to occur?

Ans:

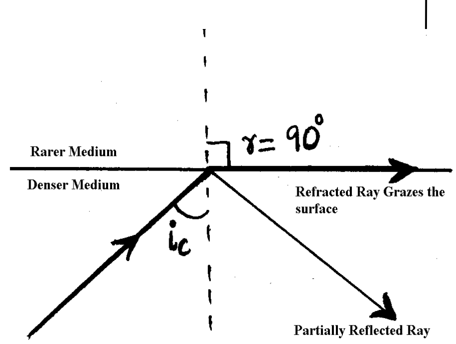
i) The light ray should travel from denser medium to rarer medium.
ii) The angle of incidence should be greater than the critical angle.

18. Define **critical angle**.

Ans: It is the angle of incidence in the denser medium for which the angle of refraction becomes 90^0.

19. Derive the relation between **critical angle** and **refractive index** of the denser medium?

Ans:



$$\text{By Snell's law, } \frac{\sin i}{\sin r} = \frac{n_1}{n_2},$$

[Here the ray goes from n_2 to n_1]

When $i = i_c$, $r = 90^0$

$$\frac{\sin i_c}{\sin 90^0} = \frac{n_1}{n_2}$$

$$\frac{\sin i_c}{1} = \frac{n_1}{n_2}$$

$$\frac{n_2}{n_1} = \frac{1}{\sin i_c}$$

If the rarer medium is air,

then $n_1 = 1$ and let $n_2 = n$

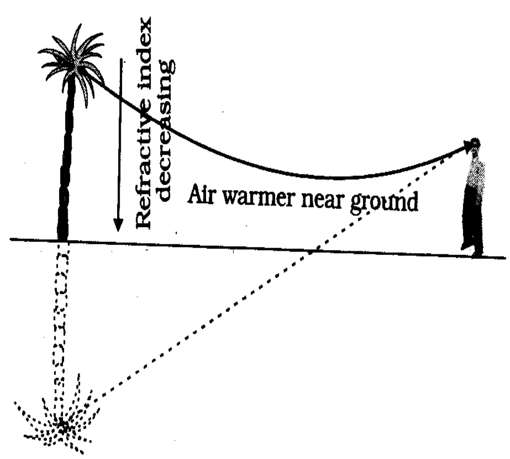
$$n = \frac{1}{\sin i_c}$$

APPLICATIONS OF TIR

20. What are the applications of total internal reflection?

Ans:

i) Mirage



In hot sunny days the layer of air in contact with sand in a desert (or tar road), becomes hot and rarer. The upper layers are comparatively cooler and denser. Therefore the ray of light coming down from a distant object like a tree is travelling from a denser medium to a rarer medium and it suffers total internal reflection. Thus for an observer the image of a distant object is seen inverted. This makes the illusion that the tree is standing near a pool of water. This phenomenon is called mirage.

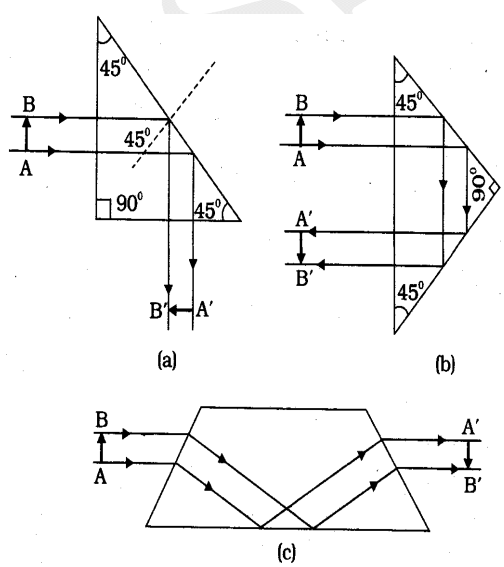
ii) Brilliance of diamond

The refractive index of diamond is very high [n = 2.42] and the critical angle is very low [c = 24.4^0]. Moreover the faces of diamond are cut in such a way that, a ray entering the diamond, undergoes multiple total internal reflections inside it and finally comes out only through few faces. These faces appear glittering.

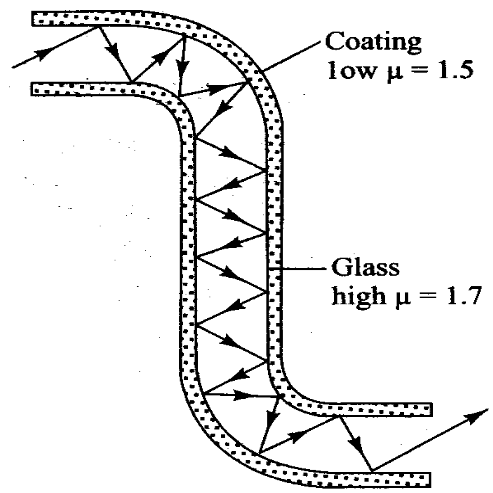
iii) Total reflecting prisms

Total reflecting prisms are designed to bent light or to invert images without changing their size, based on total internal reflection.

(Used in periscopes)



(iv) Optical fibres



Core of optical fibre is made up of glass or quartz [n = 1.7]. There is a thin layer of outer coating called **cladding**. Cladding is made up of a material of lower refractive index [n = 1.5]. When a ray of light enters the fibre at one end, it undergoes multiple total internal reflections inside the fibre and finally comes out at the other end.

21. What are the uses of Optical fibres?

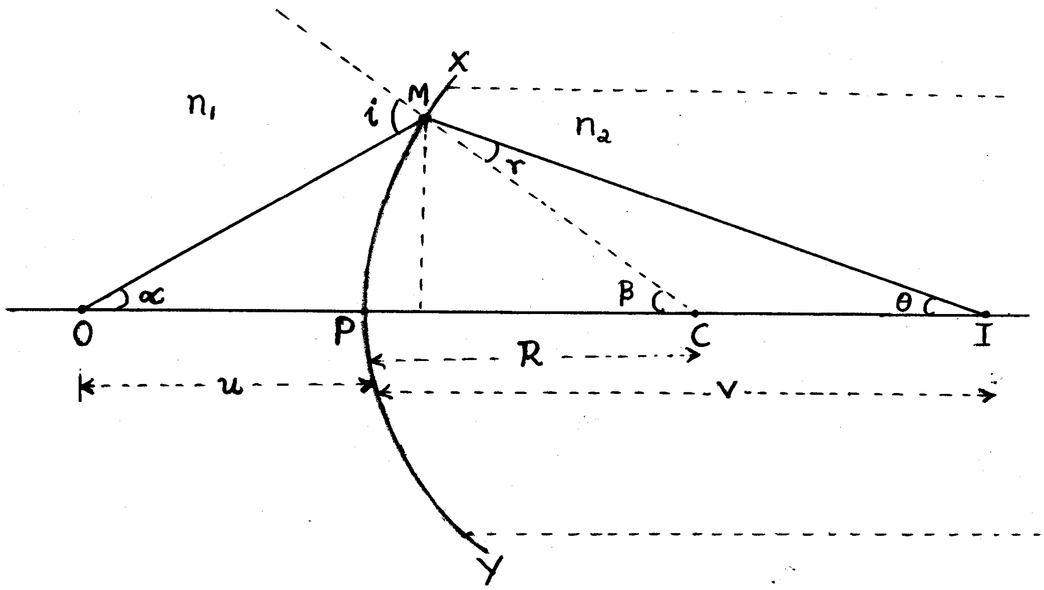
Ans:

i) Optical fibres are used as a light pipe for visual examination of internal organs.
ii) Optical fibres are used to carry electrical signals which are converted to light.

22. Derive the **curved surface formula**.

Or Derive the expression for refraction at a convex surface.

Ans:



Consider a convex surface XY separating two transparent media of refractive indices n_1 and n_2. Let O be a point object in medium n_1 on the principal axis of the convex surface. I is the image of O formed on the other side of the convex surface.

Ans:

We know that

for small angles,

$\tan\theta \approx \theta$

From ΔOMP, $\tan\alpha \approx \alpha = \frac{PM}{PO}$

From ΔPCM, $\tan\beta \approx \beta = \frac{PM}{PC}$

From ΔPMI, $\tan\theta \approx \theta = \frac{PM}{PI}$

From,

ΔOMC,

exterior angle = sum of opposite interior angles

$$i = \alpha + \beta$$

$$= \frac{PM}{PO} + \frac{PM}{PC} \text{.............(1)}$$

From ΔIMC,

$$\beta = r + \theta$$

$$\Rightarrow r = \beta - \theta$$

$$= \frac{PM}{PC} - \frac{PM}{PI} \text{.........(2)}$$

By Snell's law,

$$\frac{\sin i}{\sin r} = \frac{n_2}{n_1}$$

If i and r are small,

$\sin i \approx i$ and $\sin r \approx r$

$$\frac{i}{r} = \frac{n_2}{n_1}$$

$$n_1 i = n_2 r$$

Substituting for i and r, we get

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

$$n_1\frac{PM}{PO} + n_1\frac{PM}{PC} = n_2\frac{PM}{PC} - n_2\frac{PM}{PI}$$

$$\frac{n_1}{PO} + \frac{n_1}{PC} = \frac{n_2}{PC} - \frac{n_2}{PI}$$

$$\frac{n_1}{PO} + \frac{n_2}{PI} = \frac{n_2 - n_1}{PC} \text{.............(3)}$$

By cartesion sign convertion

PO = -u, PI = v, PC = R

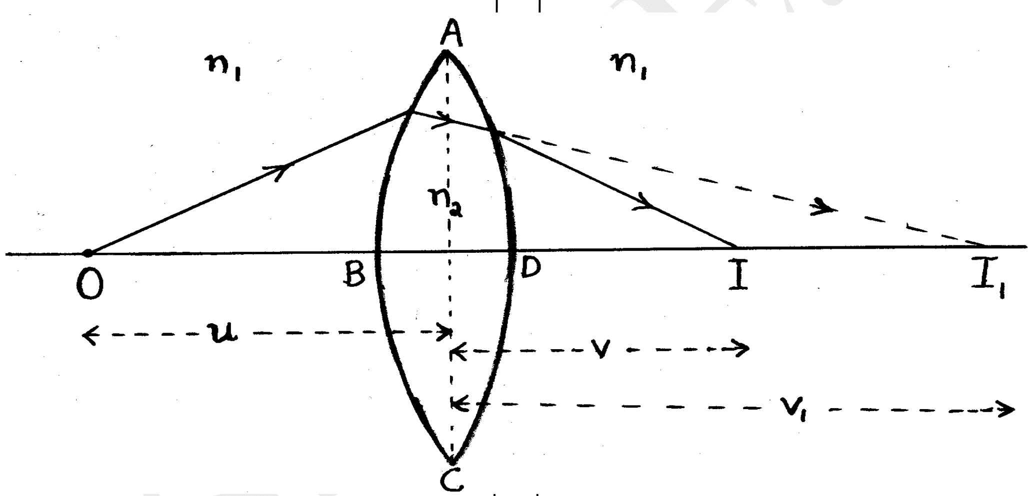
$$(3) \rightarrow \frac{n_1}{-u} + \frac{n_2}{v} = \frac{n_2 - n_1}{R}$$

i.e., $\boxed{\frac{n_2}{v} - \frac{n_1}{u} = \frac{n_2 - n_1}{R}}$

This is the eqn for refraction at a convex surface.

23. Derive **Lens Maker's formula**. Also obtain the **thin lens formula**.

Ans:



Consider a point object placed on the principal axis of a convex mirror. The image formation has two steps:

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

(ii) The image formed by the first refracting surface acts as the virtual object for the second refracting surface and the final image is formed at I

We have the curved surface formula

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

<u>For refraction at the surface ABC</u>

Light ray travels from n_1 to n_2.

O is the object and $\mathbf{I_1}$ is the image. Let the radius of curvature of ABC be $\mathbf{R_1}$

$u \rightarrow u_1, v \rightarrow v_1, R \rightarrow R_1$

$$\therefore \frac{n_2}{v_1} - \frac{n_1}{u} = \frac{n_2 - n_1}{R_1} \text{...........(1)}$$

<u>For refraction at the surface ADC</u>

Light ray travels from n_2 to n_1.

$\mathbf{I_1}$ is the object and **I** is the image. Let the radius of curvature of ADC be $\mathbf{R_2}$

$n_1 \leftrightarrow n_2, u \rightarrow v_1, v \rightarrow v, R_1 \rightarrow R_2$

$$\therefore \frac{n_1}{v} - \frac{n_2}{v_1} = \frac{n_1 - n_2}{R_2} \text{........ (2)}$$

$$\frac{n_1}{v} - \frac{n_2}{v_1} = \frac{-(n_2 - n_1)}{R_2} \text{........ (3)}$$

$(1) + (2) \rightarrow$

$$\frac{\cancel{n_2}}{\cancel{v_1}} - \frac{n_1}{u} + \frac{n_1}{v} - \frac{\cancel{n_2}}{\cancel{v_1}} = \frac{n_2 - n_1}{R_1} - \frac{n_2 - n_1}{R_2}$$

$$\frac{n_1}{v} - \frac{n_1}{u} = (n_2 - n_1)\left[\frac{1}{R_1} - \frac{1}{R_2}\right]$$

Dividing by n_1,

$$\frac{1}{v} - \frac{1}{u} = \left(\frac{n_2 - n_1}{n_1}\right)\left[\frac{1}{R_1} - \frac{1}{R_2}\right]$$

$$\frac{1}{v} - \frac{1}{u} = \left(\frac{n_2}{n_1} - 1\right)\left[\frac{1}{R_1} - \frac{1}{R_2}\right]$$

$$\frac{1}{v} - \frac{1}{u} = (n_{21} - 1)\left[\frac{1}{R_1} - \frac{1}{R_2}\right] ....(4)$$

If the object is at infinity,

image formed at the principal focus.

i.e., If $u = \infty \quad v = f$

$$\therefore\ (4) \rightarrow \frac{1}{f} - \frac{1}{\infty} = (n_{21} - 1)\left[\frac{1}{R_1} - \frac{1}{R_2}\right]$$

$$\therefore \frac{1}{f} = (n_{21} - 1)\left[\frac{1}{R_1} - \frac{1}{R_2}\right] ....(5)$$

This is lens makers formula

If the first medium is air,

$n_1 = 1$ and let $n_2 = n$, then

$$n_{21} = \frac{n_2}{n_1} = n$$

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

from (5) and (4)

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

This is called thin lens formula.

24. Define **linear magnification of a lens.**

Ans: Linear magnification,

$$m = \frac{\text{Hight of the image}}{\text{Hight of the object}}$$

$$m = \frac{h_i}{h_o}$$

m is positive for virtual images and negative for real images.

We can prove that,

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

25. Define **power of a lens** (P)

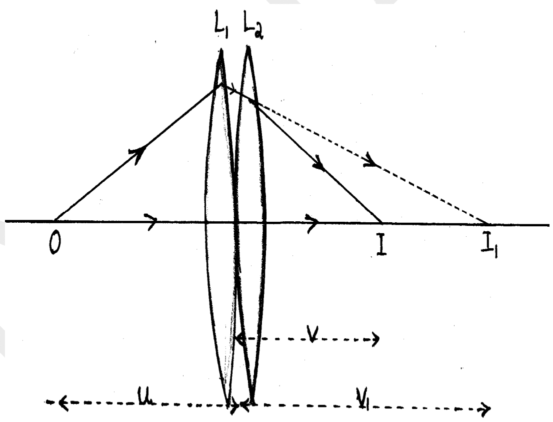
Ans: **Power of a lens is the reciprocal of focal length expressed in metre.**

$$P = \frac{1}{f(\text{in metre})}$$

SI unit of power of lens is diopetre (D)

26. Derive an expression for the effective (i) focal length (ii) power for the **combination of two thin lenses in contact**. Also write equation for effective magnification.

Ans:



For the 1st lens, object is at 'O' and image is at 'I_1'.

$u \rightarrow u,\ v \rightarrow v_1,\ f \rightarrow f_1$

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

For the second lens object is I_1 and image is I

$u \rightarrow v_1,\ v \rightarrow v,\ f \rightarrow f_2$

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

$(1) + (2) \Rightarrow$

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

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

If the combination of the two lenses is replaced by a single lens of focal length **f** such that the image of the same object is formed at the same position. Then we have

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

from (3) and (4)

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

Power, $P = P_1 + P_2$

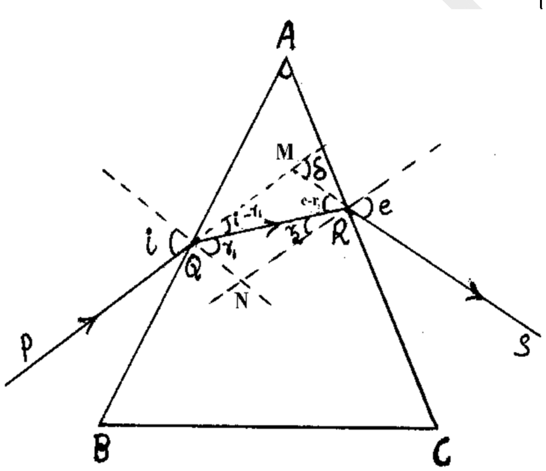
Magnification $m = m_1 \times m_2$

In general,

$$\boxed{\begin{array}{l} \frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2} + \frac{1}{f_3} + \ldots\ldots\ldots \\ P = P_1 + P_2 + P_3 + \ldots\ldots\ldots \\ m = m_1 \times m_2 \times m_3 \times \ldots\ldots\ldots \end{array}}$$

27. Explain the **refraction through a prism**. Derive an expression for the refractive index of the material of the prism (**prism formula**)

Ans:



Consider a triangular prism ABC. AB and AC are the refracting surfaces and BC is the base of the prism.

A $\rightarrow$ Angle of the prism

PQ $\rightarrow$ incident ray

QR $\rightarrow$ Refracted ray

RS $\rightarrow$ emergent ray

In the quadrilateral AQNR

$\angle Q + \angle R = 180^0$

$\therefore A + \angle N = 180^0 \ldots\ldots (1)$

from Δ QNR,

$r_1 + r_2 + \angle N = 180^0 \ldots (2)$

from (1) and (2), we get

$r_1 + r_2 = A \ldots\ldots\ldots\ldots\ldots (3)$

from Δ QRM,

exterior angle = sum of opposite interior angles

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

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

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

$[\text{from (3) } r_1 + r_2 = A]$

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

or

$i + e = A + \delta \ldots\ldots\ldots (4)$

If we increase the angle of incidence, the angle of deviation decreases, reaches a minimum value and then increases.

At the minimum deviation condition

$i = e$, $r_1 = r_2 = r$ and $\delta = D_m$

$D_m \rightarrow$ angle of minimum

At the minimum Deviation position

(3) $\rightarrow r + r = A$

$2r = A$

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

(4) $\rightarrow i + i = A + D_m$

$2i = A + D_m$

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

By snell's law,

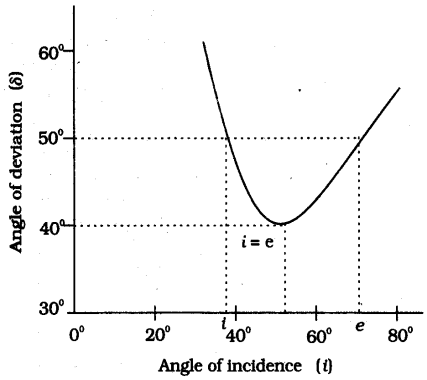
refractive index of the material of the prism,

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

$$\boxed{n_{21} = \frac{\sin\left(\frac{A+D_m}{2}\right)}{\sin\left(\frac{A}{2}\right)}}$$

28. Draw the **i –δ Curve**. Define angle of minimum deviation.

Ans:



It is the graph between angle of incidence (i) and angle of deviation (δ).

As the angle of incidence increases the angle of deviation decreases at first, reaches a minimum value, and then increases. The minimum value of deviation is called angle of minimum deviation.

29. Write the **prism formula for a small angled prism.**

Ans: We have the prism formula:

$$n_{21} = \frac{\sin\left(\frac{A+D_m}{2}\right)}{\sin\left(\frac{A}{2}\right)}$$

For a small angled prism D_m is also very small, and then we have

$$n_{21} = \frac{\sin\left(\frac{A+D_m}{2}\right)}{\sin\left(\frac{A}{2}\right)} \approx \frac{\frac{A+D_m}{2}}{\frac{A}{2}}$$

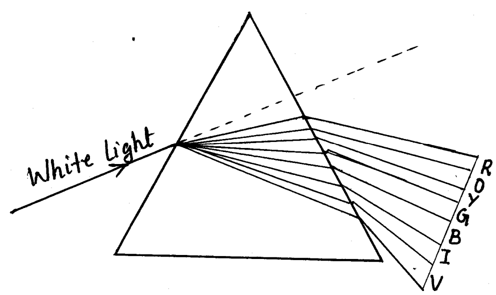
$$\Rightarrow n_{21} = \frac{A+D_m}{A} = 1 + \frac{D_m}{A}$$

$$\Rightarrow \frac{D_m}{A} = n_{21} - 1$$

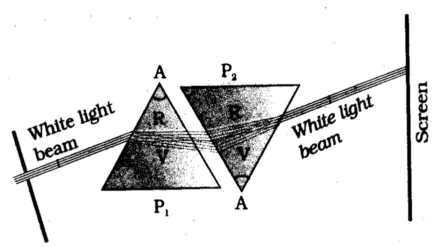
$$\Rightarrow \boxed{D_m = (n_{21} - 1)A}$$

30. Explain **dispersion of light**

Ans: The phenomenon of splitting of composite light into its component colours is called dispersion.



When white light is passed through a prism, it splits into its seven component colours **(VIBGYOR).**



If we place a second prism in an inverted position, close to the first prism, the second prism recombines the colours and we get white light.

31. What is the cause of dispersion?

Ans: Colour of light is associated with wavelength of light. Dispersion takes place because the refractive index of medium is different for different wave lengths (colours). Refractive index of the medium for violet light is greater than that for red light. So red light travels faster than violet in a prism.

32. Distinguish between **dispersive medium and non-dispersive medium.**

Ans: The medium in which the different colours of light travel with different velocities is called a dispersive medium.

Eg: Glass

The medium in which the different colours of light travel with the same velocity is called non-dispersive medium.

Eg: Vacuum

Rainbow

33. How rainbow is formed ?

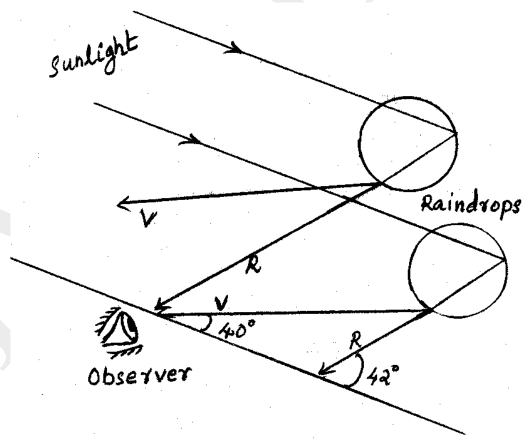
Ans: Rainbow is formed due to the combined effect of dispersion, refraction and total internal reflection of sunlight by the rain drops.

34. What is the condition for a person to see rainbow?

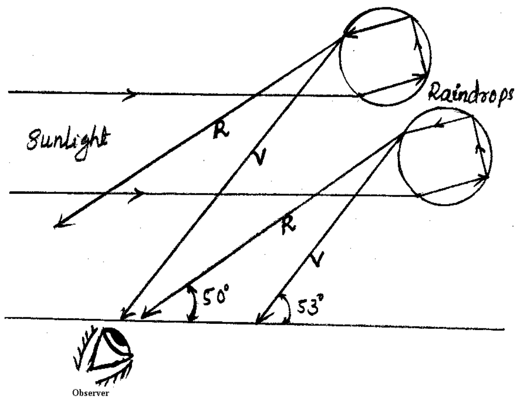
Ans: The condition for observing a rainbow is that the sun should be shining in one part of the sky while it is raining in the opposite part of the sky. An observer can therefore see a rainbow only when his back is towards the sun.

35. What are the differences in the formation and appearance of primary and secondary rainbows?

Ans:



A primary rainbow is a result of three-step process: refraction, total internal reflection and again refraction. In a primary rainbow the violet light emerges from raindrops at an angle of 40^0 relative to the incoming sunlight and red light emerges at an angle of 42^0. Thus an observer sees a primary rainbow with red colour on the top and violet on the bottom.



A secondary rainbow is a result of four- step process: refraction, total internal reflection, again total internal reflection and refraction. In a secondary rainbow the violet light emerges from the raindrops at an angle of 53^0 relative to the incoming sunlight and red light emerges at an angle of 50^0. Thus an observer sees a secondary rainbow with violet colour on the top and red on the bottom. Secondary rainbow is fainter than primary rainbow.

Scattering

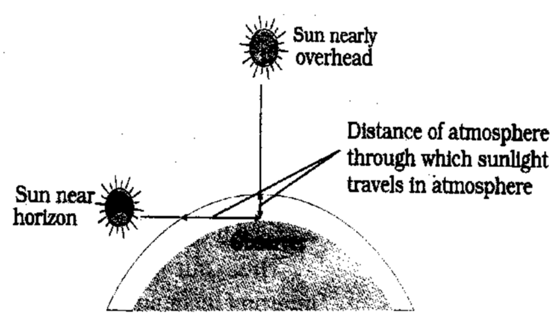
33. What is **scattering**?

Ans: The irregular and partial reflection of light at the dust particles and air molecules in the atmosphere is called scattering.

34. State **Rayleigh's scattering law.**

Ans: According to Rayleigh's scattering law the intensity of the scattered light is inversely proportional to forth power of wave length.

$$I_s \alpha \frac{1}{\lambda^4}$$



35. Why sky appears blue?

Ans: When sun light comes through the atmosphere it undergoes scattering at the dust particles and air molecules.

Thus the low wavelength region (bluish region) is more scattered. Since our eyes are more sensitive to blue than violet, sky appears blue.

36. Why sun appears red during sunrise and sunset?

Ans: During sunrise and sunset light has to travel more distance through the atmosphere. Thus most part of low wavelength region is scattered away and the least scattered longer wavelength region (reddish region) reaches our eye. Therefore the sun appears red.

37. Why sea appears blue?

Ans: It is due to the scattering of sunlight at the water molecules and dust particles. By Rayleigh's scattering law, low wavelength region (blue region) is more scattered. Therefore, sea appears blue.

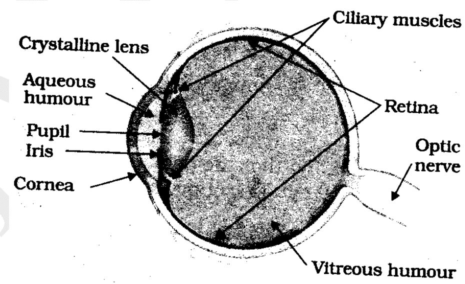
38. Why cloud appears white?

Ans: The particles of cloud are comparatively bigger in size. Therefore, all colours of sunlight are almost equally scattered. Thus clouds appear white.

Optical Instruments

39. Briefly explain the working of our eye.

Ans: Light enters the eye through a curved front surface, the **cornea**. It passes through the **pupil** which is the central hole in the **iris**. The size of the pupil can change under control of muscles. The light is further focuses by the **eye lens** on the **retina**. The image is formed on the retina. The retina contains **rod cells** and **cone cells** which senses light intensity and colour respectively.



40. What is meant by **accommodation**?

Ans: The curvature and hence the focal length of the eye lens can be adjusted by the ciliary muscles. This ability of the eye is called accommodation.

41. Define **near point** of eye

Ans: If the object is too close to the eye, the lens cannot curve enough to focus the image on to the retina, and image is blurred. *The closest distance for which the lens can focus light on the retina is called least distance of distinct vision or near point.* For normal eye it is about **25cm**.it is denoted by **D**.

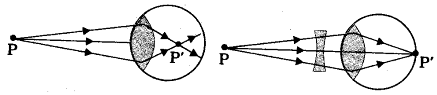
42. What is **presbyopia**?

Ans: The least distance of distinct vision increases with age, because of the decreasing effectiveness of ciliary muscles and the loss of flexibility of the lens. Thus if an elderly person tries to read a book at about 25cm, the image appears blurred. This defect of the eye is called presbyopia.

43. What is near-sightedness (**short sight**) or **myopia**? How can it be corrected?

Ans: In certain eyes, the light from a distant object arriving at the eye lens may get converged at a point in front of the retina. This type of defect is called near-sightedness or myopia.

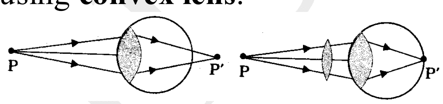
This defect can be compensated by using a **concave lens**.



44. What is far sightedness (**long sight**) or **hypermetropia**?

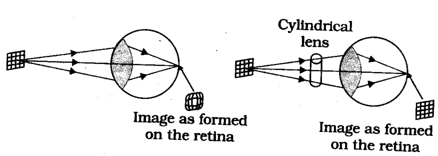
Ans: In certain eyes, the light from a near object is focused at a point behind the retina. This defect is called farsightedness or hypermetropia.

This defect can be corrected by using **convex lens**.



45. What is **astigmatism**?

Ans: Astigmatism occurs when the cornea is not spherical in shape. This can be corrected using cylindrical lens.



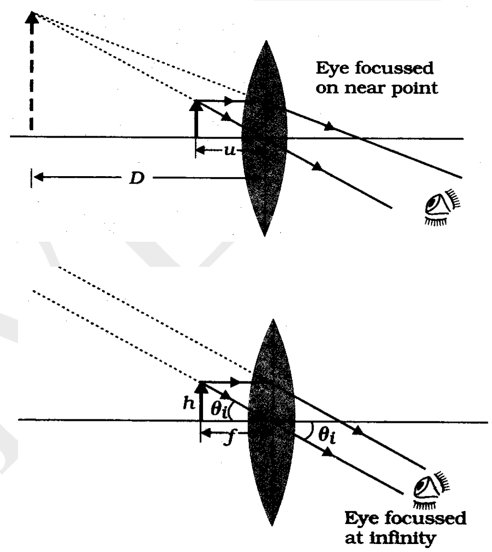
Microscopes

46. What is the use of a microscope?

Ans: Microscope is used to get magnified images of near objects.

47. By drawing a neat ray diagram, explain the image formation in a **simple microscope**. Derive the equation for magnification. Write the nature of the image formed? What is the limitation of a simple microscope?

Ans:



Converging lens (convex lens) of small focal length is used as a simple microscope. If the object is at the focus, the image is at infinity. If the object is brought closer, then the image is formed at a distance closer than infinity. The position of the object can be adjusted so that the image is formed at the least distance of distinct vision.

Magnification

$$m = \frac{v}{u} = v.\frac{1}{u} \qquad \left| \frac{1}{v} - \frac{1}{u} = \frac{1}{f} \right.$$

$$= v.\left(\frac{1}{v} - \frac{1}{f}\right) \qquad \left| \frac{1}{v} - \frac{1}{f} = \frac{1}{u} \right.$$

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

If the image is formed at the near point, $v = -D$

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

If the image is formed at infinity $\boxed{m = \frac{D}{f}}$

Nature of the image

The image is erect, magnified and virtual.

Limitation of simple microscope

The magnification of the simple microscope, m≤9. To get further magnification we use compound microscope.

48. By drawing a neat ray diagram explain the image formation in a **compound microscope**. What is the nature of image formed? Derive an expression for the magnification produced by compound microscope.

Ans:

Compound microscope consists of two convex lenses objective and eye piece. The focal length and aperture of objective is less than those of eye piece.

When an object is placed beyond the focal length of the objective, a magnified, real and inverted image is formed beyond the '2f' of the objective on the other side. The distance between the lenses is adjusted so that this image falls within the focal length of the eye piece. Now the eyepiece acts as a simple microscope and the final image is formed at the least distance of distinct vision.

Nature of final image

The final image is enlarged, inverted and virtual w. r. t. the object.

Magnification

If $m_0 \rightarrow$ Magnification of object and

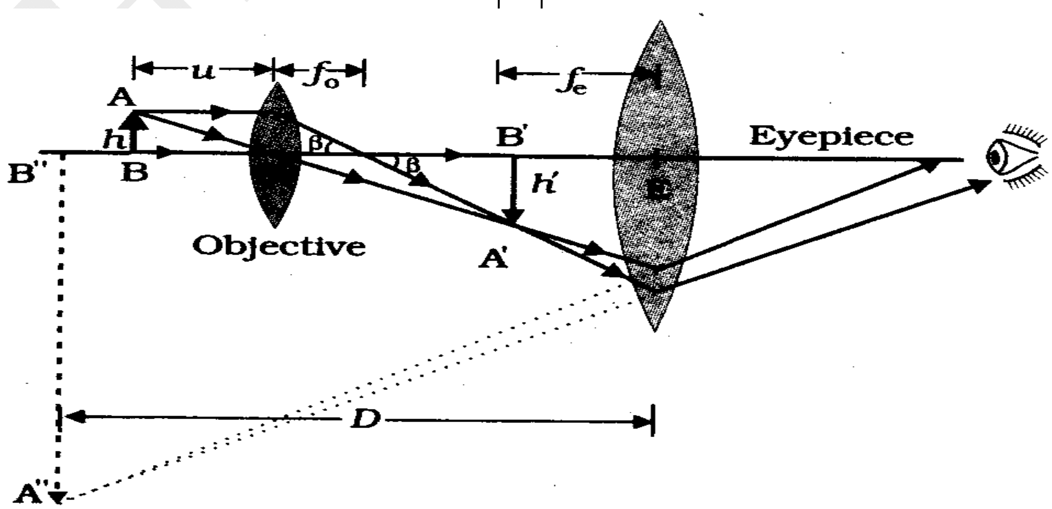
$m_e \rightarrow$ Magnification of image

Then, the magnification of the compound microscope is given by

$$m = m_0 . m_e$$

$$= \left(\frac{v_0}{u_0}\right)\left(1 + \frac{D}{f_e}\right)$$

Since the object is placed very near to the focus of the objective, $u_0 \approx f_0$ and $v_0 \approx L$, length of microscope tube



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

If the final image is formed at infinity

$$\boxed{m = \left(\frac{L}{f_o}\right)\left(\frac{D}{f_e}\right)}$$

From the above equation, it is very clear that, to achieve a large magnification of a small object, the objective and eyepiece should have small focal lengths.

49. Define the resolving power of a microscope.

Ans: Resolving power of a microscope is defined as the reciprocal of minimum separation between two point objects which can be distinctly seen by it.

$$R.P. = \frac{1}{d_{min}} = \frac{2n\sin\beta}{1.22\lambda}$$

Where λ is the wavelength of the light used, n is the refractive index of the transparent medium between the object and the objective of the microscope, and β is half of the angle subtended by the diameter of the objective lens at the focus of the microscope.

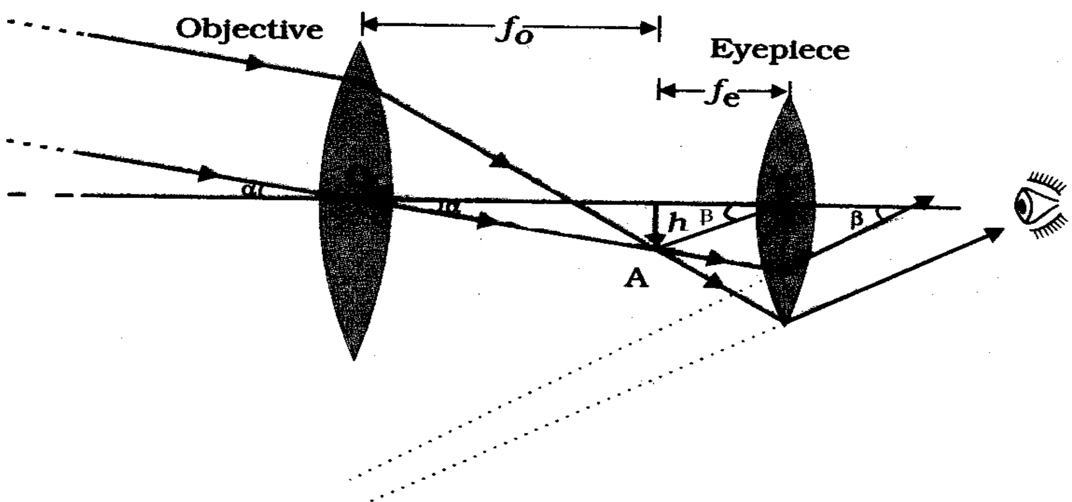
The quantity $n\sin\beta$ is called the numerical aperture.

Telescopes

50. By drawing a neat ray diagram explain the image formation in a **refracting type telescope**. Derive an expression for the magnification produce by it. What is the nature of the image?

Ans:

Use: - Telescope is used to provide angular magnification of distant



objects.

In a telescope there are two convex lenses- the objective and eyepiece. The objective has a large focal length and much larger aperture than the eyepiece.

Light from a distant object enters the objective and a real and inverted image is formed at its focus (F_o). The eyepiece magnifies this image producing a final inverted image with respect to the object.

Magnification(m)

The magnifying power 'm' is the ratio of the angle 'β' subtended by the final image at eye to the angle 'α' subtended by the object at the lens or eye.

$$m = \frac{\beta}{\alpha} \quad \text{But we have,}$$

$$\beta \approx \tan\beta = \frac{h}{f_e} \text{ and } \alpha \approx \tan\alpha = \frac{h}{f_0}$$

$$\therefore m = \frac{h/f_e}{h/f_0} = \frac{f_0}{f_e} \qquad \boxed{m = \frac{f_0}{f_e}}$$

The above equation shows that to have greater magnification for the telescope, the focal length of the objective should be large and that of the eye piece should be small.

Nature of final image

The final image is enlarged, inverted and virtual w. r. t. the object.

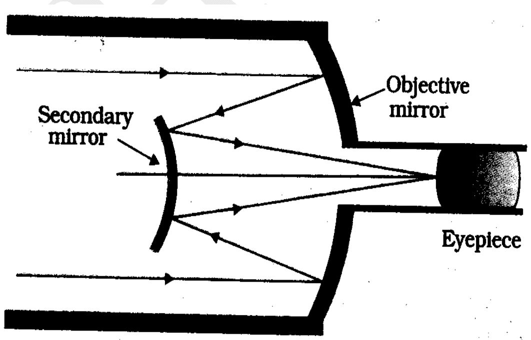
51. Give the expression for the length of an astronomical telescope.

Ans: The length of a telescope is the separation between the objective lens and eye piece.

$$L = f_o + f_e$$

52. By drawing a neat ray diagram explain the image formation by a **reflecting type telescope**.

Ans:



In reflecting type telescopes, a concave mirror is used as objective instead of convex lens.

The light from the object is reflected by the concave mirror to the secondary mirror, which again reflects the light into the eyepiece. This type of reflecting telescope is known as cassegrain telescope.

53. What are the **disadvantages of refracting telescope**?

Ans:

i) In refracting telescopes, to get better resolving power objective lens of large aperture is needed. Big lenses are very heavy and therefore, difficult to support by their edges.

ii) It is difficult and expensive to make such large sized lenses.

iii) Chromatic aberration is a main defect in a lens.

54. What are **the advantages of a reflecting type telescope**?

Ans:

i) There is no chromatic aberration in a mirror.

ii) If a parabolic mirror is chosen as the objective, spherical aberration can be removed.

iii) Mechanical support is much less of a problem since a mirror weighs much less than a lens of equivalent optical quality, and can be supported over its entire back surface, not just over its rim.

55. How can you remove spherical aberration in a reflecting type telescope?

Ans: Spherical aberration can be removed by using parabolic concave mirror.

56. Define the resolving power of a telescope. Give its equation

Ans: The resolving power of a telescope is defined as the reciprocal of smallest angular separation between two distant objects whose images are distinctly separated by the telescope. $R.P. = \frac{1}{\Delta\theta} = \frac{d}{1.22\lambda}$, where d is the diameter of telescope objective and λ is the wavelength of light used. $\Delta\theta$ is called the limit of resolution of the telescope.

Problems

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

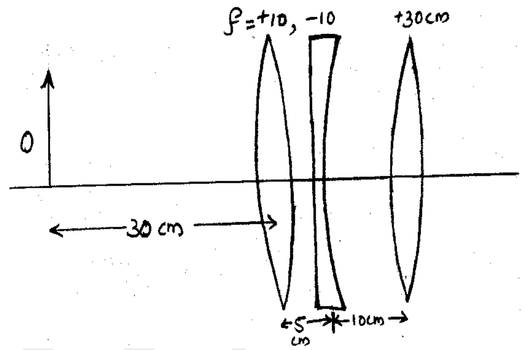
2. Light from a point source in air falls on a spherical glass surface (**n = 1.5** and radius of curvature = **20 cm**). The distance of the light source from the glass surface is **100 cm**. At what position the image is formed?

3. A magician during a show makes a glass lens with **n = 1.47** disappears in a trough of liquid. What is the refractive index of the liquid? Could the liquid be water?

4. **(i)** If **f = 0.5 m** for a glass lens, what is the power of the lens?
(ii) The radii of curvature of the faces of a double convex lens are **10 cm** and **15 cm**. What is the refractive index of glass?

(iii) A convex lens has **20 cm** focal length in air. What is focal length in water? (Refractive index of air - water = **1.33**, refractive index for air-glass = **1.5**)

5. Find the position of the image formed by the lens combination given in the fig.



6. What focal length should the reading spectacles have for a person for whom the least distance of distinct vision is **50 cm**?

7. The far point of a myopic person is **80 cm** in front of the eye. What is the power of the lens required to enable him to see very distant object clearly?

8. The near point of a hypermetropic person is **75cm** from the eye. What is the power of the lens required to enable the person to read clearly a book held at **25 cm** from the eye?

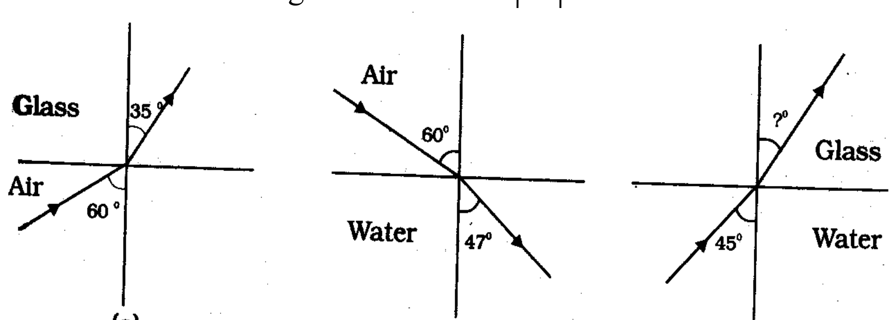
9. A small candle, **2.5 cm** in size is placed at **27 cm** in front of a concave mirror of radius of curvature **36 cm**. At what distance from the mirror should a screen be placed in order to obtain a sharp image? Describe the nature and size of the image. If the candle is moved closer to the mirror, how would the screen have to be moved?

10. A small bulb is placed at the bottom of a tank containing water to a depth of 80cm. What is the area of the surface of water through which light from the bulb can emerge out? Refractive index of water is 1.33. (Consider the bulb to be a point source.)

11. A prism is made of glass of unknown refractive index. A parallel beam of light is incident on a face of the prism. The angle of minimum deviation is measured to be 40^0. What is the refractive index of the material of the prism? The refractive angle of prism is 60^0. If the prism is placed in water (Refractive index 1.44), predict the new angle of minimum deviation of a parallel beam of light.

12. Double convex lenses are to be manufactured from a glass of refractive index 1.55, with both faces of the same radius of curvature. What is the radius of curvature required if the focal length is to be 20 cm?

13. Figures (a) and (b) show refraction of a ray in air incident at 60^0 with the normal to a glass-air and water-air interface, respectively. Predict the angle of refraction in glass when the angle of incidence in water is 45^0 with the normal to a water-glass interface.



(a) (b) (c)

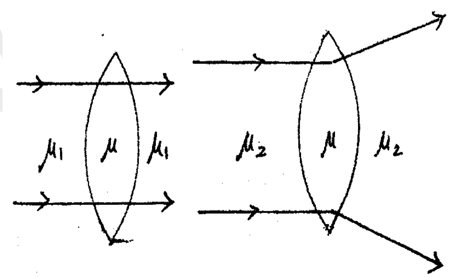
14. If the refractive index of the material of the prism is 1.5, find the critical angle of the prism.

15. The critical angle for diamond is 30^0. What is the refractive index?

16. Is it possible for a given lens to act as a converging lens in one medium and a diverging lens in another medium? Why?

17. The path of light rays through a convex lens when it is placed in two different media is shown in the figure.

What is the relation between the refractive indices μ, μ_1 and μ_2?



18. A convex lens made up of a material of refractive index n_1 is immersed in a medium of refractive index n_2. Trace the path of a parallel beam of light passing through the lens when (i) $n_1>n_2$

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

19. A concave lens made up of a material of refractive index n_1 is immersed in a medium of refractive index n_2. Trace the path of a parallel beam of light passing through the lens when (i) $n_1>n_2$ ii) $n_1=n_2$

(iii) $n_1<n_2$

20. The radius of curvature of each face of a convex lens made of glass of refractive index 1.5 is 30cm. Calculate the focal length of the lens in air.

21. Compare the focal length of a given converging lens for blue light with that using red light. Are they equal or different? Why?

22. A convex lens is held in water. What would be the change in the focal length?

23. What will happen to the angle of minimum deviation D if a prism is completely immersed in water? Justify your answer.

24. Using the data given below, state as which of the given lenses will you prefer to use as

(i) An eye-piece and

(ii) An objective to construct an astronomical telescope? Give reason for your answer.

(iii) What will be the magnifying power and the normal length of the telescope tube so constructed?

Lens	Power	Aperture
L_1	1D	0.1m
L_2	10D	0.05m
L_3	10D	0.02m
L_4	20D	0.02m

25. Using the data given below, state which of the given lenses you will use as an eye piece and as objective to construct an astronomical telescope.

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

26. Using the data given below, state as which of the given lenses will you prefer to use as

(i) An eye-piece and

(ii) An objective to construct a compound microscope? Give reason for your answer.

Lens	Power	Aperture
L_1	20D	0.02m
L_2	10D	0.02m
L_3	10D	0.05m
L_4	1D	0.1m

27. A thin convex lens of focal length 5cm is used as a simple microscope by a person with normal near point (25cm). What is the magnifying power of the microscope?

28. If the objective lens of a compound microscope is immersed in transparent oil, what will happen to the resolving power of the microscope? Explain.