Chapter

9 Optics

Quick Review

Commonly observed phenomena concerning light can be broadly split into three categories:

Ray Optics or Geometrical Optics | **Wave optics or physical optics** | **Particle nature of light**

Ray Optics

Reflection of light

- Laws of reflection:

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

ii. Incident ray, reflected ray and normal lie in one plane. Both the rays are on either side of the normal.

Refraction of light

- Laws of refraction:

i. Angle of incidence (i) and angle of reflection (r) are related by Snell's law.

ii. Incident ray, refracted ray and normal lie in one plane. Both the rays are on either side of the normal.

Total Internal Reflection

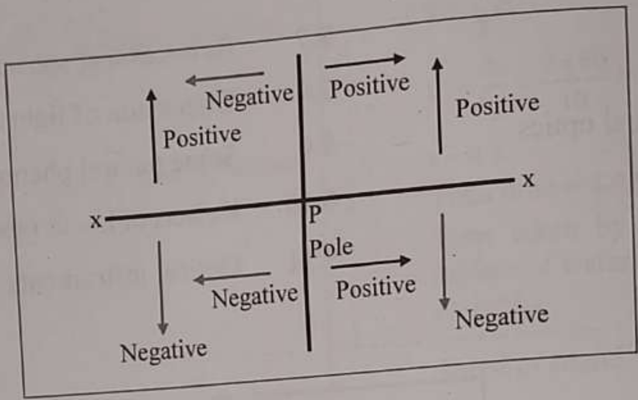
- **Critical angle:** Critical angle for a pair of refracting media can be defined as that angle of incidence in the denser medium for which the angle of refraction in the rarer medium is 90°.
- **Total Internal Reflection (TIR):** For angles of incidence larger than the critical angle, the angle of refraction is larger than 90°. Thus, all the incident light gets reflected back into the denser medium. This is called total internal reflection.

Dispersion of Light

- Splitting of a white light into its constituent colours is known as dispersion of light.
- Light passing through a prism undergoes two types of dispersion; **Linear** dispersion and **Angular** dispersion.

- **Cartesian Sign Conventions:**

  The relation between the numerical values of object distance (u), image distance (v) and Focal length of any spherical lens or mirror differs for different positions. Hence, it is important to define some conventions.



- **Reflection of light:**

Reflection of Light

Plane Mirror

Image Formed is:
- Laterally inverted
- Virtual
- Erect
- Same size as of object

Mirrors inclined with each other:
- The number of images formed depends on the angle of inclination

Spherical Mirror

Convex Mirror

Image Formed is always:
- Virtual
- Erect
- Diminished
- The mirror is diverging mirror
- Focal Length is always **Positive.**

Concave Mirror

- Nature of image depends on the position of the object
- The mirror is Converging mirror
- Focal Length is always **Negative.**

Spherical Aberrations

- Errors caused in image formation are known as aberrations.
- Assumptions on which formulae are developed are ideal and are not practically followed. This results in a distorted image.
- Spherical Aberrations are caused due to spherical shape of the mirrors.
- Spherical aberrations can be overcome by using parabolic mirrors.

➤ **Refraction of light:**

Refraction of Light

- This phenomenon of light occurs due to change in speed as well as wavelength of the light in different media.
- The emergent ray coming out of a glass slab after two refractions in parallel to incident ray but laterally displaced.
- Refractive index of material $= n = \dfrac{\sin i}{\sin r} = \dfrac{c}{v} = \dfrac{\text{Real depth}}{\text{Apparent depth}}$

Single Spherical Surface

- Formation of image depends on the refractive index of the material as well as the radii of curvatures.
- $\dfrac{n_2 - n_1}{R} = \dfrac{n_2}{v} - \dfrac{n_1}{u}$

Convex Lens

- It is a converging lens.
- Its focal length is positive.
- Nature of the image formed depends on the position of the object.

Concave Lens

- It is a diverging lens.
- Its focal length is negative.
- It forms a virtual, erect and diminished image for all positions of the object.

Aberrations in Lenses

- Aberrations in lenses are of two types: Chromatic aberrations and Spherical aberrations.
- Spherical aberrations are due to unfocussed paraxial rays.
- Chromatic aberrations are due to different refractive index of the material of lens for different colours. The image thus formed consists of different colours and one single focussed image is not formed.

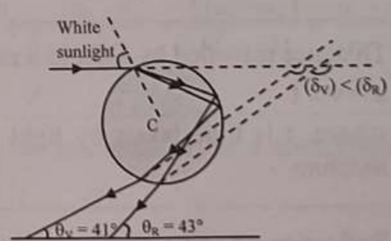
➤ **Some Natural Phenomenon due to Sunlight:**

Mirage

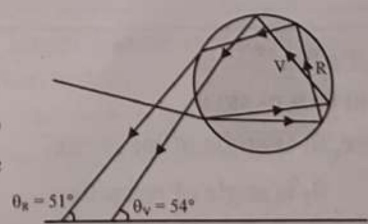
- Illusion of water on hot sunny day.
- It is result of upward bending of ray at the road.

Rainbow

- It is formed due to combination of three phenomena of light inside a single drop of rain: Refraction, dispersion and internal reflection
- **Primary rainbow:** It involves two refractions and one internal reflection of the incident sunlight.

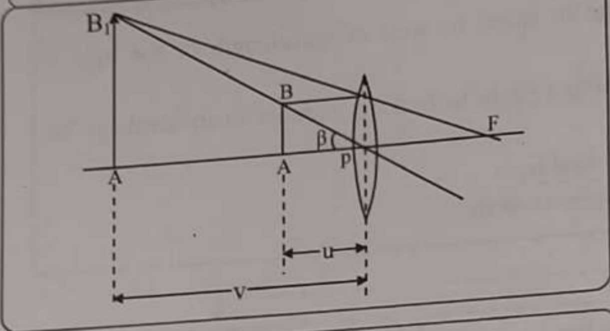


- **Secondary rainbow:** It involves two refractions and two internal reflections of the incident sunlight.

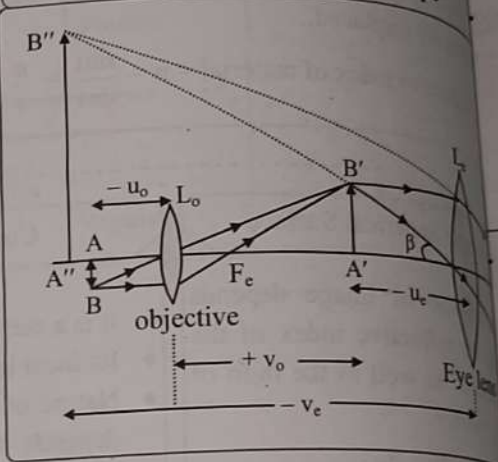


➢ **Optical Instruments:**

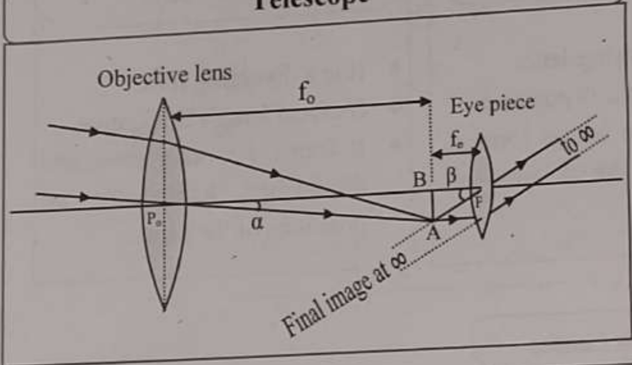
Simple Microscope



Compound Microscope



Telescope



Formulae

1. Speed of EM waves:

$$c = \sqrt{\frac{1}{\varepsilon\mu}}$$

where, ε is permittivity of medium,
μ is permeability of medium.

2. Absolute refractive index:

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

where, v is velocity of light in the medium

3. Distance travelled by light in a medium:

$s = v \times t$

where, t is time taken by light to travel in the medium

4. Reflection of light: $\angle i = \angle r$

5. Snell's law:

$n_1 \sin\theta_1 = n_2 \sin\theta_2$

where, θ_1 is angle of incidence,
θ_2 is angle of refraction,
n_1, n_2 are refractive indices of medium 1 and medium 2 respectively.

6. Image formed by inclined mirrors:

Number of images (n) formed due to two mirrors kept inclined to each other at an angle θ is given by;

i. If $\frac{360^\circ}{\theta}$ is an even integer, then

$$n = \frac{360^\circ}{\theta} - 1$$

ii. If $\frac{360^\circ}{\theta}$ is an odd integer, then

a. for an object lying symmetrically between the two mirrors,

$$n = \left[\frac{360^\circ}{\theta}\right] - 1 \text{ and}$$

b. for an object lying asymmetrically between the two mirrors, $n = \frac{360^\circ}{\theta}$

7. Relation between focal length and radius of curvature for a spherical mirror: $f = \frac{R}{2}$

8. Mirror equation:

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

where, u is object distance, v is image distance

9. Power of spherical refracting surface/lens:

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

where, f is expressed in metre.

10. Lateral magnification:

i. For spherical mirrors: $m = -\frac{v}{u}$

ii. For spherical lenses : $m = \frac{h_2}{h_1} = \frac{v}{u}$

where, h_2 is height of image,
h_1 is height of object.

11. Relative refractive index of medium 2 w.r.t. 1:

i. $^1n_2 = \frac{n_2}{n_1} = \frac{\sin i}{\sin r} = \frac{\lambda_1}{\lambda_2} = \frac{v_1}{v_2}$

Where, λ_1 and v_1 is wavelength and velocity in first medium respectively,
λ_2 and v_2 is wavelength and velocity in second medium respectively,

ii. $^1n_2 = \frac{\text{Real depth}}{\text{Apparent depth}}$

12. Critical angle:

i. $\sin i_C = \frac{1}{n}$, where, n is $\frac{n_{denser}}{n_{rarer}}$

ii. $\sin i_C = \frac{v}{c}$ iii. $\sin i_C = \frac{\lambda_2}{\lambda_1}$

13. Lens formula: $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$

14. Combination of lenses:

i. For thin lenses kept in contact:

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

ii. For two lenses kept distance d apart:

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

iii. Focal power for thin lenses kept in contact:

$$P = P_1 + P_2 + P_3 \ldots.. = \sum P_i$$

iv. Focal power for two thin lenses kept distance d apart:

$$P = P_1 + P_2 - dP_1P_2$$

15. Refraction through thin curved surface:

i. For refraction from rarer to denser medium,

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

ii. For refraction from denser to rarer medium,

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

16. Lens maker's equation:

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

17. Prism angle: $A = r_1 + r_2$

18. Angle of deviation: $\delta = i - r$ if $i > r$

19. The relation between i, e, A and δ for prism:
$i + e = A + \delta$

20. For the minimum deviation ($i = e$):

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

21. Angle of minimum deviation for thin prism:
$\delta_m = A(n - 1)$

22. Mean deviation: $\delta = \frac{(\delta_1 + \delta_2)}{2}$

23. Refractive index of material of the prism/ prism formula: $n = \dfrac{\sin\left(\frac{A+\delta_m}{2}\right)}{\sin\left(\frac{A}{2}\right)}$

24. For thin prism: $n = 1 + \frac{\delta}{A}$

25. Mean refractive index for two colours:

$$n = \frac{n_1 + n_2}{2}$$

26. Mean deviation for white light:

i. $\delta_{VR} = \delta_V - \delta_R$
$= A(n_V - 1) - A(n_R - 1) = A(n_V - n_R)$.

where, n_V and n_R are refractive index for violet and red colour respectively.

ii. $\delta_{VR} = \frac{\delta_V + \delta_R}{2} \approx \delta_Y = A(n_Y - 1)$

Where, n_Y is refractive index for yellow colour.

27. Dispersive power for the extreme colours of white light:

$$\omega = \frac{\delta_V - \delta_R}{\left(\frac{\delta_V + \delta_R}{2}\right)} \approx \frac{\delta_V - \delta_R}{\delta_Y} = \frac{A(n_V - n_R)}{A(n_Y - 1)} = \frac{n_V - n_R}{n_Y - 1}$$

28. Condition for achromatism of a combination of lenses: $\frac{(f_Y)_2}{(f_Y)_1} = -\frac{\omega_2}{\omega_1}$

29. Angular magnification or magnifying power of simple microscope:

i. $M = \frac{\text{Visual angle of the image}}{\text{Visual angle of the object at D}} = \frac{\beta}{\alpha}$

ii. $M = \frac{D}{u}$

where, D is least distance of distinct vision.

30. Magnifying power of simple microscope:

i. $M_{Max} = 1 + \frac{D}{f}$ ii. $M_{Min} = \frac{D}{f}$

31. Length of compound microscope: $L = v_o + u_e$

32. Magnifying power of compound microscope:

$M = m_o \times M_e$

where, $m_o = \frac{v_o}{u_o}$ is the linear (lateral) magnification of objective and $M_e = \left(\frac{D}{u_e}\right)$ is the angular magnification or magnifying power of the eye lens.

33. Length of telescope:

i. For normal adjustment $L = f_o + f_e$.

where, f_o is focal length of the objective

f_e is focal length of the eye-piece

ii. $L = f_o + |u_e|$

....(Image at the least distance of distinct

34. Magnifying power of telescope:

i. $M_{D.D.V} = \frac{f_o}{f_e}\left(1 + \frac{f_e}{D}\right)$

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

Shortcuts

1. If the distance travelled by a ray of light in two media are s_1 and s_2 in the same time 't' then the r refractive index of the 2nd medium to 1st medium is given by

$${}^1n_2 = \frac{v_1}{v_2} = \frac{s_1}{s_2}$$

2. If a spherical mirror produces an image 'm' times the size of the object (m = magnification) then u, v are given by the following relation,

$$u = \left(\frac{m-1}{m}\right)f \text{ and } v = -(m-1)f$$

3. When a convex lens of R.I. n_1 is surrounded by a medium of refractive index n_2 ($n_2 > n_1$), then the behaves as diverging lens.

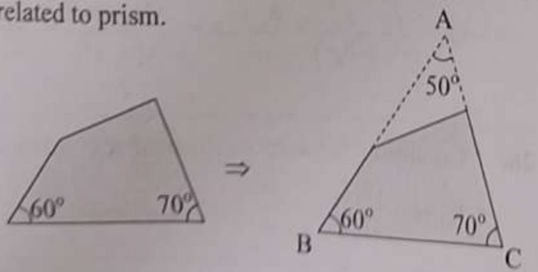
4. If the angle of minimum deviation is equal to the refracting angle then we can directly use the formula

$$n = 2\cos\frac{A}{2}$$

5. If dispersive power (ω) and R.I of two extreme colours (say n_1 and n_2, $n_2 > n_1$) are given then to find the of mean colour (n_m) use the formula

$$n_m = 1 + \frac{n_2 - n_1}{\omega}$$

6. Sometimes in the question, a portion of a prism with some of the angles is provided. In such a situation should first complete the figure for prism and then use the procedure generally applied to solve prob related to prism.



7. If four convex lenses with focal lengths $f_1 > f_2 > f_3 > f_4$ are provided, and we have to choose suitable le for microscopes and telescopes, then the process can be carried out as:

Telescope – $f_1(o)$, $f_4(e)$ as difference in focal lengths of objective and eyepiece in telescope shoul considerably large.

Microscope – $f_4(o)$, $f_3(e)$ as difference in focal lengths of objective and eyepiece in microscope shoul smaller than that in telescope.

8. Focal length of various lens types:

Lens	R_1	R_2	Focal length (f)
Bi-convex/convex	$+R_1$	$-R_2$	$+f$
Equi-convex 	R	–R	$\frac{R}{2(n-1)}$
Plano-convex 	∞	–R	$\frac{R}{n-1}$

Lens	R_1	R_2	Focal length (f)
Bi-concave/concave	$-R_1$	$+R_2$	$-f$
Equi-concave 	–R	R	$\frac{-R}{2(n-1)}$
Plano-concave 	∞	R	$\frac{-R}{(n-1)}$

Mindbenders

1. A transparent solid is invisible in a liquid of same refractive index (because of no refraction).
2. When a glass slab is placed over a page in which letters are printed in different colours, the image of all the letters will not lie in the same plane. This is because, refractive index of glass is different for different colours. Thus, images of different coloured letters are raised differently.
3. The concept of focus is defined only for rays which have angle of incidence close to zero degree (say less than 10°). These rays are called paraxial rays. If the rays are not paraxial, the image is not sharp.
4. As every part of mirror forms a complete image, if a part of the mirror is obstructed, full image will be formed but intensity will be reduced.
5. Light gathering power depends upon diameter of the lens aperture. Hence if such a lens is painted half or covered with opaque paper then the image will be less intense only. The size or position of the image is unaffected.
6. In a compound microscope, objective lens and eye lens are fixed distance apart. For focussing an object, we adjust distance of objective lens from the object by moving rack and pinion arrangement.
7. If a parrot were sitting on the objective of a large telescope and we take photograph of a distant astronomical object through it, parrot will not be seen in the photograph, but brightness of image would certainly reduce slightly.
8. If objective and eye lens of a telescope are interchanged, it will not behave as a microscope but object appears very small.