Ray Optics & Optical Instruments

Class 12 Physics · Chapter 9 · CBSE

Handwritten Notes · Sequence: NCERT + S.L. Arora

How to use these notes: Topics follow the NCERT order. Extra topics from S.L. Arora are added where they fit and marked [S.L. Arora]. Derivations and sample problems follow the reference theory material, written step by step. Boxed formulas are the ones to remember. **20 CBSE previous-year questions** are at the end.

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1. Introduction NCERT 9.1

→ Light is an electromagnetic wave. Visible range: about **400 nm (violet) to 750 nm (red)**.

→ Speed of light in vacuum: $c = 2.99792458 \times 10^8$ m/s — the highest speed possible in nature.

→ The wavelength of light is very small compared with the size of ordinary objects, so light can be taken to travel in **straight lines**.

> **Ray:** the path along which light energy travels. **Beam:** a bundle of rays — parallel, converging or diverging.

Ray optics (geometrical optics) studies reflection, refraction and image formation using rays.

2. Reflection by Spherical Mirrors NCERT 9.2

> **Laws of reflection:** (i) angle of incidence = angle of reflection ($i = r$); (ii) incident ray, reflected ray and the normal at the point of incidence lie in the same plane.

→ **Pole (P)** — centre of the mirror surface. **Centre of curvature (C)** — centre of the sphere of which the mirror is a part. **Aperture** — effective diameter of the reflecting surface.

→ **Principal focus (F)** — when paraxial rays parallel to the principal axis fall on a mirror, the point where they meet (concave) or appear to meet (convex) after reflection. **Focal length f = PF**.

Cartesian sign convention

→ All distances are measured from the **pole** (for a lens: from the optical centre).

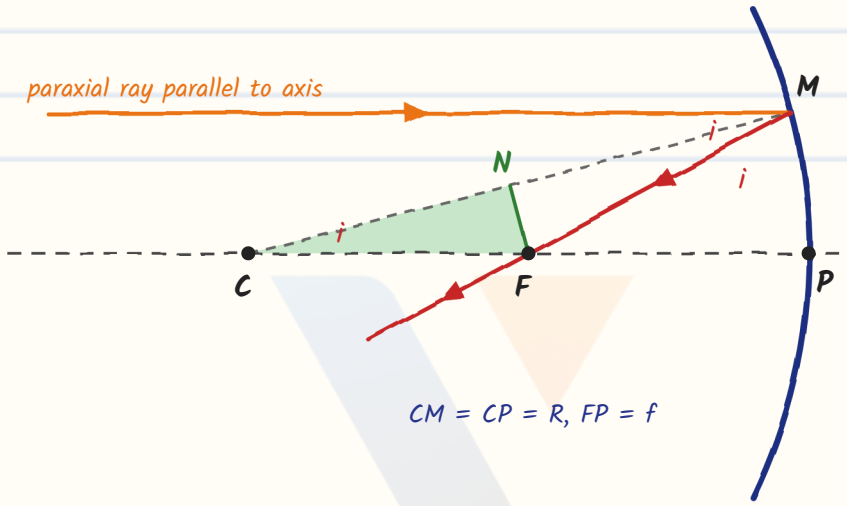
→ Distances in the direction of incident light → **positive**; opposite to it → **negative**.

→ Heights **above** the principal axis → positive; **below** → negative.

So for a concave mirror f and R are negative; for a convex mirror f and R are positive.

A real object always has u negative.

Focal length of a spherical mirror — derivation



FN ⊥ CM. ∠FCM = ∠CMF = i, so ΔCMF is isosceles and N is the mid-point of CM.

⇒ $\Delta CNF \sim \Delta MNF$ (FN ⊥ CM, FC = FM) ⇒ $CN = NM = \frac{R}{2}$

⇒ In ΔCNF: $\cos i = \frac{CN}{CF} = \frac{R/2}{CF} \Rightarrow CF = \frac{R}{2\cos i}$

⇒ $FP = CP - CF = R - \frac{R}{2\cos i}$

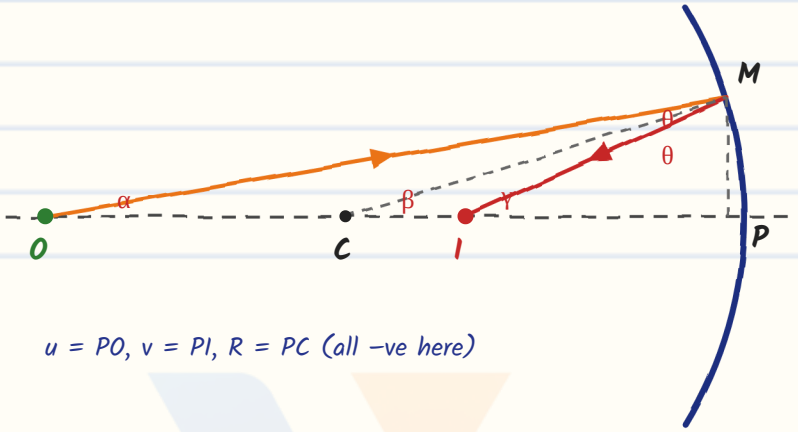
⇒ If i is very small (paraxial rays), $\cos i \approx 1 \Rightarrow FP = R - \frac{R}{2}$

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

→ **Marginal rays** (large i): FP = R − R/(2 cos i) is **less** than R/2 — they meet closer to the mirror. That is why only paraxial rays give a sharp focus.

3. Mirror Formula & Magnification NCERT 9.2.3

Relation between u, v and f



$u = PO$, $v = PI$, $R = PC$ (all −ve here)

⇒ For small angles: $\alpha = \frac{MP}{u}$, $\beta = \frac{MP}{R}$, $\gamma = \frac{MP}{v}$ (magnitudes)

⇒ From ΔCMO (exterior angle at C): $\beta = \alpha + \theta \Rightarrow \theta = \beta - \alpha$

⇒ From ΔCMI (exterior angle at I): $\gamma = \beta + \theta \Rightarrow \theta = \gamma - \beta$

⇒ So $\beta - \alpha = \gamma - \beta \Rightarrow 2\beta = \gamma + \alpha$

⇒ Put the values: $\frac{2}{R} = \frac{1}{v} + \frac{1}{u}$, and $R = 2f$

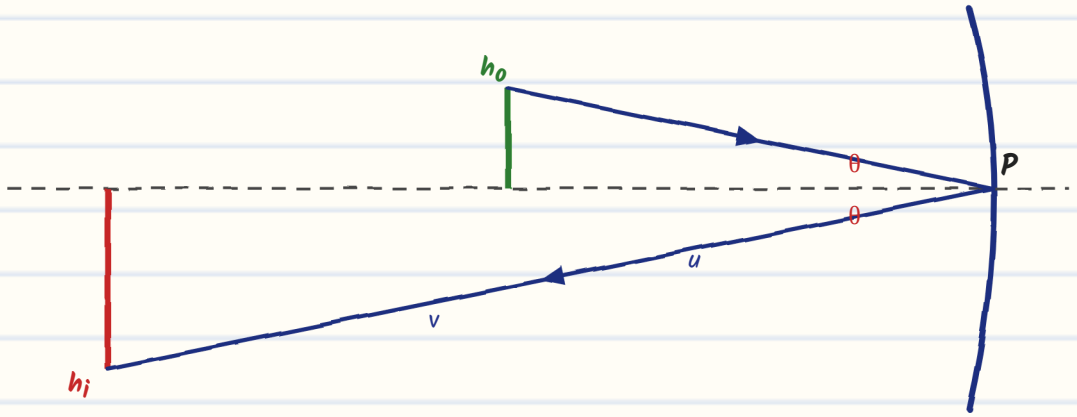
$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$ (mirror formula)

Sample problem: A point object is 25 cm in front of a concave mirror of focal length 20 cm. Find the position and nature of the image.

$u = -25$ cm, $f = -20$ cm. $1/v + 1/(-25) = 1/(-20) \Rightarrow 1/v = -1/20 + 1/25 = -1/100$

⇒ **$v = -100$ cm** → real image, 100 cm in front of the mirror.

Transverse (lateral) magnification — derivation



⇒ Ray from the top of the object to the pole P reflects at equal angle θ.

⇒ $\tan\theta = \frac{h_o}{u}$ and $\tan\theta = \frac{h_i}{v} \Rightarrow \frac{h_i}{h_o} = \frac{v}{u}$ (magnitudes)

⇒ Put the values with sign: $u \to -u$, $v \to -v$, $h_i \to -h_i$, $h_o \to +h_o$: $\frac{-h_i}{h_o} = \frac{-v}{-u}$

$$m = \frac{h_i}{h_o} = -\frac{v}{u} = \frac{f}{f-u} = \frac{f-v}{f}$$

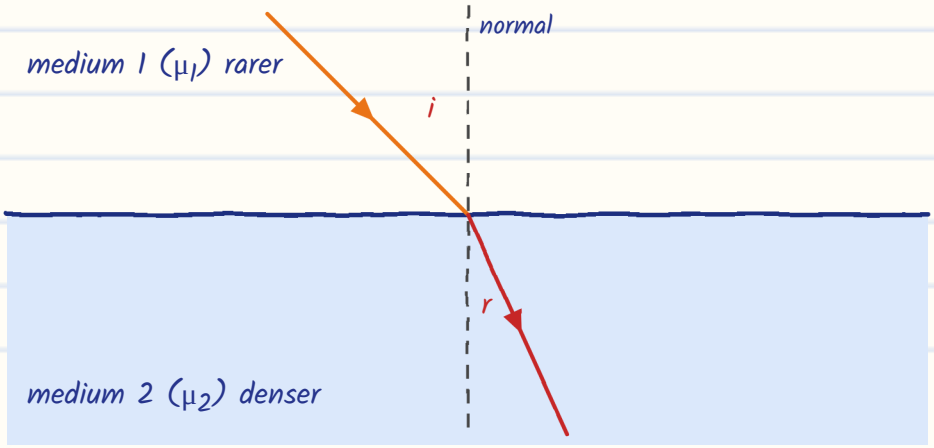
→ m negative → real and inverted image; m positive → virtual and erect image.

Sample problem: An object 4 cm high is 20 cm in front of a concave mirror of focal length 10 cm. Find position, nature and size of the image.

$u = -20$, $f = -10$. $m = f/(f-u) = -10/(-10+20) = -1 = -v/u \Rightarrow$ **$v = -20$ cm**

$h_i = m\,h_o =$ **-4 cm** → real, inverted, same size.

4. Refraction NCERT 9.3



Refraction: bending of light when it passes obliquely from one medium into another. **Snell's law:** incident ray, refracted ray and normal lie in one plane, and

$$\mu_1 \sin i = \mu_2 \sin r$$

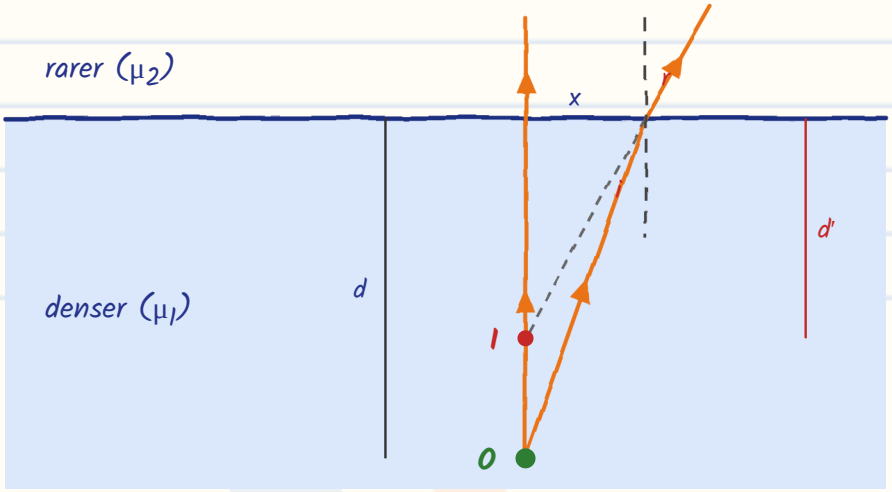
→ Absolute refractive index $\mu = c/v$. Relative: $\mu_{21} = \mu_2/\mu_1 = v_1/v_2 = \lambda_1/\lambda_2$.

→ Rarer → denser: ray bends **towards** the normal. Denser → rarer: bends **away** from the normal. Normal incidence: no bending (still called refraction).

→ Frequency does **not** change on refraction; speed and wavelength change.

5. Apparent Depth, Normal & Lateral Shift NCERT 9.3

Refraction through a single plane surface (apparent depth)



⇒ Snell's law at the surface: $\mu_1 \sin i = \mu_2 \sin r$

⇒ Paraxial rays: $\sin r \approx \tan r = \frac{x}{d'}$, $\sin i \approx \tan i = \frac{x}{d}$

⇒ $\mu_1 \frac{x}{d} = \mu_2 \frac{x}{d'}$

$$\frac{\text{apparent distance}}{\text{actual distance}} = \frac{d'}{d} = \frac{\mu_2}{\mu_1}$$

→ μ_2 = medium the light **enters** (observer side); μ_1 = medium of the object. d and d' are measured from the boundary.

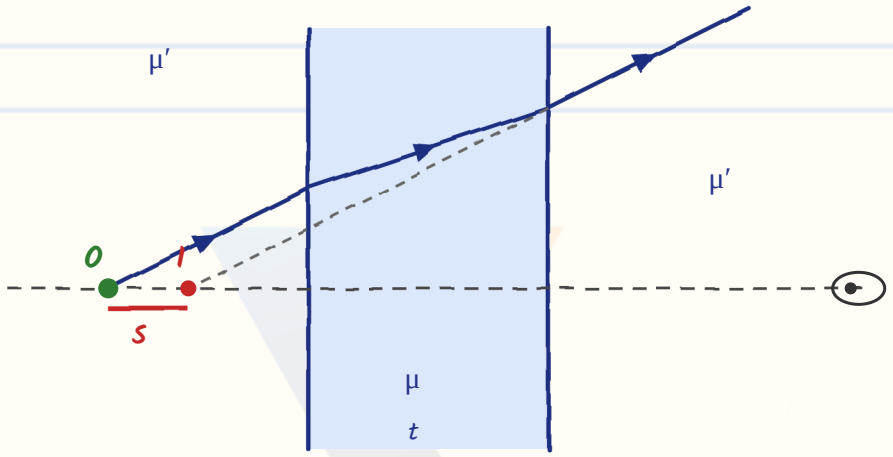
→ Observer in rarer medium → object looks **raised** ($d' < d$). Observer in denser medium → object looks **farther** ($d' > d$).

Sample problem: A fish is 24 cm below the water surface ($\mu = 4/3$) and a bird is 36 cm above it. Find the distance of the fish as seen by the bird.

Object = fish, observer = bird: $d'/24 = 1/(4/3) \Rightarrow d' = 18$ cm below the surface.

Apparent distance = 18 + 36 = **54 cm**

Glass slab — normal shift



⇒ Object O at distance x from the 1st surface, slab of thickness t, refractive index μ, surroundings μ′.

⇒ **1st refraction** (μ′ → μ): $\frac{d'}{x} = \frac{\mu}{\mu'} \Rightarrow d' = \frac{\mu}{\mu'} x$ (image I′ from 1st surface)

⇒ **2nd refraction** (μ → μ′): image of 1st refraction acts as object at $(d' + t)$:

$$\frac{d''}{d' + t} = \frac{\mu'}{\mu} \Rightarrow d'' = \frac{\mu'}{\mu}(d' + t)$$

⇒ Shift $S = (x + t) - d'' = x + t - \frac{\mu'}{\mu}\left(\frac{\mu}{\mu'}x + t\right) = t - \frac{\mu'}{\mu} t$

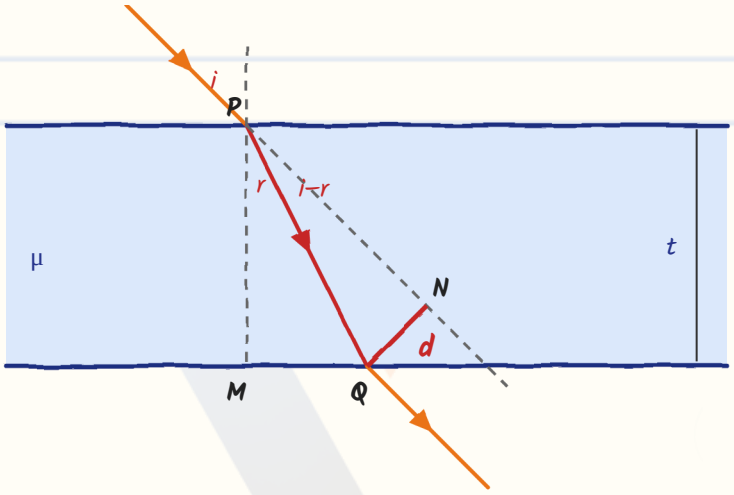
$$S = t\left(1 - \frac{\mu_{surrounding}}{\mu_{slab}}\right)$$ in air: $S = t(1 - 1/\mu)$

→ Shift is **independent** of the distance between object and slab. S positive → object appears shifted towards the direction of incident light.

Sample problem: An object in air is viewed through a slab 15 cm thick ($\mu = 3/2$). Find the normal shift.

$S = 15(1 - 1/(3/2)) = 15 \times (1/3) = 5$ cm (positive) → object appears 5 cm closer, towards the slab.

Glass slab — lateral shift [S.L. Arora]



⇒ Emergent ray is parallel to the incident ray (deviation $\delta = 0$) but shifted sideways by $d = QN$.

⇒ In ΔPQM: $\cos r = \frac{PM}{PQ} \Rightarrow PQ = \frac{t}{\cos r}$

⇒ In ΔPQN: $\sin(i - r) = \frac{QN}{PQ} \Rightarrow QN = PQ \sin(i - r)$

$$d = \frac{t}{\cos r} \sin(i - r)$$

⇒ **Time to cross the slab:** $T = \frac{PQ}{v}$, with $PQ = \frac{t}{\cos r}$ and $v = \frac{c}{\mu} \Rightarrow T = \frac{\mu t}{c \cos r}$

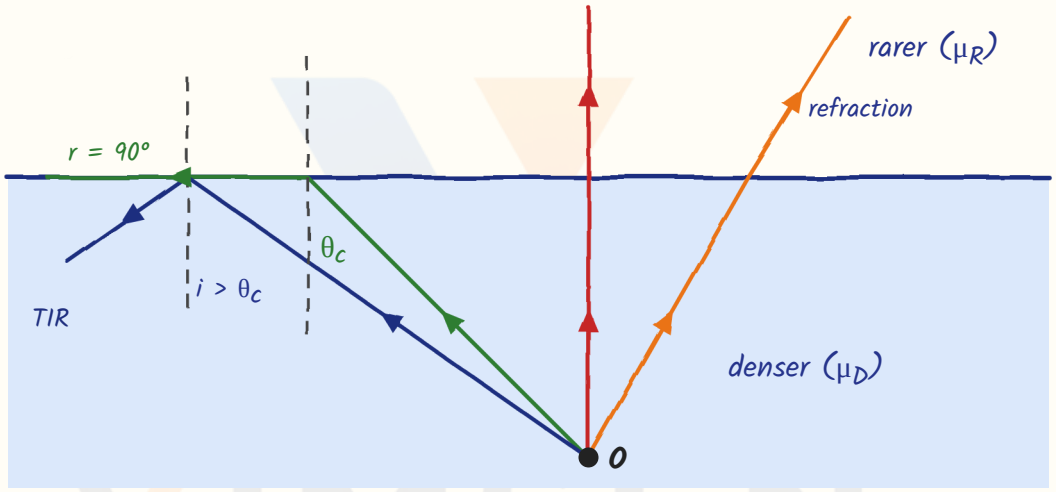
Sample problem: A ray falls at 60° on a slab 10 cm thick with $\mu = \sqrt{3}$. Find the lateral shift and the time to cross.

$1 \cdot \sin 60° = \sqrt{3} \sin r \Rightarrow \sin r = ½ \Rightarrow r = 30°$

$d = (10/\cos 30°) \sin 30° = 10/\sqrt{3}$ cm ≈ 5.77 cm

$T = (\sqrt{3} \times 0.10)/(3 \times 10^8 \times \sqrt{3}/2) = (2/3) \times 10^{-9}$ s

6. Total Internal Reflection NCERT 9.4



When light goes from denser to rarer medium it bends away from the normal. As i increases, r increases. At one value of i the refracted ray makes 90° with the normal — this i is the **critical angle θ_c**. If i increases further, the ray comes back into the same medium — **total internal reflection**.

Calculation of critical angle

⇒ Snell's law at the critical angle: $\mu_D \sin \theta_c = \mu_R \sin 90°$

$$\sin \theta_c = \frac{\mu_R}{\mu_D} = \frac{v_D}{v_R} = \frac{\lambda_D}{\lambda_R}$$ rarer = air: $\sin \theta_c = 1/\mu$

Conclusion: for TIR, light must go from **denser to rarer**. $i < \theta_c \rightarrow$ refraction; $i = \theta_c \rightarrow$ grazing emergence; $i > \theta_c \rightarrow$ TIR.

Sample problem: A ray falls normally on face BC of a right-angled isosceles prism and meets face AB at 45°. What should be the refractive index so that TIR occurs at AB?

TIR at AB $\Rightarrow 45° > \theta_c \Rightarrow \sin 45° > 1/\mu \Rightarrow 1/\sqrt{2} > 1/\mu \Rightarrow \mu > \sqrt{2}$

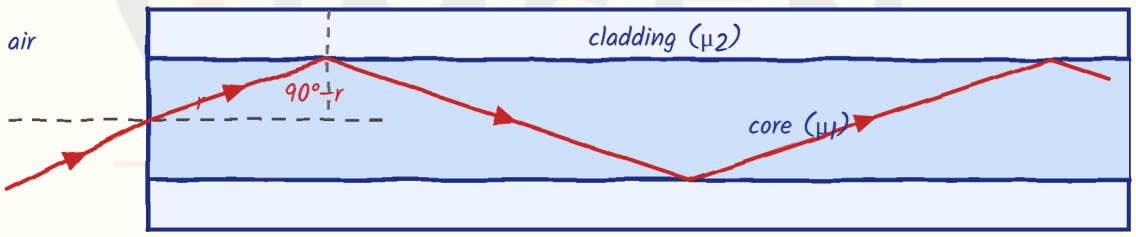
7. Applications of TIR NCERT 9.4.1

→ **Mirage:** air near a hot road is rarer. Light from a tall object bends away from the normal layer by layer and finally suffers TIR — we see an inverted image like a pool of water.

→ **Sparkling of diamond:** $\mu \approx 2.42$, $\theta_c \approx 24.4°$. Facets are cut so light suffers TIR many times before coming out.

→ **Totally reflecting prisms:** right-angled isosceles prisms (θ_c of glass $\approx 42° < 45°$) bend rays by 90° or 180° — periscopes, binoculars.

Optical fibre — acceptance angle



TIR at every reflection

→ Core of higher μ_1 surrounded by cladding of lower μ_2. Light travels by repeated TIR with almost no loss — used in telecommunication and endoscopy.

⇒ Snell's law at the air/core end face: $1 \times \sin i = \mu_1 \sin r \Rightarrow \sin r = \frac{\sin i}{\mu_1}$

⇒ At the core/cladding wall the angle of incidence is $(90° - r)$; critical angle: $\sin \theta_c = \frac{\mu_2}{\mu_1}$

⇒ For TIR: $90° - r > \theta_c \Rightarrow \sin(90° - r) > \sin \theta_c \Rightarrow \cos r > \sin \theta_c$

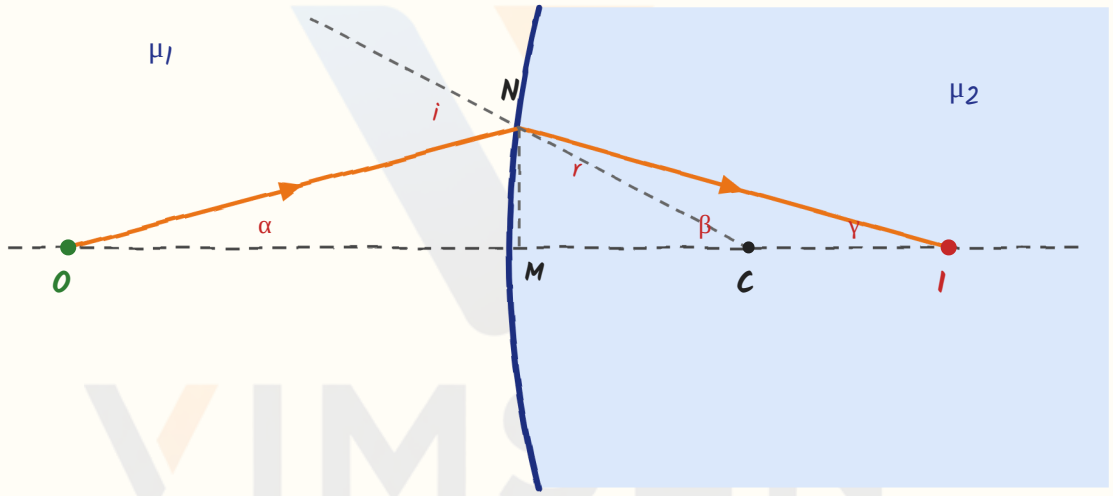
⇒ $\sqrt{(1 - \sin^2 r)} > \frac{\mu_2}{\mu_1} \Rightarrow 1 - \frac{\sin^2 i}{\mu_1^2} > \frac{\mu_2^2}{\mu_1^2} \Rightarrow \mu_1^2 - \sin^2 i > \mu_2^2$

$\sin i < \sqrt{(\mu_1^2 - \mu_2^2)}$ max. acceptance angle: $\sin i_{max} = \sqrt{(\mu_1^2 - \mu_2^2)}$

Sample problem: A ray enters the end face of a glass slab (in air) at 60° and travels inside by TIR. Find the minimum refractive index of the glass.

Here $\mu_2 = 1$: $\sin 60° < \sqrt{(\mu^2 - 1)} \Rightarrow 3/4 < \mu^2 - 1 \Rightarrow \mu^2 > 7/4 \Rightarrow \mu_{min} = \sqrt{7}/2 \approx 1.32$

8. Refraction at a Single Curved Surface NCERT 9.5.1



⇒ Snell's law: $\mu_1 \sin i = \mu_2 \sin r$. Paraxial rays: $\sin i \approx i$, $\sin r \approx r \Rightarrow \mu_1 i = \mu_2 r$ ... (1)

⇒ In ΔNOC: $\alpha + \beta = i$ ... (2) In ΔNIC: $\gamma + r = \beta \Rightarrow r = \beta - \gamma$ ... (3)

⇒ Put (2) and (3) in (1): $\mu_1(\alpha + \beta) = \mu_2(\beta - \gamma) \Rightarrow \mu_1\alpha + \mu_2\gamma = (\mu_2 - \mu_1)\beta$

⇒ $\tan\alpha = \frac{MN}{OM} \approx \alpha$, $\tan\beta = \frac{MN}{MC} \approx \beta$, $\tan\gamma = \frac{MN}{MI} \approx \gamma$

⇒ $\mu_1\frac{MN}{OM} + \mu_2\frac{MN}{MI} = (\mu_2 - \mu_1)\frac{MN}{MC} \Rightarrow \frac{\mu_2}{MI} + \frac{\mu_1}{OM} = \frac{\mu_2 - \mu_1}{MC}$

⇒ OM, MI, MC are magnitudes. Cartesian signs: $OM = -u$, $MI = +v$, $MC = +R$

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

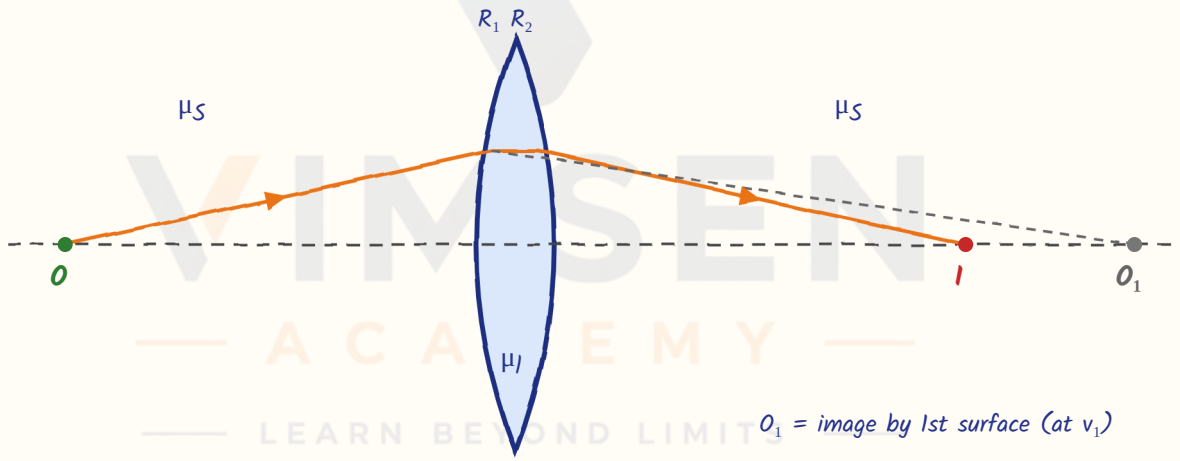
→ Rays paraxial; μ_2 = medium light enters after refraction, μ_1 = medium before; put v, u, R with sign.

Sample problem: A point object in air is 30 cm from a convex glass surface (μ = 1.5) of radius 10 cm. Find the image.

$\mu_1 = 1$, $\mu_2 = 1.5$, $u = -30$ cm, $R = +10$ cm

$1.5/v - 1/(-30) = 0.5/10 \Rightarrow 1.5/v = 1/20 - 1/30 = 1/60 \Rightarrow$ **v = +90 cm** (real image)

9. Lens Maker's Formula NCERT 9.5.2



⇒ **Refraction at 1st surface** ($\mu_S \to \mu_1$): use $\frac{\mu_2}{v} - \frac{\mu_1}{u} = \frac{\mu_2 - \mu_1}{R}$ with $\mu_2 = \mu_1$, $\mu_1 = \mu_S$, $u = u$, $v = v_1$, $R = R_1$:

⇒ $\frac{\mu_1}{v_1} - \frac{\mu_S}{u} = \frac{\mu_1 - \mu_S}{R_1}$ … (1)

⇒ **Refraction at 2nd surface** ($\mu_1 \to \mu_S$): image O_1 acts as object; $\mu_2 = \mu_S$, $\mu_1 = \mu_1$, $u = v_1$, $v = v$, $R = R_2$:

⇒ $\frac{\mu_S}{v} - \frac{\mu_1}{v_1} = \frac{\mu_S - \mu_1}{R_2}$ … (2)

⇒ Add (1) and (2): $\frac{\mu_S}{v} - \frac{\mu_S}{u} = (\mu_1 - \mu_S)\left[\frac{1}{R_1} - \frac{1}{R_2}\right]$

⇒ Divide by μ_S: $\frac{1}{v} - \frac{1}{u} = \left(\frac{\mu_l}{\mu_S} - 1\right)\left[\frac{1}{R_1} - \frac{1}{R_2}\right]$ … (3)

⇒ If the object is at infinity ($u = -\infty$), the image is at the focus ($v = f$):

$$\frac{1}{f} = \left(\frac{\mu_l}{\mu_S} - 1\right)\left[\frac{1}{R_1} - \frac{1}{R_2}\right]$$ (lens maker's formula)

→ Conditions: rays paraxial, lens thin, same medium on both sides. R_1 = surface light meets first; R_2 = second surface. Convex lens in air: f +ve; concave lens in air: f −ve.

→ **Lens in a liquid** [S.L. Arora]: if $\mu_S > \mu_l$, $(\mu_l/\mu_S - 1)$ is negative — a convex lens behaves as a diverging lens. If $\mu_S = \mu_l$, $f \to \infty$.

Sample problem: Find the focal length of a biconvex lens ($\mu = 1.5$) in air with radii 20 cm and 30 cm.

Light from the left: $R_1 = +20$ cm, $R_2 = -30$ cm

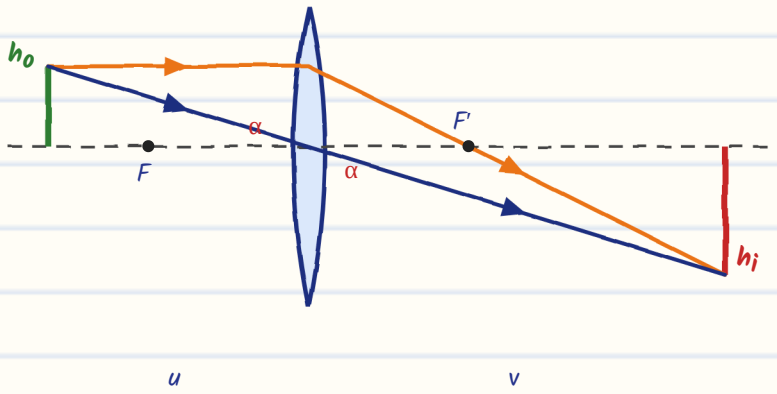
$1/f = (1.5 - 1)(1/20 + 1/30) = 0.5 \times 5/60 = 1/24 \Rightarrow$ **f = 24 cm** (same if light comes from the right)

10. Lens Formula, Magnification & Power NCERT 9.5

⇒ From (3) and the lens maker's formula:

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

Transverse magnification of a lens — derivation



⇒ Ray through the optical centre goes undeviated: $\tan\alpha = \frac{h_o}{u} = \frac{h_i}{v} \Rightarrow \frac{h_i}{h_o} = \frac{v}{u}$

$$m = \frac{h_i}{h_o} = \frac{v}{u} = \frac{f}{f+u} = \frac{f-v}{f}$$

Sample problem: An object 3 cm high is 30 cm in front of a convex lens of focal length 20 cm. Find position, nature and size of the image.

$u = -30$, $f = +20$: $v = uf/(u+f) = (-30 \times 20)/(-30+20) =$ **+60 cm** (real)

$m = v/u = 60/(-30) = -2 \Rightarrow h_i =$ **−6 cm** → inverted, enlarged.

Optical power

Optical power: the degree to which a lens, mirror or other optical system converges or diverges light. Unit: dioptre ($D = m^{-1}$). Converging system → P positive; diverging → P negative.

⇒ **Spherical surface:** $P = \frac{\mu_2 - \mu_1}{R}$ (flat surface: $R \to \infty \Rightarrow P = 0$)

⇒ **Thin lens:** $P = \frac{\mu_s}{f} = \mu_s\left(\frac{\mu_l}{\mu_s} - 1\right)\left[\frac{1}{R_1} - \frac{1}{R_2}\right]$

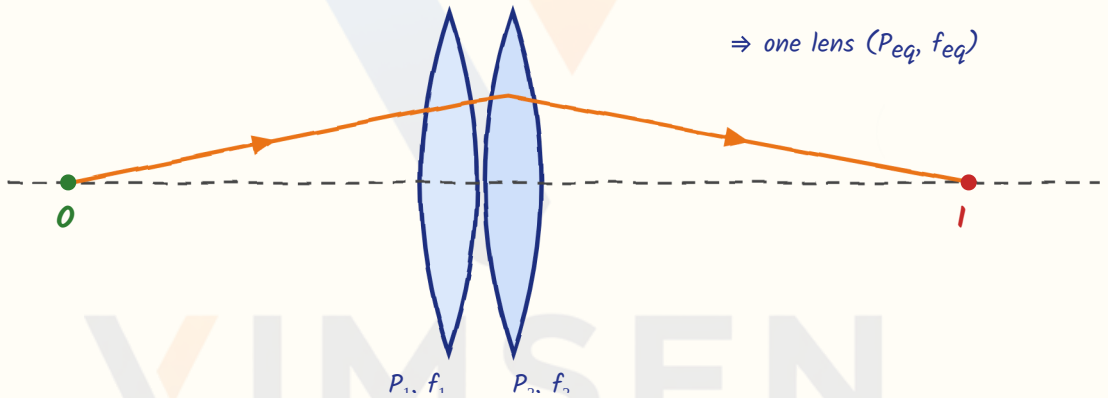
$$P = (\mu_l - \mu_s)\left[\frac{1}{R_1} - \frac{1}{R_2}\right]$$

→ Lens in air: $P = 1/f$ (f in metre). Spherical mirror: $P = -1/f$.

Sample problem: Find the optical power of a convex spherical surface (R = 10 cm) separating air from glass of $\mu = 3/2$.

$P = (\mu_2 - \mu_1)/R = (3/2 - 1)/(0.10\ m) =$ **+5 D** (converging)

11. Combination of Thin Lenses in Contact NCERT 9.5.4



Two or more thin lenses placed in contact act as a single lens whose power is the sum of the individual powers.

$$P_{eq} = P_1 + P_2 + \ldots \Rightarrow \frac{1}{f_{eq}} = \frac{1}{f_1} + \frac{1}{f_2} + \ldots$$

→ P_{eq} +ve → converging; −ve → diverging; zero → acts as a plane surface. Use signs.

→ **Lenses separated by distance d** [S.L. Arora]: $\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2} - \frac{d}{f_1 f_2}$

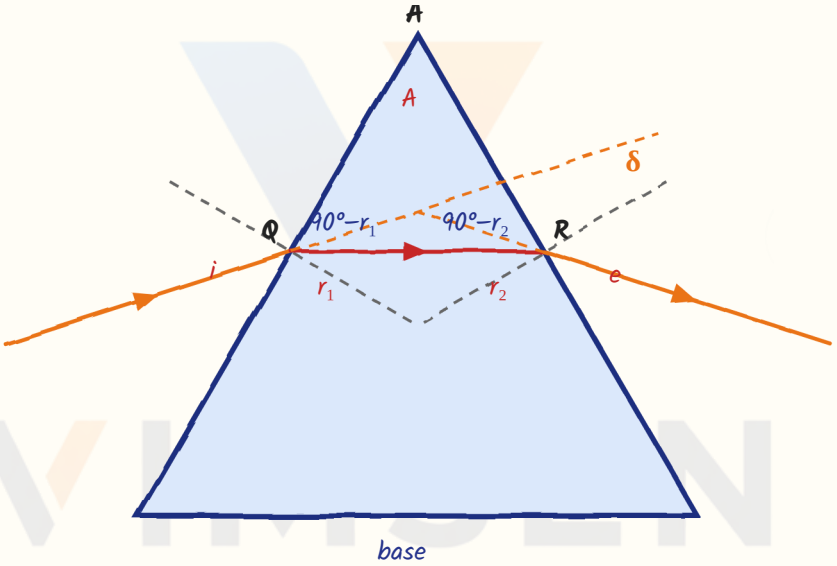
Sample problem: A biconvex lens ($\mu = 3/2$, radii 20 cm each) is in contact with a biconcave lens ($\mu = 2$, radii 20 cm and 30 cm), in air. Find f_{eq} and P_{eq}.

$1/f_1 = (3/2 - 1)(1/20 + 1/20) = 1/20 \Rightarrow f_1 = 20$ cm

$1/f_2 = (2 - 1)(-1/20 - 1/30) = -1/12 \Rightarrow f_2 = -12$ cm

$1/f_{eq} = 1/20 - 1/12 = -1/30 \Rightarrow$ **$f_{eq} = -30$ cm**, $P_{eq} = -100/30 =$ **$-10/3$ D** (diverging)

12. Refraction through a Prism NCERT 9.6



Important results regarding prism

⇒ In ΔAQR, the angles at Q and R are $(90° - r_1)$ and $(90° - r_2)$:

⇒ $A + (90° - r_1) + (90° - r_2) = 180°$

$$A = r_1 + r_2$$

⇒ Deviation at 1st surface $\delta_1 = i - r_1$; at 2nd surface $\delta_2 = e - r_2$ (both in the same sense)

⇒ $\delta_{net} = \delta_1 + \delta_2 = (i - r_1) + (e - r_2) = (i + e) - (r_1 + r_2)$

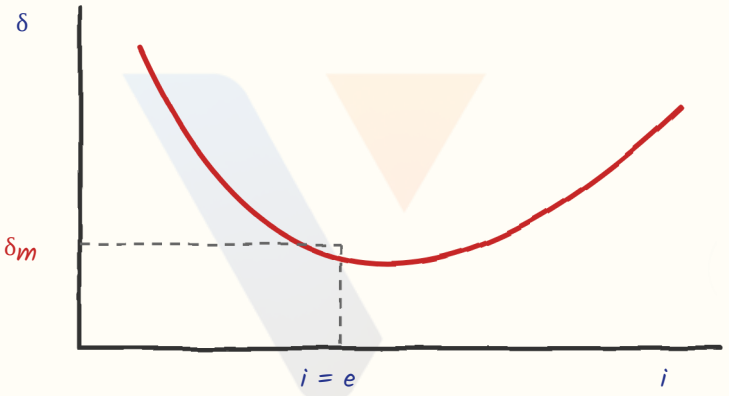
$$\delta = (i + e) - A$$

Sample problem: A ray falls at 60° on a prism of angle 60° and $\mu = \sqrt{3}$ (in air). Find the deviation.

$1 \cdot \sin 60° = \sqrt{3} \sin r_1 \Rightarrow \sin r_1 = ½ \Rightarrow r_1 = 30°$; $r_2 = A - r_1 = 30°$

$\sqrt{3} \sin 30° = \sin e \Rightarrow e = 60°$. $\delta = 60° + 60° - 60° = \mathbf{60°}$

Minimum deviation



⇒ From the graph, condition of minimum deviation: $i = e \Rightarrow r_1 = r_2 = \frac{A}{2}$

⇒ From $\delta = i + e - A$: $\delta_m = 2i - A \Rightarrow i = \frac{\delta_m + A}{2}$

⇒ Snell's law at 1st surface: $\mu_s \sin i = \mu_p \sin \frac{A}{2} \Rightarrow \mu_s \sin\left(\frac{\delta_m + A}{2}\right) = \mu_p \sin \frac{A}{2}$

$$\frac{\mu_p}{\mu_s} = \frac{\sin[(\delta_m + A)/2]}{\sin(A/2)}$$

→ For an isosceles / equilateral prism at minimum deviation, light inside travels **parallel to the base**.

Sample problem: μ of a prism is √2 and A = 60°. Find the minimum deviation.

$\sqrt{2} = \sin[(\delta_m + 60°)/2] / \sin 30° \Rightarrow \sin[(\delta_m + 60°)/2] = 1/\sqrt{2}$

$(\delta_m + 60°)/2 = 45° \Rightarrow \boldsymbol{\delta_m = 30°}$

Thin prism (A < 10°)

⇒ All angles small, so $\sin\theta \approx \theta$: $\frac{\mu_p}{\mu_s} = \frac{(\delta_m + A)/2}{A/2} \Rightarrow \frac{\mu_p}{\mu_s} A = \delta_m + A$

$$\boldsymbol{\delta = \left(\frac{\mu_p}{\mu_s} - 1\right) A} \qquad \text{in air: } \delta = (\mu - 1)A$$

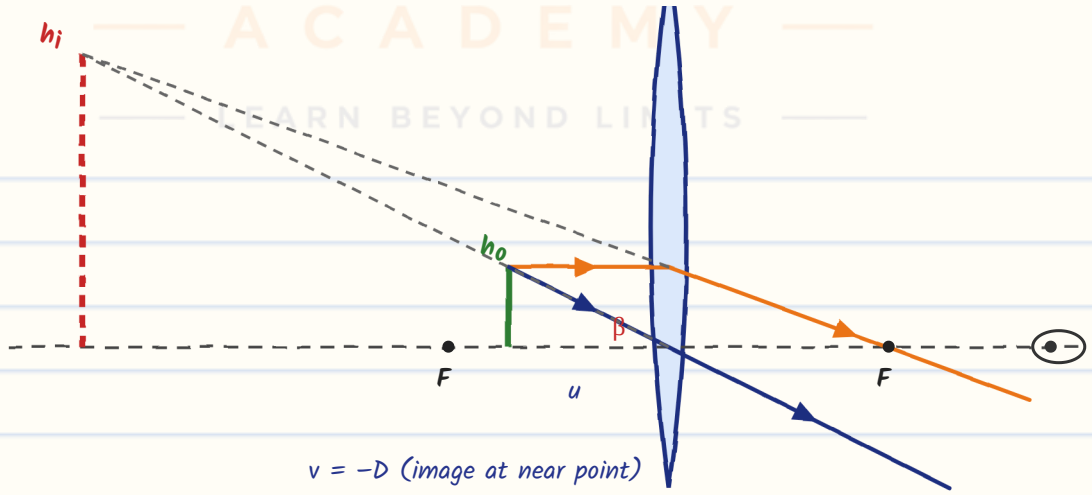
→ The deviation of a thin prism is **independent of the angle of incidence**.

Sample problem: A thin prism of angle 5° gives a deviation of 3.2°. Find μ.

$\delta = A(\mu - 1) \Rightarrow 3.2 = 5(\mu - 1) \Rightarrow \boldsymbol{\mu = 1.64}$

→ **Dispersion** [S.L. Arora]: μ is different for different colours ($\mu_{violet} > \mu_{red}$), so $\delta_{violet} > \delta_{red}$ — white light splits into a spectrum (VIBGYOR).

13. Simple Microscope NCERT 9.7.1



⇒ Angle subtended at the eye (lens) by object and image: $\tan\beta = \frac{h_o}{u} = \frac{h_i}{v}$;

small angle ⇒ $\beta = \frac{h_o}{u}$

⇒ Object at near point without lens: $\tan\alpha \approx \alpha = \frac{h_o}{D}$

⇒ $M.P. = \frac{\beta}{\alpha} = \frac{h_o/u}{h_o/D} \Rightarrow$ **$M.P. = \frac{D}{|u|}$**

⇒ **Case 1 — image at D**: $v = -D$, object at $-u$ (u = magnitude): $\frac{1}{-D} - \frac{1}{-u} = \frac{1}{f}$

$\Rightarrow \frac{1}{u} = \frac{1}{D} + \frac{1}{f}$; multiply by D:

$$(M.P.)_{max} = \frac{D}{u_{min}} = 1 + \frac{D}{f}$$

⇒ **Case 2 — image at infinity**: $v = -\infty \Rightarrow \frac{1}{-\infty} - \frac{1}{-u} = \frac{1}{f} \Rightarrow u = f$

$$(M.P.)_{min} = \frac{D}{u_{max}} = \frac{D}{f}$$

Sample problem 1: A convex lens of focal length 2.5 cm is used as a simple microscope. Find its maximum and minimum magnifying power.

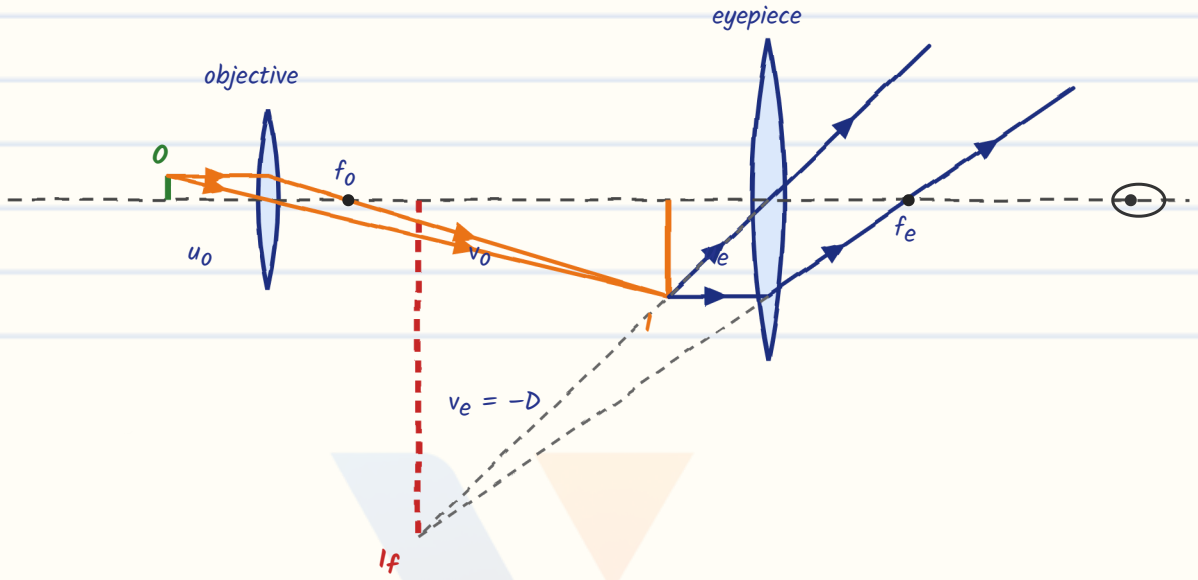
$(M.P.)_{max} = 1 + 25/2.5 = 11$; $(M.P.)_{min} = 25/2.5 = 10$

Sample problem 2: A person with normal vision reads small print with a magnifying glass of focal length 5 cm. Find the closest and farthest distance of the lens from the print.

Closest: $D/u_{min} = 1 + D/f \Rightarrow 25/u_{min} = 1 + 25/5 = 6 \Rightarrow u_{min} = 25/6$ cm ≈ 4.2 cm

Farthest: $u_{max} = f = 5$ cm

14. Compound Microscope NCERT 9.7.1



→ **Objective** forms a real, inverted, magnified image I; the **eyepiece** works as a simple microscope on I.

⇒ Total M.P. = linear magnification of objective × angular magnification of eyepiece

⇒ $m_o = \frac{v_o}{u_o}$, $m_e = \frac{D}{|u_e|}$ ⇒

$$\text{M.P.} = m_o \times m_e = -\frac{v_o}{u_o} \cdot \frac{D}{u_e}$$

⇒ **Case 1 — final image at D:** $m_e = 1 + \frac{D}{f_e}$ ⇒ $\text{M.P.} = \frac{v_o}{u_o}\left[1 + \frac{D}{f_e}\right]$, $L = v_o + |u_e|$

⇒ **Case 2 — final image at infinity:** $u_e = -f_e$ ⇒ $\text{M.P.} = \frac{v_o}{u_o}\left[\frac{D}{f_e}\right]$, $L = v_o + f_e$

⇒ Using the lens formula, v_o/u_o can also be written as $\frac{f_o}{f_o + u_o} = \frac{f_o - v_o}{f_o}$.

→ Signs for numericals: u_o −ve, v_o +ve, f_o +ve, u_e −ve, v_e −ve, f_e +ve, m_o −ve, m_e +ve ⇒ M.P. is −ve (final image inverted).

In terms of tube length l (image at infinity)

⇒ Tube length l = distance between the 2nd focal point of the objective and the 1st focal point of the eyepiece.

⇒ Ray through F_o': $\tan\theta = \frac{h_o}{f_o} = \frac{h_i}{l} \Rightarrow \frac{h_i}{h_o} = \frac{l}{f_o}$

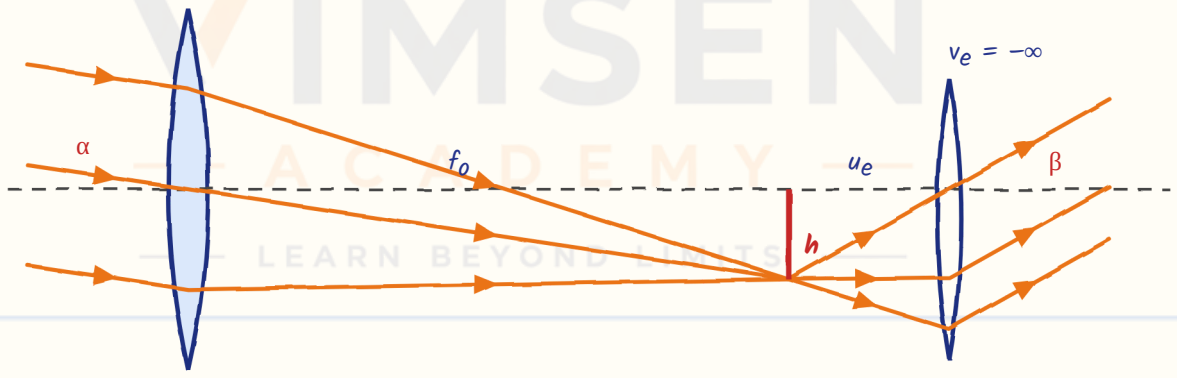
$$\text{M.P.} = -\frac{l}{f_o} \times \frac{D}{f_e}$$

Sample problem: A compound microscope has M.P. 30×. Focal length of the eyepiece is 5 cm and the final image is at 25 cm. Find the magnification of the objective.

$m_e = 1 + D/f_e = 1 + 25/5 = 6$. $\text{M.P.} = m_o \times m_e \Rightarrow -30 = m_o \times 6 \Rightarrow \mathbf{m_o = -5}$

15. Telescopes NCERT 9.7.2

Refracting (astronomical) telescope



⇒ The objective forms an image of height h at its focus (distance f_o).

⇒ Visual angle for unaided eye: $\alpha \approx \frac{h}{f_o}$; visual angle with instrument: $\beta \approx \frac{h}{|u_e|}$

⇒ $\text{M.P.} = \frac{\beta}{\alpha} = \frac{h/|u_e|}{h/f_o}$; final image is inverted $\Rightarrow \mathbf{M.P. = -\frac{f_o}{|u_e|}}$

⇒ **Case 1 — final image at D**: $v_e = -D$: $\frac{1}{-D} - \frac{1}{-|u_e|} = \frac{1}{f_e} \Rightarrow \frac{1}{|u_e|} = \frac{1}{f_e}\left[1 + \frac{f_e}{D}\right]$

$$M.P. = -\frac{f_o}{f_e}\left[1 + \frac{f_e}{D}\right] \qquad L = f_o + |u_e|$$

⇒ **Case 2 — final image at infinity** (normal adjustment): $v_e = -\infty \Rightarrow |u_e| = f_e$

$$M.P. = -\frac{f_o}{f_e} \qquad L = f_o + f_e$$

→ Objective: **large aperture** (more light, better resolution) and **large focal length** (higher M.P.).

Sample problem 1: The moon (diameter 3.5×10^3 km, distance 3.8×10^5 km) is seen through a telescope with $f_o = 4$ m, $f_e = 10$ cm in normal adjustment. Find the angular diameter of the image.

$\alpha = 3.5 \times 10^3 / 3.8 \times 10^5 \approx 0.009$ rad; $M.P. = 400/10 = 40$

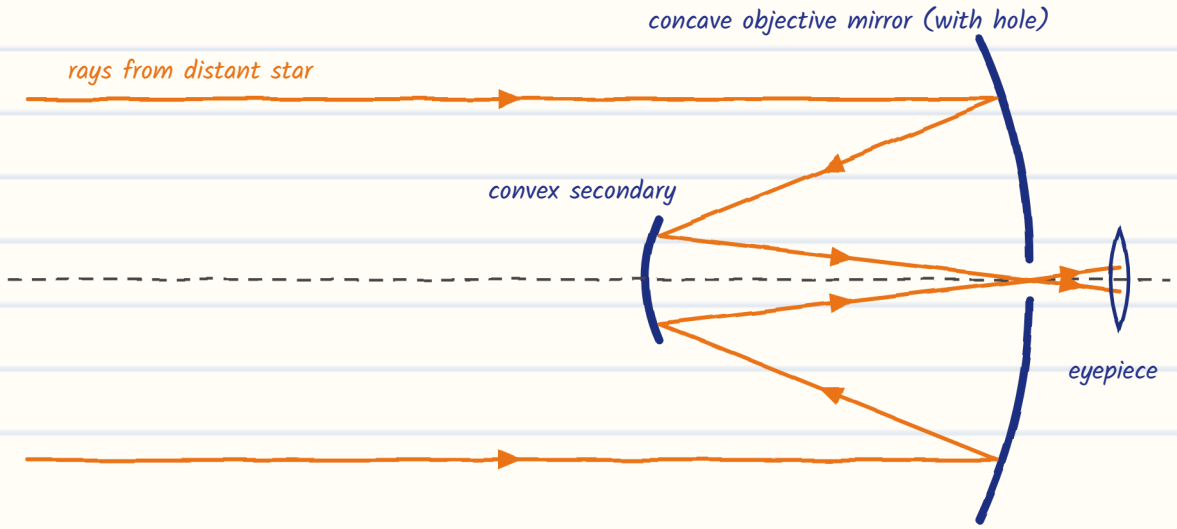
$\beta = M.P. \times \alpha = 40 \times 0.009 =$ **0.36 rad ≈ 21°**

Sample problem 2: A telescope has $f_o = 40$ cm, $f_e = 4$ cm. To view an object 200 cm from the objective (final image at infinity), find the separation of the lenses.

$v_o = u_o f_o/(u_o + f_o) = (-200 \times 40)/(-200 + 40) = 50$ cm

$L = v_o + f_e = 50 + 4 =$ **54 cm**

Cassegrain telescope (reflecting telescope)



→ Big lenses are heavy, hard to support by their edges, and expensive to make free of chromatic aberration. So modern telescopes use a **concave mirror** as the objective.

→ A convex **secondary mirror** reflects the converging light back through a **hole in the primary** to the eyepiece — this solves the problem of the focus lying inside the tube.

Advantages of a reflecting telescope
No chromatic aberration in a mirror.
A mirror weighs much less than a lens of equal optical quality.
A mirror can be supported over its entire back surface, not just its rim.

16. Formula Sheet — Quick Revision

Mirror	$f = R/2,\ 1/f = 1/u + 1/v,\ m = -v/u = f/(f-u)$
Snell's law	$\mu_1 \sin i = \mu_2 \sin r,\ \mu = c/v$
Apparent depth	$d'/d = \mu_2/\mu_1$
Normal shift	$S = t(1 - \mu_{surr}/\mu_{slab})$
Lateral shift	$d = t\sin(i-r)/\cos r,\ T = \mu t/(c\cos r)$
Critical angle	$\sin\theta_c = \mu_R/\mu_D = 1/\mu$ (in air)
Optical fibre	$\sin i_{max} = \sqrt{(\mu_1^2 - \mu_2^2)}$
Curved surface	$\mu_2/v - \mu_1/u = (\mu_2 - \mu_1)/R$
Lens maker	$1/f = (\mu_1/\mu_S - 1)(1/R_1 - 1/R_2)$
Lens	$1/v - 1/u = 1/f,\ m = v/u = f/(f+u)$
Power	$P = (\mu_1 - \mu_S)(1/R_1 - 1/R_2),\ P_{eq} = P_1 + P_2$
Prism	$A = r_1 + r_2,\ \delta = i + e - A$
Min. deviation	$\mu_p/\mu_s = \sin[(\delta_m + A)/2] \,/\, \sin(A/2)$
Thin prism	$\delta = (\mu_p/\mu_s - 1)A$
Simple microscope	$M.P. = D/\lvert u\rvert;\ 1 + D/f$ (at D), D/f (at ∞)
Compound microscope	$M.P. = (v_o/u_o)(1 + D/f_e)$ at D; $(v_o/u_o)(D/f_e)$ at ∞
Telescope	$M.P. = -f_o/f_e\ (L = f_o + f_e);\ -(f_o/f_e)(1 + f_e/D)$ at D

17. CBSE Previous Year Questions

*20 questions asked in CBSE Class 12 board papers — MCQs, assertion–reason, short and long answers, numericals and a case study. Short answers / hints are given in **green**.*

Section A — MCQ & Assertion–Reason (1 mark each)

Q1. A biconvex lens of focal length f is cut into two identical halves along a plane perpendicular to its principal axis. The focal length of each half is [1]

(a) f/2 (b) f (c) 2f (d) 4f

Ans: (c) 2f — each half is plano-convex: $1/f = (n-1)(1/R)$.

Q2. A convex lens of refractive index 1.5 has focal length f in air. When immersed in water ($n = 4/3$), its focal length becomes [1]

(a) f (b) 2f (c) 4f (d) f/4

Ans: (c) 4f — $(1.5/1.33 - 1) = 0.125 = ¼ \times (1.5 - 1)$.

Q3. The critical angle for a medium of refractive index $\sqrt{2}$ is [1]

(a) 30° (b) 45° (c) 60° (d) 90°

Ans: (b) 45° — $\sin C = 1/\sqrt{2}$.

Q4. A convex lens of focal length 20 cm and a concave lens of focal length 40 cm are kept in contact. The power of the combination is [1]

(a) +7.5 D (b) +2.5 D (c) −2.5 D (d) −7.5 D

Ans: (b) +2.5 D — $P = 5 - 2.5$.

Q5. When a ray passes through a prism in the position of minimum deviation, [1]

(a) $i > e$ (b) $i < e$ (c) the ray inside is parallel to the base (d) $r_1 > r_2$

Ans: (c) — $i = e$ and $r_1 = r_2 = A/2$.

Q6. The image formed by a convex mirror of a real object is always [1]

(a) real and inverted (b) virtual and enlarged (c) virtual, erect and diminished

(d) real and diminished

Ans: (c)

Q7. An astronomical telescope has f_o = 100 cm and f_e = 5 cm. In normal adjustment its magnifying power and length are [1]

(a) 20, 105 cm (b) 20, 95 cm (c) 500, 105 cm (d) 0.05, 95 cm

Ans: (a) — $m = 100/5$, $L = 100 + 5$.

Q8. **Assertion (A):** A diamond sparkles brilliantly. **Reason (R):** The critical angle for diamond–air interface is very small. [1]

(a) Both true, R explains A (b) Both true, R does not explain A

(c) A true, R false (d) A false, R true

Ans: (a) — $C \approx 24.4°$, so light suffers repeated TIR.

Q9. **Assertion (A):** The focal length of a concave mirror does not change when it is immersed in water. **Reason (R):** The focal length of a mirror depends only on its radius of curvature. [1]

(a) Both true, R explains A (b) Both true, R does not explain A

(c) A true, R false (d) A false, R true

Ans: (a) — $f = R/2$, independent of the medium.

Q10. For greater magnifying power and brighter image, the objective of an astronomical telescope should have [1]

(a) small f, small aperture (b) large f, large aperture (c) small f, large aperture

(d) large f, small aperture

Ans: (b)

Section B — Short & Long Answer

Q11. Define critical angle. State the conditions for total internal reflection and obtain the relation between the critical angle and the refractive index of a medium. 2

Ans: see Topic 6 — $\sin\theta_c = \mu_R/\mu_D = 1/\mu$.

Q12. Draw a ray diagram for refraction at a convex spherical surface separating two media of refractive indices n_1 and n_2 ($n_2 > n_1$). Derive $n_2/v - n_1/u = (n_2 - n_1)/R$. 3

Ans: see Topic 8.

Q13. Using the formula for refraction at a spherical surface, derive the lens maker's formula for a thin double convex lens. 3

Ans: see Topic 9 — $1/f = (\mu_1/\mu_S - 1)(1/R_1 - 1/R_2)$.

Q14. Two thin lenses of focal lengths f_1 and f_2 are kept in contact. Obtain the expression for the focal length of the combination. 2

Ans: see Topic 11 — $P_{eq} = P_1 + P_2$, i.e. $1/f = 1/f_1 + 1/f_2$.

Q15. Draw a ray diagram showing refraction through a triangular prism. Plot a graph of angle of deviation versus angle of incidence and derive the expression for the refractive index of the prism in terms of A and δ_m. 3

Ans: see Topic 12 — $\mu = \sin[(A + \delta_m)/2] / \sin(A/2)$.

Q16. A ray of light incident on an equilateral glass prism shows minimum deviation of 30°. Calculate the speed of light through the glass prism. 2

Ans: $n = \sin 45°/\sin 30° = \sqrt{2}$; $v = c/n = 3 \times 10^8/1.414 =$ **2.12×10^8 m/s**

Q17. Draw a labelled ray diagram of a compound microscope when the final image is formed at the least distance of distinct vision. Derive the expression for its magnifying power. 3

Ans: see Topic 14 — $M.P. = (v_o/u_o)(1 + D/f_e)$.

Q18. Draw a labelled ray diagram of an astronomical telescope in normal adjustment and write the expression for its magnifying power. Draw a schematic diagram of a Cassegrain reflecting telescope and give two advantages over a refracting telescope. 5

Ans: see Topic 15 — M.P. = $-f_o/f_e$; no chromatic aberration, mirror easier to support.

Q19. 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? (n of water = 1.33) 3

Ans: $\sin C = 1/1.33 \Rightarrow C \approx 48.75°$, $\tan C \approx 1.14$. Radius $r = 0.80 \times 1.14 = 0.91$ m. Area $= \pi r^2 \approx$ **2.6 m²**

Q20. **Case study — Optical fibres.** Optical fibres carry light signals over long distances by total internal reflection. A fibre has a core of refractive index n_1 surrounded by a cladding of refractive index n_2. Answer: 4

(i) For TIR at the core–cladding boundary, how must n_1 and n_2 compare?

(ii) If $n_1 = 1.5$ and $n_2 = 1.2$, find the critical angle at the boundary.

(iii) Why is there very little loss of energy in an optical fibre?

(iv) Give two uses of optical fibres.

Ans: (i) $n_1 > n_2$. (ii) $\sin C = n_2/n_1 = 0.8 \Rightarrow$ **$C \approx 53.1°$**. (iii) light is totally reflected at every point, none is refracted out. (iv) telecommunication, endoscopy.