FREE NOTES · NCERT + JEE/NEET LEVEL

Ray Optics & Optical Instruments

Mirrors, refraction, total internal reflection, lenses, the lens maker's formula, power, prisms, dispersion, microscopes and telescopes. With the sign convention, ray diagrams and solved numericals.

01 Reflection & sign convention
02 Spherical mirrors
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01 Reflection & sign convention

Laws: (1) angle of incidence = angle of reflection. (2) The incident ray, reflected ray and normal lie in one plane.

NEW CARTESIAN SIGN CONVENTION

- Measure all distances from the **pole / optical centre**.
- Along the direction of incident light (usually left to right) is +, opposite is −.
- Above the principal axis +, below −.
- The object is usually on the left ⇒ u is always **negative**.

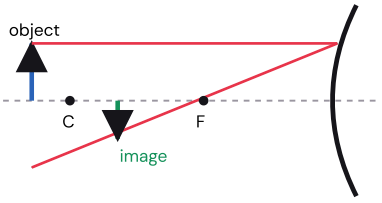
Plane mirror: image as far behind as the object is in front, virtual, erect, same size, laterally inverted. Rotating the mirror by θ turns the reflected ray by 2θ.

02 Spherical mirrors

$$1/v + 1/u = 1/f,\ f = R/2$$

$$\text{Magnification } m = h'/h = -v/u$$

Concave: f negative. Convex: f positive. m negative ⇒ real, inverted image. m positive ⇒ virtual, erect.



Concave mirror: real, inverted image

Object (concave mirror)	Image
At infinity	At F, highly diminished, real
Beyond C	Between F and C, diminished, real, inverted
At C	At C, same size, real, inverted
Between F and C	Beyond C, enlarged, real, inverted
At F	At infinity
Between F and P	Behind the mirror, enlarged, virtual, erect (shaving mirror)

Convex mirror: always virtual, erect and diminished. Shows a wide area ⇒ vehicle rear-view mirror.

03 Refraction

$$\text{Snell's law: } n_1 \sin i = n_2 \sin r$$

$n = c/v$ (refractive index), $n_{21} = n_2/n_1$

Going from a rarer to a denser medium (air → glass), the ray bends toward the normal. Frequency stays the same; speed and λ change.

APPARENT DEPTH

A coin in water looks raised: apparent depth = real depth/n. Shift = d(1 − 1/n).

GLASS SLAB

The emergent ray is parallel to the incident ray, only **shifted sideways** (lateral shift). Thicker slab or larger i ⇒ more shift.

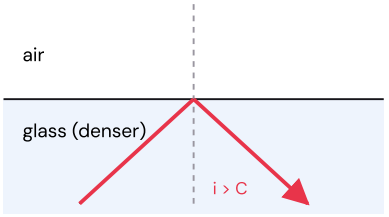
The Sun is visible even when it's just below the horizon (atmospheric refraction) ⇒ the day is ≈ 4 minutes longer. Stars twinkle for the same reason.

04 Total internal reflection (TIR)

Light going from a denser to a rarer medium: as the angle increases, at one angle the refracted ray grazes the surface. Beyond it, the light is **totally** reflected back.

$$\sin C = 1/n \; (n = n_{dense}/n_{rare})$$

Two conditions: (1) denser to rarer, (2) i > C. Glass C ≈ 42°, water ≈ 49°, diamond ≈ 24°.



All the light reflects back inside

Examples: a diamond's sparkle (small C), optical fibres (repeated TIR inside), mirages (hot air over sand), totally reflecting prisms (periscopes, binoculars).

05 Refraction at a curved surface

$$n_2/v - n_1/u = (n_2 - n_1)/R$$

n_1 = medium the light comes from, n_2 = medium it enters. Same sign convention. The lens formula is derived from this.

06 Lenses & the lens maker's formula

LENS MAKER'S FORMULA

$$1/f = (n - 1)(1/R_1 - 1/R_2)$$

In a medium, replace n by n_{lens}/n_{medium}. If $n_{lens} = n_{medium}$, the lens disappears (f = ∞). In a denser medium a convex lens acts like a concave one (like an air bubble in water).

THIN LENS FORMULA

$$1/v - 1/u = 1/f$$

$$m = v/u$$

Convex (converging): f +. Concave (diverging): f -.

MIRROR VS LENS

Mirror: 1/v + 1/u, m = -v/u. Lens: 1/v − 1/u, m = +v/u. This is the most common mistake.

A convex lens's image table is like a concave mirror's (with 2F and F). Object inside F ⇒ virtual, enlarged image (magnifying glass). Concave lens: always virtual, erect, diminished.

07 Power & combination of lenses

$$P = 1/f \text{ (f in metres)}$$

Unit dioptre (D). Convex +, concave −. This is the number on a spectacle prescription.

LENSES IN CONTACT

$P = P_1 + P_2$, $1/f = 1/f_1 + 1/f_2$

Separated by d: $1/f = 1/f_1 + 1/f_2 - d/(f_1 f_2)$

Total magnification $m = m_1 \times m_2$

Covering half a lens: the full image still forms, only dimmer (half the intensity). **Cutting a biconvex lens:** cut along the principal axis into two halves and each keeps the same f; cut parallel to the lens plane through the middle (two plano-convex halves) and each has f doubled.

08 Prism

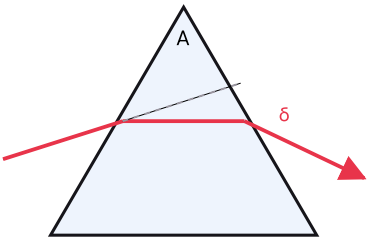
$A = r_1 + r_2$

Deviation $\delta = i + e - A$

At minimum deviation: i = e, $r_1 = r_2 = A/2$, the ray inside is parallel to the base.

$$n = \sin((A + \delta_m)/2) \,/\, \sin(A/2)$$

Thin prism (small A): $\delta = (n - 1)A$.



The ray bends toward the base

09 Dispersion & scattering

White light splits into 7 colours in a prism (VIBGYOR) because each colour has a different n. **Violet has the largest n** ⇒ bends most; red the least.

$$\text{Angular dispersion} = \delta_v - \delta_r = (n_v - n_r)A$$

$$\text{Dispersive power } \omega = (n_v - n_r)/(n - 1)$$

Phenomenon	Reason
Rainbow	Refraction + internal reflection + dispersion in drops; the Sun must be behind you
Blue sky	Scattering $\propto 1/\lambda^4$ (Rayleigh): blue scatters most
Red sunrise/sunset	Long path; blue is scattered away, red remains
White clouds	Large droplets scatter all colours equally
Red danger signals	Red scatters least, visible from far away

10 Simple & compound microscope

THE EYE

Least distance of distinct vision D = 25 cm (normal eye). Near point 25 cm, far point infinity.

SIMPLE MICROSCOPE (CONVEX LENS)

$$\text{Image at D: } m = 1 + D/f$$

$$\text{Image at infinity: } m = D/f$$

COMPOUND MICROSCOPE

$$m = m_o \times m_e$$

$$\text{At infinity: } m \approx (L/f_o)(D/f_e)$$

Both objective and eyepiece have short f. L = tube length.

11 Telescope

REFRACTING (ASTRONOMICAL) TELESCOPE

Normal adjustment (image at infinity): $m = f_o/f_e$, tube length $L = f_o + f_e$

Image at D: $m = (f_o/f_e)(1 + f_e/D)$

Objective: long f and large aperture (more light, better resolving power); eyepiece: short f.

	Microscope	Telescope
Objective	Short f, small aperture	Long f, large aperture
Used for	Small nearby objects	Distant objects

REFLECTING TELESCOPE (CASSEGRAIN)

A concave mirror replaces the objective. Advantages: no chromatic aberration; a large mirror is easier to make and support (lenses are heavy and fragile); a parabolic mirror removes spherical aberration.

12 JEE Extra + Tricks

JEE LEVEL

- Prism: $n = \sin((A + \delta_m)/2)/\sin(A/2)$; thin prism $\delta = (n - 1)A$.
- Apparent depth = real depth / n (seen normally); shift = $t(1 - 1/n)$.
- Lens combination: $P = P_1 + P_2$ (in contact); separated by d: $P = P_1 + P_2 - dP_1P_2$.
- Silvered lens acts as a mirror: $P_{eq} = 2P_{lens} + P_{mirror}$.
- Lens cut along axis: f same, intensity halves; cut perpendicular to axis: each half has 2f.
- Microscope $M \approx (L/f_o)(D/f_e)$; telescope $M = f_o/f_e$, length $f_o + f_e$ (normal adjustment).

13 Solved numericals

Q1. Concave mirror f = 15 cm, object at 30 cm. Where is the image and what is it like?
$1/v = 1/f - 1/u = -1/15 + 1/30 = -1/30 \Rightarrow v = -30$ cm. $m = -1$. **Ans: 30 cm in front, real, inverted, same size**

Q2. Convex lens f = 10 cm, object at 15 cm. Image?
$1/v = 1/f + 1/u = 1/10 - 1/15 = 1/30 \Rightarrow v = +30$ cm. $m = v/u = -2$. **Ans: 30 cm, real, inverted, twice the size**

Q3. Glass n = 1.5. Critical angle?
$\sin C = 1/1.5 = 0.667 \Rightarrow C \approx 41.8°$. **Ans: ≈ 42°**

Q4. Biconvex lens $R_1 = R_2 = 20$ cm, n = 1.5. f and power?
$1/f = 0.5(1/20 + 1/20) = 1/20 \Rightarrow f = 20$ cm, $P = +5$ D. **Ans: 20 cm, +5 D**

Q5. +4 D and −2 D lenses in contact. f?
$P = +2$ D $\Rightarrow f = 50$ cm (convex). **Ans: 50 cm**

Q6. Prism A = 60°, $\delta_m = 30°$. n?
$n = \sin 45°/\sin 30° = 0.707/0.5 \approx 1.414$. **Ans: √2**

Q7. Telescope $f_o = 100$ cm, $f_e = 5$ cm. m and tube length in normal adjustment?
m = 20, L = 105 cm. **Ans: 20, 105 cm**

14 Common mistakes

- Mixing up the + and − in the mirror and lens formulas.
- Putting u as positive (object on the left ⇒ u negative).
- Keeping f in cm when finding power (use metres).
- Forgetting the TIR condition: light must go from denser to rarer.
- Thinking violet bends least (it bends most).
- Thinking covering half a lens gives half an image.

15 Formula sheet

Mirror	$1/v + 1/u = 1/f,\ f = R/2,\ m = -v/u$
Snell	$n_1 \sin i = n_2 \sin r$
Apparent depth	real/n
Critical angle	$\sin C = 1/n$
Spherical surface	$n_2/v - n_1/u = (n_2 - n_1)/R$
Lens maker	$1/f = (n-1)(1/R_1 - 1/R_2)$
Lens	$1/v - 1/u = 1/f,\ m = v/u$
Power	$P = 1/f,\ P = P_1 + P_2$
Prism	$n = \sin((A + \delta_m)/2)/\sin(A/2),\ \delta = (n-1)A$
Simple microscope	$m = 1 + D/f$
Compound microscope	$(L/f_o)(D/f_e)$
Telescope	$f_o/f_e,\ L = f_o + f_e$

16 Practice questions

1. Convex mirror f = 20 cm, object at 20 cm. Image?
2. How deep does a 2 m deep pond of water (n = 4/3) appear?
3. A convex lens (n = 1.5, f = 20 cm) is placed in water (4/3). New f?
4. A magnifying glass has f = 5 cm. Maximum magnification?

ANSWERS

1) v = +10 cm, virtual, m = 0.5 · 2) 1.5 m · 3) (1.5 − 1)/(1.125 − 1) = 4 times ⇒ 80 cm · 4) 1 + 25/5 = 6

17 Quick revision: 5 minutes before the exam

MIRROR & LENS

- Mirror $1/v + 1/u$; lens $1/v - 1/u$.
- u is always −.
- P = 1/f (m), dioptre.

REFRACTION

- $n_1 \sin i = n_2 \sin r$.
- $\sin C = 1/n$; denser → rarer.
- Diamond, fibre, mirage = TIR.

PRISM

- δ_m: i = e.
- Violet bends most.
- Blue sky: $1/\lambda^4$.

INSTRUMENTS

- Simple: 1 + D/f.
- Telescope: f_o/f_e.
- Reflecting: no chromatic aberration.

Have a doubt? Ask the AI Doubt Solver at padhaiadda.netlify.app, or take the mock test on this chapter.