KSQUARE CAREER INSTITUTE

RAY OPTICS & OPTICAL INSTRUMENTS

Class 12 Physics • Complete Chapter Notes with Ray Diagrams • NEET / JEE

Scan to get all notes

Chapter at a Glance

1. Reflection — laws, plane mirror, spherical mirrors, sign convention, mirror formula, magnification
2. Refraction — Snell's law, refractive index, real & apparent depth, lateral shift
3. Total internal reflection — critical angle & applications (optical fibre, mirage, diamond, prism)
4. Refraction at spherical surfaces, lens maker's formula, thin lens formula, power & combination of lenses
5. Prism — deviation, minimum deviation, thin prism, dispersion; scattering of light
6. Optical instruments — human eye & its defects, simple & compound microscope, telescopes
7. Formula sheet, important points & PYQ-style practice

NEET Point / PYQ Alert

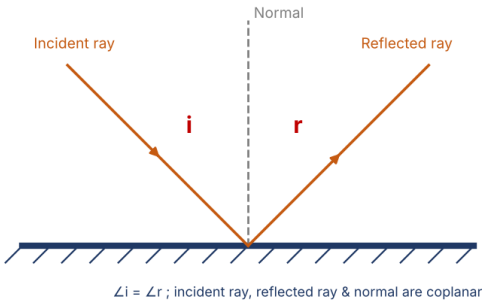
Ray optics regularly carries **2–3 questions in NEET** — mirror/lens formula numericals, prism and microscope/telescope magnification are the favourites.

1. REFLECTION OF LIGHT

Laws of reflection

(i) The **angle of incidence = angle of reflection** ($\angle i = \angle r$).

(ii) The **incident ray, reflected ray and the normal** at the point of incidence lie in the **same plane**.



$\angle i = \angle r$; incident ray, reflected ray & normal are coplanar

Plane Mirror

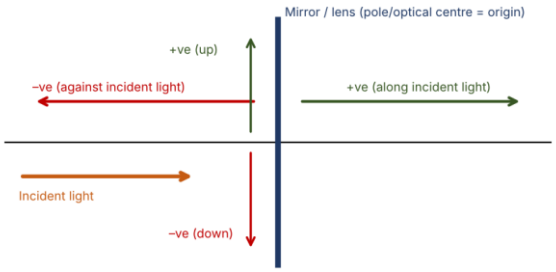
- Image is **virtual, erect, laterally inverted**, same size, and as far behind the mirror as the object is in front (magnification m = +1).
- Minimum length of mirror to see the full image of a person = **half the height** of the person.

- If the mirror is rotated by θ, the reflected ray rotates by **2θ**.
- Number of images by two mirrors inclined at θ: n = 360°/θ – 1 (if 360°/θ is even); n = 360°/θ (if odd, object asymmetric).
- If a mirror moves with speed v, the image moves with **2v** relative to the object (for motion along the normal).

2. SPHERICAL MIRRORS

Term	Meaning
Pole (P)	Centre of the reflecting surface
Centre of curvature (C)	Centre of the sphere of which the mirror is a part
Radius of curvature (R)	Distance PC
Principal focus (F)	Point where rays parallel to the axis meet (concave) or appear to diverge from (convex) after reflection
Focal length (f)	PF; **f = R/2**

New Cartesian Sign Convention



1. All distances are measured from the **pole** (mirror) or **optical centre** (lens).
2. Distances **along the incident light** are **+ve**; against it are **–ve**.
3. Heights **above** the principal axis are **+ve**, below are **–ve**.

NEET Point / PYQ Alert

Concave mirror: **f, R negative**; convex mirror: **f, R positive**. Real object: u is always negative.

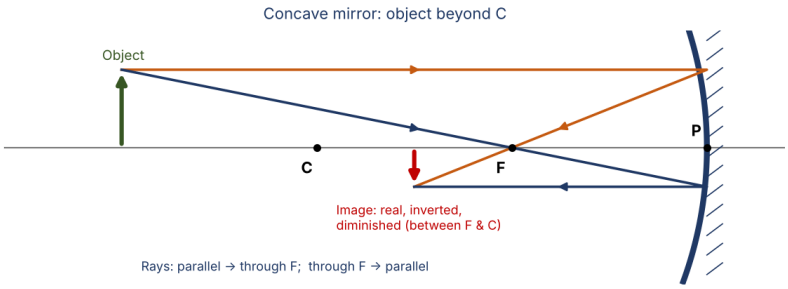
Mirror Formula & Magnification

Mirror

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

$$m = h'/h = -v/u$$

$$\text{Areal magnification} = m^2\,; \ \text{longitudinal magnification (small objects)} = -m^2$$



▸ Image Formation by a Concave Mirror

Object position	Image position	Nature & size
At infinity	At F	Real, inverted, highly diminished (point)
Beyond C	Between F and C	Real, inverted, diminished
At C	At C	Real, inverted, same size
Between C and F	Beyond C	Real, inverted, magnified
At F	At infinity	Real, inverted, highly magnified
Between F and P	Behind the mirror	**Virtual, erect, magnified**

▸ Image Formation by a Convex Mirror

- For any position of a real object, the image is **virtual, erect, diminished**, formed **between P and F** behind the mirror.
- Uses: **rear-view mirror** in vehicles (wide field of view); concave mirror: shaving/dental mirror, headlight & solar-furnace reflectors.

Quick rules for ray diagrams

Ray parallel to the axis → passes through F (concave) / appears to come from F (convex).

Ray through F → becomes parallel to the axis.

Ray through C → retraces its path.

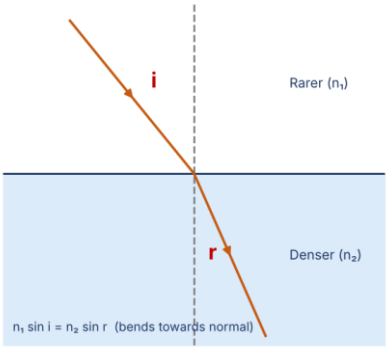
Ray striking the pole → reflects symmetrically about the axis.

3. REFRACTION OF LIGHT

Laws of refraction

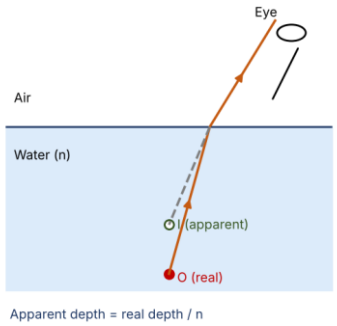
(i) Incident ray, refracted ray and normal lie in the **same plane**.

(ii) **Snell's law:** $n_1 \sin i = n_2 \sin r \Rightarrow \sin i / \sin r = n_2/n_1 = {}_1n_2$ (constant).



- Absolute refractive index **n = c/v** (speed of light in vacuum / in medium).
- Going from **rarer → denser**, the ray bends **towards the normal**; denser → rarer bends **away**.
- Frequency does **not** change on refraction; **speed and wavelength** change: $\lambda_{medium} = \lambda/n$.
- n depends on the medium and wavelength ($n_{violet} > n_{red}$) — **Cauchy's relation**: $n = A + B/\lambda^2$.

Real & Apparent Depth



Apparent depth

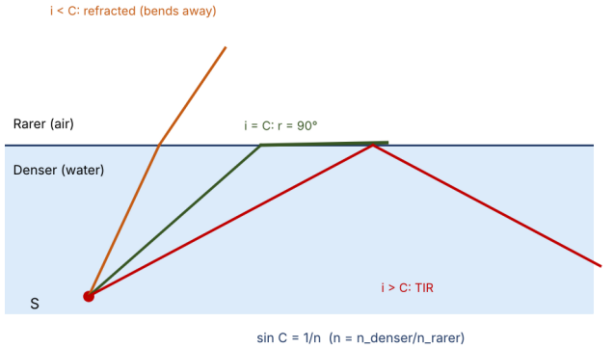
$$\text{Apparent depth} = \text{Real depth} / n$$

$$\text{Apparent shift (normal rise)} = t\,(1 - 1/n)$$

$$\text{For several slabs: apparent depth} = \Sigma\,(t_i / n_i)$$

- Examples: a pond appears shallower; a coin in water appears raised; a pencil dipped in water appears bent.
- **Lateral shift** through a glass slab of thickness t: $d = t \sin(i - r)/\cos r$ (emergent ray is parallel to incident ray).

4. TOTAL INTERNAL REFLECTION (TIR)



- When light goes from a **denser to a rarer** medium and the angle of incidence **exceeds the critical angle C**, light is **totally reflected** back into the denser medium.
- **Conditions:** (i) light must travel from denser to rarer; (ii) i > C.

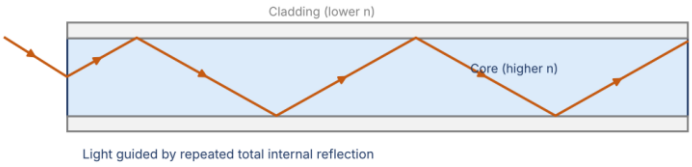
Critical angle

$$\sin C = 1/n = n_{rarer}/n_{denser}$$

Glass ($n = 1.5$): $C \approx 42°$; water ($n = 1.33$): $C \approx 48.75°$; diamond ($n = 2.42$): $C \approx 24.4°$

Applications of TIR

Application	Explanation
Optical fibres	Light travels through the high-n core by repeated TIR at the core–cladding boundary; used in telecommunication, endoscopy
Sparkling of diamond	Very small critical angle (≈ 24°) — light entering undergoes multiple TIR before emerging
Mirage	Hot air near the ground is rarer; light from distant objects is totally reflected — an inverted image appears like water
Totally reflecting prisms	Right-angled isosceles prisms bend light by 90° or 180° (periscopes, binoculars)
Looming	In cold regions, objects appear to float in air (inverted mirage)



5. REFRACTION AT A SPHERICAL SURFACE & LENSES

Single spherical surface

$$n_2/v - n_1/u = (n_2 - n_1)/R \quad \text{(light from medium } n_1 \text{ to } n_2\text{)}$$

Lens maker's formula

$$1/f = (n_{rel} - 1)\,(1/R_1 - 1/R_2)\,, \quad n_{rel} = n_{lens}/n_{medium}$$

Biconvex (R_1 +, R_2 −) ⇒ converging; biconcave ⇒ diverging

Thin lens formula & magnification

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

$$m = h'/h = v/u$$

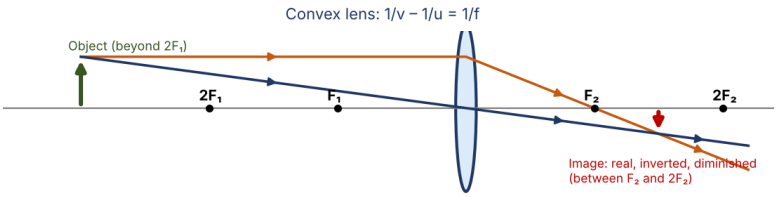


Image Formation by a Convex Lens

Object position	Image position	Nature & size
At infinity	At F_2	Real, inverted, point-sized
Beyond $2F_1$	Between F_2 and $2F_2$	Real, inverted, diminished
At $2F_1$	At $2F_2$	Real, inverted, same size
Between F_1 and $2F_1$	Beyond $2F_2$	Real, inverted, magnified
At F_1	At infinity	Real, inverted, highly magnified
Between F_1 and O	Same side as object	**Virtual, erect, magnified** (magnifying glass)

- A **concave lens** always forms a **virtual, erect, diminished** image between F and O for a real object.

Important lens facts

If a lens is immersed in a liquid of the **same n**, it behaves like a plane glass plate (f → ∞).

If $n_{medium} > n_{lens}$, a convex lens behaves as a **diverging** lens.

Covering half of a lens does **not** cut the image — only its **intensity (brightness) reduces**.

Cutting a lens perpendicular to the axis (two plano-convex halves): each half has f' = **2f**; cutting along the axis: f unchanged.

Power of a Lens & Combination

Power

$$P = 1/f \text{ (in metre)} \quad \text{unit: dioptre (D)}$$

Convex: P positive; concave: P negative

Lenses in contact: $1/F = 1/f_1 + 1/f_2$; $P = P_1 + P_2$; $m = m_1 \times m_2$

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

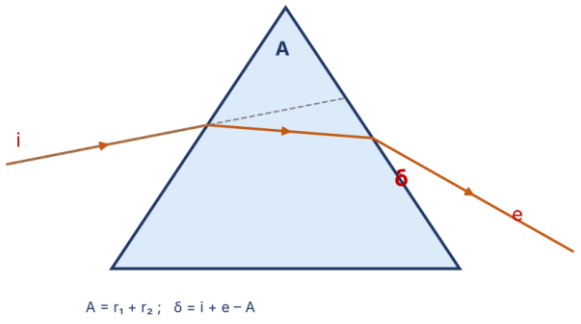
Silvered Lens / Lens–Mirror Combination

Silvered lens behaves as a mirror

$$1/F = 2/f_{lens} + 1/f_{mirror} \quad (P = 2P_L + P_M)$$

Plano-convex silvered on the plane face: $F = f/2$; silvered on the curved face: $F = R/2n$

6. REFRACTION THROUGH A PRISM



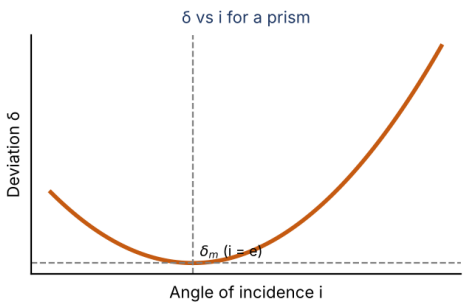
Prism relations

$$A = r_1 + r_2$$

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

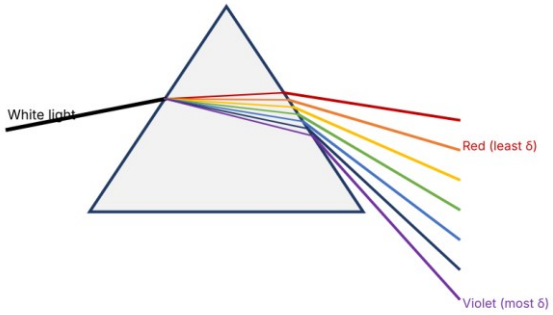
At minimum deviation: $i = e$, $r_1 = r_2 = A/2$

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



- As i increases, δ first **decreases**, reaches a **minimum δ_m** (ray passes symmetrically, parallel to the base for an equilateral prism) and then increases.
- **Thin prism** (A small): **$\delta = (n - 1)A$**.
- **Condition of no emergence:** if A > 2C, no ray emerges from the second face.

Dispersion of Light



- Splitting of white light into its constituent colours (**VIBGYOR**) by a prism, because n depends on wavelength.
- **Violet deviates most** (highest n, smallest λ); **red deviates least**.
- **Angular dispersion** = $\delta_V - \delta_R = (n_V - n_R)A$; **dispersive power** $\omega = (n_V - n_R)/(n_Y - 1)$.
- **Rainbow** — dispersion + refraction + **internal reflection** in water droplets (primary: one internal reflection, red outside; secondary: two reflections, colours reversed).

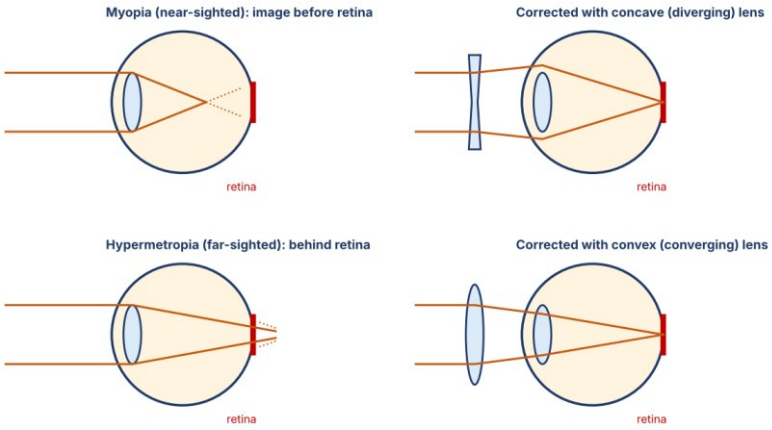
Scattering of Light

- **Rayleigh scattering:** intensity of scattered light $\propto 1/\lambda^4$ (for particles much smaller than λ).
- **Sky is blue** — blue light (short λ) is scattered most by air molecules.
- **Sun appears red at sunrise/sunset** — light travels a longer path, blue is scattered away, red reaches the eye.
- **Clouds appear white** — large droplets scatter all colours nearly equally.
- Danger signals are **red** — least scattered, visible from far.

7. OPTICAL INSTRUMENTS

Human Eye

- Eye lens forms a **real, inverted** image on the **retina**; **ciliary muscles** change the focal length — **power of accommodation**.
- **Near point** (least distance of distinct vision) D = **25 cm**; **far point** = **infinity** for a normal eye.



Defect	Cause	Image	Correction
Myopia (short-sightedness)	Eyeball too long / lens too converging; far point < ∞	Forms **in front of** retina	**Concave lens**, f = – (far point distance)
Hypermetropia (long-sightedness)	Eyeball too short / lens less converging; near point > 25 cm	Forms **behind** retina	**Convex lens**: 1/f = 1/25 – 1/(near point) (cm)
Presbyopia	Ageing — ciliary muscles weaken, lens loses flexibility	Near objects blurred	**Bifocal lens** (concave top, convex bottom)
Astigmatism	Cornea not spherical (different curvature in different planes)	Lines in one direction blurred	**Cylindrical lens**

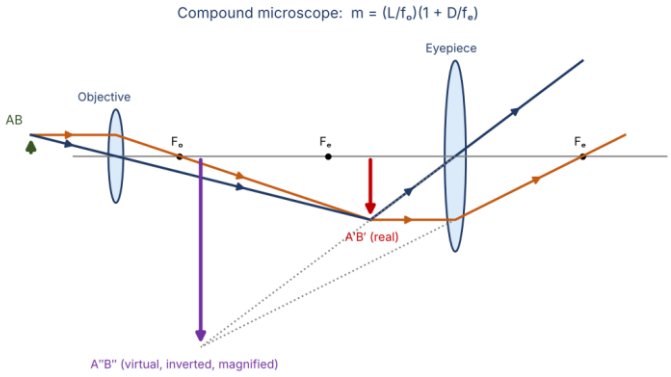
Simple Microscope (Magnifying Glass)

Magnifying power

Image at D (near point): $m = 1 + D/f$

Image at infinity (relaxed eye): $m = D/f$

Compound Microscope



- **Objective** — small focal length & small aperture; forms a **real, inverted, magnified** image A’B’ within the focus of the eyepiece.

- **Eyepiece** — acts as a simple microscope, giving a **virtual, magnified** final image (inverted w.r.t. the object).

Magnifying power

$$m = m_o \times m_e$$

Final image at D: $m = (L/f_o)(1 + D/f_e)$

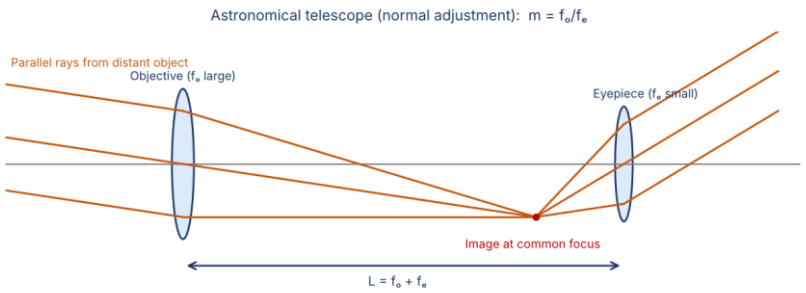
Final image at infinity (normal adjustment): $m = (L/f_o)(D/f_e)$

$L \approx$ length of tube (distance between the second focal point of objective and first focal point of eyepiece)

NEET Point / PYQ Alert

For high magnifying power, **both f_o and f_e should be small** ($f_o < f_e$).

Astronomical (Refracting) Telescope



- **Objective** — large focal length & large aperture (gathers more light, better resolution); **eyepiece** — small focal length.

Magnifying power

Normal adjustment (final image at ∞): $m = f_o/f_e$; length $L = f_o + f_e$

Final image at D: $m = (f_o/f_e)(1 + f_e/D)$; $L = f_o + u_e$

NEET Point / PYQ Alert

For high magnifying power: **f_o large, f_e small**. Final image is **inverted** — use a terrestrial telescope (erecting lens) or Galilean telescope for erect images.

Reflecting Telescope (Cassegrain)

- Uses a large **concave (parabolic) mirror** as objective and a small convex secondary mirror.
- Advantages: **no chromatic aberration**, spherical aberration removed with a parabolic mirror, easier to support (large mirrors are lighter than large lenses), cheaper, higher resolving power.

▸ Resolving Power (Brief)

- Telescope: RP = D/(1.22λ) (D = aperture) — larger aperture ⇒ better resolution.
- Microscope: RP = 2n sin θ/(1.22λ) — use of oil (higher n) or shorter λ improves resolution.

PRACTICE QUESTIONS (PYQ-STYLE)

Q1. An object is placed 40 cm from a concave mirror of focal length 15 cm. If the object is displaced 20 cm towards the mirror, the displacement of the image is **[NEET 2018]**

(a) 30 cm towards the mirror
(b) 36 cm away from the mirror
(c) 30 cm away from the mirror
(d) 36 cm towards the mirror

Answer: (b) — u = –40: v = –24 cm; u = –20: v = –60 cm ⇒ image moves 36 cm away from the mirror.

Q2. An astronomical telescope has objective and eyepiece of focal lengths 40 cm and 4 cm. To view an object 200 cm away from the objective in normal adjustment, the lenses must be separated by **[NEET 2016]**

(a) 54.0 cm
(b) 37.3 cm
(c) 46.0 cm
(d) 50.0 cm

Answer: (a) — Objective: 1/v = 1/40 – 1/200 ⇒ v = 50 cm; L = 50 + 4 = 54 cm.

Q3. The critical angle for glass of refractive index 1.5 ($\sin^{-1}$ 0.67) is about

(a) 30°
(b) 42°
(c) 48°
(d) 60°

Answer: (b) — sin C = 1/1.5.

Q4. A coin at the bottom of a 12 cm deep water tank (n = 4/3) appears raised by

(a) 9 cm
(b) 3 cm
(c) 4 cm
(d) 1.5 cm

Answer: (b) — Apparent depth = 12/(4/3) = 9 cm ⇒ shift 3 cm.

Q5. The power of a lens of focal length –25 cm is

(a) +4 D
(b) –4 D
(c) –0.25 D
(d) +0.25 D

Answer: (b) — P = 1/(–0.25 m).

Q6. A convex lens of focal length 20 cm (n = 1.5) is immersed in water (n = 4/3). Its focal length becomes

(a) 20 cm
(b) 40 cm
(c) 60 cm
(d) 80 cm

Answer: (d) — $f \propto 1/(n_{rel} - 1)$: (1.5 – 1)/(1.125 – 1) = 4 ⇒ 80 cm.

Q7. A thin prism of angle 5° and n = 1.5 produces a deviation of

(a) 2.5°
(b) 5°
(c) 7.5°
(d) 1°

Answer: (a) — $\delta = (n - 1)A$.

Q8. For an equilateral prism at minimum deviation $\delta_m = 60°$, the refractive index is

(a) √2
(b) √3
(c) 1.5
(d) 2

Answer: (b) — $n = \sin 60°/\sin 30°$.

Q9. The sky appears blue because

(a) blue light is absorbed
(b) blue light is scattered most ($\propto 1/\lambda^4$)
(c) red light is scattered most
(d) of dispersion

Answer: (b)

Q10. A myopic person has a far point of 2 m. The power of the lens required is

(a) +0.5 D
(b) –0.5 D
(c) –2 D
(d) +2 D

Answer: (b) — $f = -2$ m.

Q11. A compound microscope has $f_o = 1$ cm, $f_e = 5$ cm and tube length L = 15 cm. Magnifying power in normal adjustment (D = 25 cm) is

(a) 15
(b) 75
(c) 90
(d) 125

Answer: (b) — $m = (L/f_o)(D/f_e) = 15 \times 5$.

Q12. Two thin lenses of power +5 D and –3 D are placed in contact. The focal length of the combination is

(a) 50 cm
(b) 20 cm
(c) 33 cm
(d) 12.5 cm

Answer: (a) — $P = +2$ D $\Rightarrow f = 0.5$ m.

Q13. If the lower half of a convex lens is covered with black paper,

(a) only half the image is formed
(b) no image is formed
(c) full image forms but its intensity is reduced
(d) image becomes inverted

Answer: (c)

Q14. For a telescope with large magnifying power we need

(a) f_o small, f_e large
(b) f_o large, f_e small
(c) both large
(d) both small

Answer: (b) — $m = f_o/f_e$.

FORMULA SHEET

Topic	Formula
Mirror	$1/v + 1/u = 1/f$; $f = R/2$; $m = -v/u$
Snell's law	$n_1 \sin i = n_2 \sin r$; $n = c/v$; $\lambda_{medium} = \lambda/n$
Apparent depth	$d' = d/n$; shift $= t(1 - 1/n)$
Critical angle	$\sin C = 1/n$
Spherical surface	$n_2/v - n_1/u = (n_2 - n_1)/R$
Lens maker	$1/f = (n_{rel} - 1)(1/R_1 - 1/R_2)$
Thin lens	$1/v - 1/u = 1/f$; $m = v/u$; $P = 1/f$ (m)
Combination	$P = P_1 + P_2$; $1/F = 1/f_1 + 1/f_2 - d/f_1f_2$
Prism	$A = r_1 + r_2$; $\delta = i + e - A$; $n = \sin[(A + \delta_m)/2]/\sin(A/2)$; thin: $\delta = (n - 1)A$
Dispersion	$\theta = (n_V - n_R)A$; $\omega = (n_V - n_R)/(n_Y - 1)$
Simple microscope	$m = 1 + D/f$ (at D); D/f (at ∞)
Compound microscope	$m = (L/f_o)(1 + D/f_e)$; $(L/f_o)(D/f_e)$ at ∞
Telescope	$m = f_o/f_e$, $L = f_o + f_e$ (normal); $m = (f_o/f_e)(1 + f_e/D)$ at D
Rayleigh scattering	$I \propto 1/\lambda^4$

See it, draw it, solve it — ray diagrams are the key to ray optics!