APPLIED PHYSICS 2

2nd Semester — Diploma / Polytechnic

UNIT 2: OPTICS

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1. Basic Optical Laws

1.1 Reflection of Light

Reflection is the bouncing back of light when it strikes a smooth, polished surface.

Laws of Reflection:

- The incident ray, reflected ray, and normal — all lie in the same plane.
- The angle of incidence (i) is always equal to the angle of reflection (r).

Law of Reflection

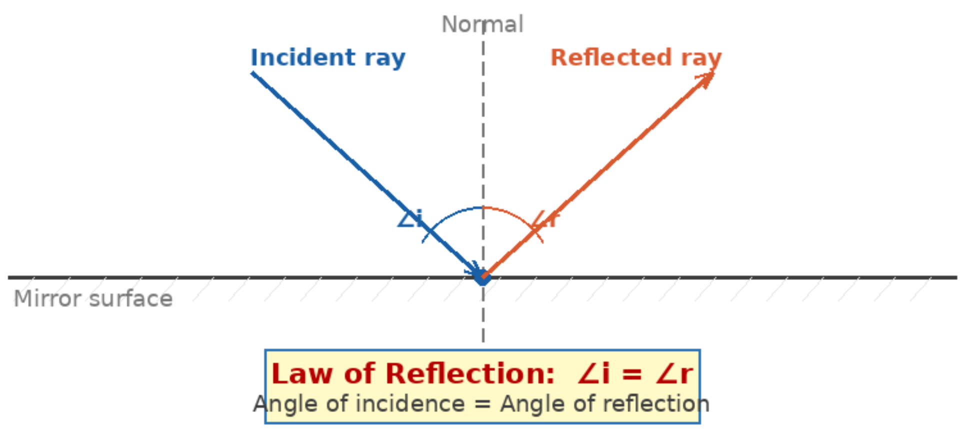
$\angle i = \angle r$

Angles measured from the Normal to the surface

Ray Diagram Description:

- Draw a flat mirror (horizontal line).
- Draw the Normal (perpendicular to the mirror at the point of incidence).
- The incoming ray (incident ray) makes angle i with the Normal.
- The outgoing ray (reflected ray) makes equal angle r on the other side of the Normal.

Diagram 1: Law of Reflection



1.2 Refraction of Light

Refraction is the bending of light when it passes from one medium to another due to a change in speed.

Laws of Refraction (Snell's Law):

- The incident ray, refracted ray, and normal at the point of incidence all lie in the same plane.
- The ratio of the sine of the angle of incidence to the sine of the angle of refraction is constant for a given pair of media.

Snell's Law

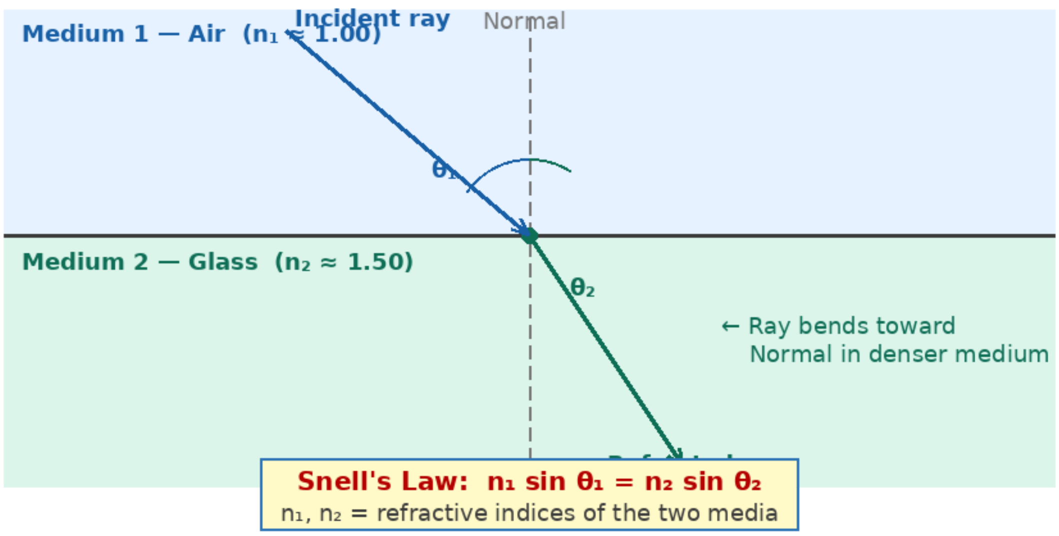
$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

n_1 , n_2 = refractive indices of medium 1 and 2

Ray Diagram Description:

- Draw an interface between two media (e.g., air above, glass below).
- Draw the Normal perpendicular to the interface.
- The incident ray in air makes angle θ_1 with the Normal.
- On entering glass (denser medium), the ray bends towards the Normal, making smaller angle θ_2 .
- On going from denser to rarer medium, the ray bends away from the Normal.

Diagram 2: Refraction — Snell's Law



1.3 Refractive Index

The refractive index (n) of a medium is the ratio of the speed of light in vacuum to the speed of light in that medium.

Refractive Index

$$n = c / v$$

c = speed of light in vacuum (3×10^8 m/s), v = speed in medium

- For air/vacuum: $n \approx 1$
- For glass: $n \approx 1.5$
- For water: $n \approx 1.33$
- Higher refractive index → denser medium → light slows down more.

2. Thin Lenses

A lens is a transparent medium bounded by two curved surfaces. Thin lenses are those whose thickness is negligible compared to their radii of curvature.

Types of Lenses:

- Convex Lens (Converging Lens): Thicker at the centre, converges parallel rays to a focal point.
- Concave Lens (Diverging Lens): Thinner at the centre, diverges parallel rays away from a focal point.

2.1 Image Formation by Lenses

Convex Lens – Image Formation Rules:

- A ray parallel to the principal axis passes through the principal focus (F) after refraction.
- A ray passing through the optical centre goes straight without bending.
- A ray passing through (or directed towards) F emerges parallel to the principal axis.

Image positions (Convex Lens):

Object Position	Image Position	Nature / Size
Beyond 2F	Between F and 2F	Real, Inverted, Diminished
At 2F	At 2F	Real, Inverted, Same size
Between F and 2F	Beyond 2F	Real, Inverted, Magnified
At F	At Infinity	Real, Inverted, Very large
Between F and Lens	Same side as object	Virtual, Erect, Magnified

2.2 Lens Formula

The lens formula relates the object distance (u), image distance (v), and focal length (f) of a lens.

Lens Formula

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

Use Sign Convention: Distances measured from optical centre. Distances along incident light = positive.

2.3 Lens Maker's Formula

This formula relates the focal length of a lens to its radii of curvature and refractive index.

Lens Maker's Formula

$$1/f = (n - 1)\ [\ 1/R_1 - 1/R_2\ ]$$

n = refractive index of lens material, R_1 , R_2 = radii of curvature of two surfaces

2.4 Power of a Lens

Power of a lens is its ability to converge or diverge light. It is the reciprocal of focal length in metres.

Power of Lens

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

Unit: Dioptre (D). Convex lens → positive power. Concave lens → negative power.

2.5 Magnification

Linear (transverse) magnification is the ratio of the height of the image to the height of the object.

Magnification

$$m = v/u = h_2/h_1$$

h_2 = image height, h_1 = object height, v = image distance, u = object distance

- $m > 1$ → Magnified image
- $m < 1$ → Diminished image
- $m = 1$ → Same size
- Positive m → Virtual and erect image
- Negative m → Real and inverted image

2.6 Numerical Examples

Example 1 — Find image distance using Lens Formula
Given: Object distance u = −30 cm, Focal length f = +20 cm (convex lens)
Find: Image distance v
Using Lens Formula: 1/f = 1/v − 1/u
1/20 = 1/v − 1/(−30)
1/20 = 1/v + 1/30
1/v = 1/20 − 1/30 = 3/60 − 2/60 = 1/60
v = + 60 cm
Answer: Image is formed 60 cm on the other side of the lens (real and inverted).

Example 2 — Power of a Lens
Given: Focal length f = +50 cm = 0.50 m
Find: Power
P = 1/f = 1/0.50 = +2 D

Answer: Power = +2 Dioptres (Converging lens)

Example 3 — Magnification
Given: Object distance u = −10 cm, Image distance v = +30 cm
Find: Magnification
m = v/u = 30 / (−10) = −3
Answer: m = −3 → Image is 3 times magnified, real and inverted.

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3. Total Internal Reflection (TIR)

3.1 Definition

Total Internal Reflection is a phenomenon in which light travelling from a denser medium to a rarer medium is completely reflected back into the denser medium instead of getting refracted, when the angle of incidence exceeds the critical angle.

3.2 Critical Angle

The critical angle (C) is the angle of incidence in the denser medium for which the angle of refraction in the rarer medium becomes exactly 90°.

Critical Angle Formula

$$\sin C = n_2 / n_1 = 1/n \quad \text{(if rarer medium is air)}$$

n = refractive index of denser medium, C = critical angle

3.3 Conditions for Total Internal Reflection

- Light must travel from a denser medium to a rarer medium (e.g., glass to air).
- The angle of incidence in the denser medium must be greater than the critical angle (i > C).

3.4 Applications of Total Internal Reflection

A. Optical Fibre (Most Important Application)

An optical fibre is a thin, flexible strand of glass or plastic used to transmit light over long distances with almost zero loss, based on the principle of TIR.

Structure:

- Core: Central dense glass/plastic region through which light travels.

- Cladding: Outer layer of less dense glass/plastic surrounding the core.
- The refractive index of the core is greater than that of the cladding.

Working Principle:

- Light enters the fibre at one end at a small angle.
- At the core-cladding interface, the angle of incidence is greater than the critical angle.
- TIR occurs repeatedly — light bounces along the fibre from one end to the other.
- The light exits at the far end without significant loss of intensity.

Ray Diagram Description:

- Draw a long horizontal cylinder (the optical fibre) with a core (inner) and cladding (outer) layer.
- Show a light ray entering from the left end at an angle.
- Show the ray hitting the core-cladding boundary and reflecting back inward (TIR).
- The ray zigzags (reflects multiple times) along the length of the fibre and exits from the right end.

Applications of Optical Fibre:

- Telecommunications: Carrying telephone, internet, and cable TV signals.
- Medical: Endoscopes for internal examination of the body (gastroscopy, bronchoscopy).
- Sensors: Used in pressure, temperature, and displacement sensors.
- Decorative Lighting: Fibre optic lamps.

B. Other Applications of TIR

- Diamonds sparkle due to multiple TIR inside the gem.
- Periscopes in submarines use glass prisms that work on TIR.
- Mirage: A natural optical phenomenon caused by TIR in hot air layers near the ground.

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4. Optical Instruments

4.1 Simple Microscope

A simple microscope is a single convex lens used to see magnified images of small objects. It is also called a magnifying glass.

Working:

- The object is placed between the optical centre and the focus (within focal length) of the convex lens.
- The lens produces a virtual, erect, and magnified image.
- The eye is placed close to the lens to observe the image.

Magnifying Power (Normal Adjustment — image at infinity)

$$M = D/f$$

D = Least distance of distinct vision = 25 cm, f = focal length of lens

Magnifying Power (Image at near point)

$$M = 1 + D/f$$

D = 25 cm

4.2 Compound Microscope

A compound microscope uses two convex lenses to produce very high magnification of tiny objects. It is used in laboratories for viewing bacteria, cells, etc.

Parts:

- Objective Lens: Short focal length lens placed close to the object. It forms a real, magnified, inverted image.
- Eyepiece (Ocular Lens): Longer focal length lens placed near the eye. Acts as a simple magnifier.

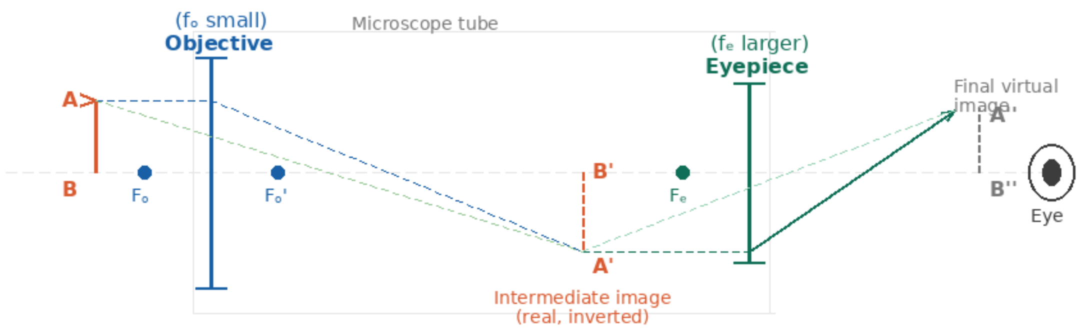
Working:

- Object is placed just beyond the focal point of the objective lens.
- The objective lens forms a real, inverted, magnified intermediate image inside the tube.
- This intermediate image acts as the object for the eyepiece.
- The eyepiece magnifies this intermediate image further and produces a final virtual image seen by the eye.

Ray Diagram Description:

- Draw two convex lenses (objective on the left, eyepiece on the right) separated by a tube.
- Object AB placed just beyond Fo (focal point of objective).
- Rays converge after objective to form intermediate image A'B' (real, inverted, magnified) within the tube.
- Eyepiece takes A'B' as object and forms a final virtual image A''B'' (further magnified).

Diagram 3: Compound Microscope



Total Magnification: $M = (L/f_o) \times (D/f_e)$

L = tube length, D = 25 cm (least distance of distinct vision)

Total Magnifying Power

$$M = M_o \times M_e = (L/f_o) \times (D/f_e)$$

f_o = focal length of objective, f_e = focal length of eyepiece, L = tube length, D = 25 cm

4.3 Astronomical Telescope (Refracting Type)

An astronomical telescope is used to observe distant celestial objects like stars, planets, and the moon. It uses two convex lenses.

Parts:

- Objective Lens: Large aperture, long focal length. Collects maximum light from distant objects.
- Eyepiece: Short focal length lens near the eye. Magnifies the image formed by the objective.

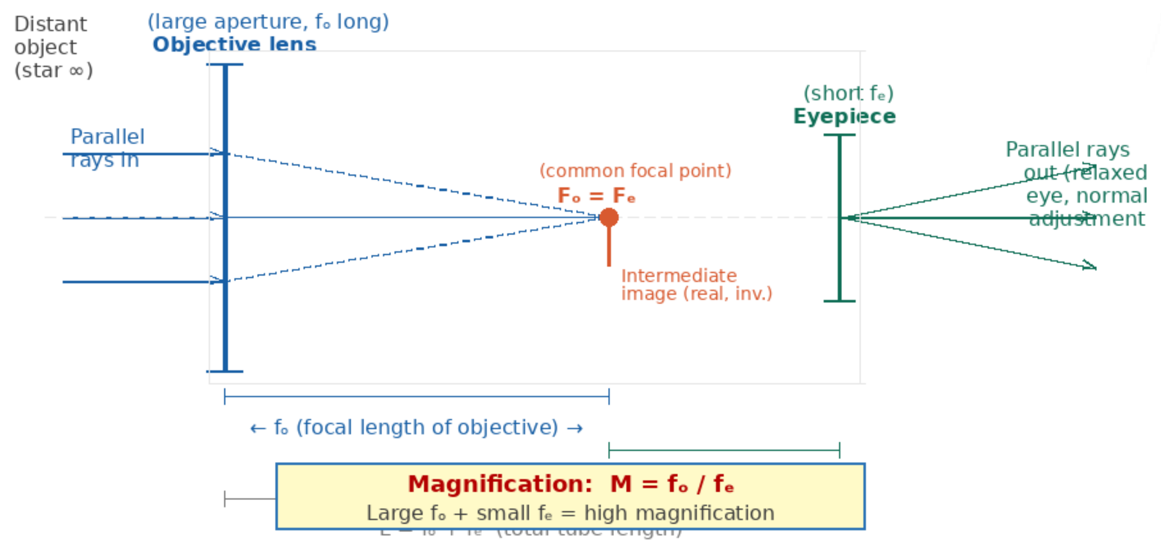
Working:

- Distant object (e.g., a star) sends nearly parallel rays to the objective lens.
- The objective forms a real, inverted, diminished image at its focal plane.
- This image acts as the object for the eyepiece.
- The eyepiece magnifies this image and produces a final virtual image seen by the observer.

Ray Diagram Description:

- Draw two convex lenses far apart: large objective on the left, small eyepiece on the right.
- Show parallel incoming rays from a distant object hitting the objective lens.
- After refraction, rays converge at the focal point of the objective (F_0).
- The eyepiece is positioned so that F_0 falls at (or near) the focal point of the eyepiece (Fe).
- Rays emerge from the eyepiece as parallel rays (for relaxed eye — normal adjustment).

Diagram 4: Astronomical Refracting Telescope



Magnifying Power (Normal Adjustment)

$$M = f_o / f_e$$

f_o = focal length of objective (large), f_e = focal length of eyepiece (small)

Length of Telescope (Normal Adjustment)

$$L = f_o + f_e$$

Total length = sum of focal lengths

- For high magnification: fo should be large and fe should be small.
- Image formed is inverted and virtual.

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5. Interference and Diffraction

(Qualitative only — no derivations required)

5.1 Interference of Light

Interference is the phenomenon of superposition of two or more coherent light waves resulting in a new wave pattern with regions of bright and dark bands.

Types:

- Constructive Interference: When two waves meet in phase (crest meets crest) → Bright fringe (maximum intensity).
- Destructive Interference: When two waves meet out of phase (crest meets trough) → Dark fringe (zero intensity).

Condition for Interference:

- The two sources must be coherent (same frequency, constant phase difference).
- The amplitude of the waves should be equal or comparable.

Example:

- Young's Double Slit Experiment (YDSE): Light passes through two narrow slits forming alternate bright and dark bands (fringes) on a screen.

5.2 Diffraction of Light

Diffraction is the bending of light around the edges of an obstacle or through a narrow slit, spreading into the geometrical shadow region.

Key Points:

- Diffraction is significant when the size of the obstacle/slit is comparable to the wavelength of light.
- Single slit diffraction produces a broad central bright band with alternating dark and bright fringes on either side.
- The central maximum is the widest and brightest.

5.3 Difference Between Interference and Diffraction

Interference	Diffraction
Superposition of waves from two coherent sources.	Bending of waves around obstacles or through slits.
Requires two separate coherent sources.	Occurs from a single source passing an obstacle/slit.
Fringes are equally bright and equally spaced.	Central maximum is very bright; others decrease in intensity.
Fringes are perfectly sharp and clear.	Fringes are not as sharp; they gradually fade.
Example: Young's Double Slit Experiment.	Example: Single slit experiment.

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6. Important Points for Exam

★ KEY FORMULAS AT A GLANCE ★

Law of Reflection	$\angle i = \angle r$
Snell's Law	$n_1 \sin \theta_1 = n_2 \sin \theta_2$
Refractive Index	$n = c / v$
Lens Formula	$1/f = 1/v - 1/u$
Lens Maker's Formula	$1/f = (n-1)(1/R_1 - 1/R_2)$
Power of Lens	$P = 1/f$ (metres), Unit: Dioptre
Magnification	$m = v/u$
Critical Angle	$\sin C = 1/n$
Simple Microscope (M)	$M = D/f$ or $M = 1 + D/f$
Compound Microscope (M)	$M = (L/f_o) \times (D/f_e)$
Telescope Magnification	$M = f_o / f_e$
Telescope Length	$L = f_o + f_e$

Remember These Key Points:

- Sign convention: All distances measured from optical centre; distances in direction of incident light = positive.
- For convex lens: f is positive. For concave lens: f is negative.
- TIR occurs only when light goes from denser to rarer medium AND angle > critical angle.
- In optical fibre, total internal reflection keeps light inside the core.
- For telescope: large fo → high magnification. For microscope: small fo and fe → high magnification.
- Constructive interference → Bright fringes; Destructive interference → Dark fringes.
- Power of combined lenses: $P\_total = P_1 + P_2$.

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7. Common Viva Questions

1. What is the law of reflection?

Ans: The angle of incidence equals the angle of reflection. The incident ray, reflected ray, and normal lie in the same plane.

2. What is Snell's Law?

Ans: $n_1 \sin \theta_1 = n_2 \sin \theta_2$. The product of refractive index and sine of angle of incidence is constant across the interface.

3. What is the refractive index of a medium?

Ans: It is the ratio of the speed of light in vacuum to the speed of light in that medium: n = c/v.

4. State the lens formula. What is the sign convention?

Ans: 1/f = 1/v − 1/u. Distances are measured from the optical centre; positive in the direction of incident light, negative against it.

5. What is the power of a lens?

Ans: Power = 1/focal length (in metres). Unit is Dioptre (D). Convex: positive; Concave: negative.

6. Define Total Internal Reflection. What are its conditions?

Ans: TIR is complete reflection of light back into the denser medium. Conditions: (1) Light travels from denser to rarer medium. (2) Angle of incidence > Critical angle.

7. How does an optical fibre work?

Ans: Light undergoes repeated TIR at the core-cladding interface and travels along the length of the fibre from one end to the other with minimal loss.

8. What is the difference between a simple and a compound microscope?

Ans: A simple microscope uses one convex lens; a compound microscope uses two lenses (objective + eyepiece) for much higher magnification.

9. What is the magnifying power of an astronomical telescope?

Ans: M = fo / fe, where fo is the focal length of the objective and fe is the focal length of the eyepiece.

10. What is the difference between interference and diffraction?

Ans: Interference results from superposition of waves from two coherent sources (equally bright fringes). Diffraction is bending of waves from a single source around obstacles (unequally bright fringes, bright central maximum).

11. What is the critical angle for glass (n = 1.5)?

Ans: sin C = 1/n = 1/1.5 = 0.667 $\rightarrow$ C ≈ 41.8°