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CUET · PHYSICS · CLASS XII · CODE 322

Wave Optics

CUET unit: Wave Optics

By **UniDrill** · NCERT-grounded study material

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📌 Snapshot

- Establishes the wave model of light (Huygens, 1678) and contrasts it with Descartes/Newton's corpuscular model — wave theory correctly predicts that light slows on entering a denser medium (NCERT §10.1, p. 255-256).
- Develops Huygens' geometrical construction of wavefronts and uses it to derive the laws of reflection and refraction (Snell's law $n_1 \sin i = n_2 \sin r$) (NCERT §10.2-10.3, p. 257-260).
- Builds the principle of superposition into a quantitative theory of interference: coherent vs incoherent sources, resultant intensity $I = 4 I_0 \cos^2(\phi/2)$, and Young's double-slit fringe pattern with fringe positions $x_n = n\lambda D/d$ (NCERT §10.4-10.5, p. 262-266).
- Introduces single-slit diffraction — central maximum at $\theta = 0$, minima at $a \sin \theta = n\lambda$ — and links diffraction to the resolution limit of optical instruments (NCERT §10.6, p. 266-268).
- Demonstrates the transverse nature of light through polarisation by polaroids and Malus' law $I = I_0 \cos^2\theta$ (NCERT §10.7, p. 269-271).

📖 Detailed Notes

2.1 Core concepts

- The corpuscular model (Descartes 1637, popularised by Newton in OPTICKS) wrongly predicted higher speed of light in a denser medium; Huygens' wave model (1678) correctly predicted lower speed, confirmed by Foucault's 1850 experiment (NCERT §10.1, p. 255).
- Young's 1801 interference experiment firmly established the wave nature of light; Maxwell later identified light as an electromagnetic wave, explaining how it can travel through vacuum (NCERT §10.1, p. 256).
- A **wavefront** is a surface of constant phase; energy propagates perpendicular to the wavefront, and the speed of the wavefront equals the wave speed. A point source gives spherical wavefronts; far from the source these become effectively plane (NCERT §10.2, p. 257).
- **Huygens' principle:** every point on a wavefront acts as a source of secondary spherical wavelets that spread out at the wave speed; the new wavefront at time t is the forward envelope (common tangent) of these wavelets. The backwave is

suppressed because the amplitude is maximum forward and zero backward (NCERT §10.2, p. 257-258).

- **Refraction by Huygens' construction:** if a plane wavefront AB hits the interface and the wavefront travels distance $v_1\tau$ in medium 1 while a secondary wavelet in medium 2 has radius $v_2\tau$, geometry gives $\sin i / \sin r = v_1/v_2 = n_2/n_1$, i.e., Snell's law $n_1 \sin i = n_2 \sin r$ (NCERT §10.3.1, p. 258-259, Eqs. 10.3, 10.6).
- On refraction into a denser medium ($v_1 > v_2$) the wavelength and speed decrease but the frequency $\nu = v/\lambda$ is unchanged (NCERT §10.3.1, p. 259-260).
- **Refraction at a rarer medium** ($v_2 > v_1$) bends the wave away from the normal; the **critical angle** $\sin i_c = n_2/n_1$ defines the onset of total internal reflection for $i > i_c$ (NCERT §10.3.2, p. 260, Eq. 10.8).
- **Reflection by Huygens' construction** gives congruent triangles EAC and BAC, so the angle of incidence equals the angle of reflection (NCERT §10.3.3, p. 260-261).
- The total time taken from object point to image point is the same along every ray — e.g., the central ray through a convex lens traverses less distance but moves slower through thicker glass (NCERT §10.3.3, p. 261).
- **Coherent sources** maintain a constant phase difference at every point (like two needles oscillating in phase in a trough); when waves of amplitude a superpose in phase, resultant amplitude is $2a$ and intensity is $4 I_0$ (NCERT §10.4, p. 262-263).
- For path difference $S_1P \sim S_2P = n\lambda$ we get **constructive interference** ($I = 4 I_0$); for $S_1P \sim S_2P = (n + 1/2) \lambda$ we get **destructive interference** ($I = 0$) (NCERT §10.4, p. 263-264, Eqs. 10.9, 10.10).
- General intensity formula: $I = 4 I_0 \cos^2(\phi/2)$; if two sources are **incoherent** (rapidly fluctuating phase) intensities just add, giving $I = 2 I_0$ everywhere (NCERT §10.4, p. 264, Eqs. 10.11, 10.12).
- Two independent sodium lamps cannot give interference fringes because each ordinary source undergoes abrupt phase changes on a 10^{-10} s timescale; Young solved this by deriving S_1 and S_2 from a single primary pinhole S so the two phases are locked (NCERT §10.5, p. 265).
- **Young's double-slit fringe positions:** bright fringes at $x_n = n\lambda D/d$ and dark fringes at $x_n = (n + 1/2) \lambda D/d$; bright and dark fringes are equally spaced (NCERT §10.5, p. 266, Eqs. 10.13, 10.14).
- **Single-slit diffraction:** for a slit of width a illuminated normally, the central maximum sits at $\theta = 0$; minima occur at $\theta \approx n\lambda/a$, $n = \pm1, \pm2, \pm3, \cdots$; secondary maxima at $\theta \approx (n + 1/2) \lambda/a$, growing weaker with n (NCERT §10.6.1, p. 267).
- A double-slit pattern is actually a superposition of single-slit diffraction from each slit on the double-slit interference pattern (NCERT §10.6.1, p. 267).
- Quoting Feynman: there is no sharp physical distinction between interference and diffraction — "interference" is used for a few sources, "diffraction" when there are many (NCERT §10.6.1, p. 267).

- In both interference and diffraction, light energy is only redistributed — no gain or loss — consistent with energy conservation (NCERT §10.6.2, p. 268).
- **Polarisation and transverse nature:** a wave with displacement at right angles to its propagation direction is transverse; if displacement stays in one plane, the wave is **linearly (plane) polarised** (NCERT §10.7, p. 269-270, Eq. 10.15).
- **Unpolarised wave:** plane of vibration changes randomly in very short intervals while remaining perpendicular to the propagation direction; natural light (e.g., sunlight) is unpolarised (NCERT §10.7, p. 270; Summary point 6, p. 272).
- A **polaroid** has long aligned chain molecules that absorb the electric vector along the molecular axis and transmit the perpendicular component (the "pass-axis"). Unpolarised light through a single polaroid loses half its intensity, independent of orientation (NCERT §10.7, p. 270-271).
- **Malus' law:** when polarised light of intensity `I0` passes through a polaroid whose pass-axis makes angle θ with the polarisation direction, the transmitted intensity is `I = I0 cos²θ` (NCERT §10.7, p. 270, Eq. 10.18).
- Two crossed polaroids transmit zero intensity; a third polaroid placed between them at angle θ transmits `(I0/4) sin²(2θ)`, maximum at $\theta = \pi/4$ (NCERT §10.7, Example 10.2, p. 271).
- Polaroid applications: sunglasses, windowpanes, photographic cameras, 3D movie cameras (NCERT §10.7, p. 271).
- **Conditions for sustained interference:** the two sources must be coherent (constant phase difference), monochromatic (single wavelength), and of nearly equal intensity (else dark fringes are not strictly dark). Path difference must be small compared with the coherence length of the source (NCERT §§10.4–10.5, p. 262–266).
- **Fringe width $\beta = \lambda D/d$** is independent of fringe order; all fringes are equally spaced. β increases if λ is larger, D is larger, or d is smaller; immersing the apparatus in a medium of refractive index n reduces λ to λ/n, so β shrinks by the same factor (NCERT §10.5, p. 266).
- **Energy conservation in interference and diffraction**: the redistribution of light over the screen produces brighter maxima and darker minima, but the total energy reaching the screen equals what would arrive without interference; light is neither created nor destroyed (NCERT §10.6.2, p. 268).
- **Polarisation by scattering, reflection and selective absorption** are three distinct ways of producing polarised light from natural unpolarised sunlight; polaroids (selective absorption) are the most common. Scattered sunlight from the sky is partially polarised, which is what polarising sunglasses exploit (NCERT §10.7, p. 270–271).

2.2 Definitions to memorise

Term	Definition	Page
Wavefront	Locus of points oscillating in phase; surface of constant phase	257
Huygens' principle	Every point on a wavefront is a source of secondary wavelets; the new wavefront is the forward envelope (common tangent) of these wavelets after time t	257
Refractive index	n = c/v, where c is speed of light in vacuum and v is speed in the medium	259
Critical angle	Angle ic such that sin ic = n2/n1 (rarer medium); for i > ic total internal reflection occurs	260
Coherent sources	Sources whose phase difference at any point does not change with time	262
Constructive interference	Path difference = nλ ; resultant intensity = 4 I0	263
Destructive interference	Path difference = (n + 1/2) λ ; resultant intensity = 0	264
Incoherent addition	Phase difference varies rapidly; intensities add (I = 2 I0)	264
Fringe positions (Young's)	Bright: x_n = nλD/d ; Dark: x_n = (n + 1/2) λD/d	266
Diffraction	Bending of waves around obstacles / spreading from narrow slits; gives a central maximum with weaker secondary maxima	266-267
Single-slit minima	a sin $\theta \approx n\lambda$, n = ±1, ±2, ±3,⋯ (also written $\theta \approx n\lambda/a$)	267
Single-slit secondary maxima	$\theta \approx (n + 1/2)\lambda/a$	267
Transverse wave	Displacement is perpendicular to direction of propagation	269
Unpolarised wave	Plane of vibration changes randomly with time (still perpendicular to propagation)	270
Pass-axis of polaroid	Direction perpendicular to the aligned chain molecules along which the electric vector is transmitted	270
Malus' law	I = I0 $\cos^2\theta$, where θ is the angle between pass-axis and polarisation direction	270
Polaroid	Sheet with aligned long-chain molecules that absorbs one polarisation and transmits the perpendicular component (pass-axis)	270
Linearly polarised light	Light whose electric vector vibrates in a fixed plane perpendicular to propagation	269–270
Plane wavefront		257

Term	Definition	Page
	Wavefront whose normal at every point is parallel; produced when the source is very far away	
Spherical wavefront	Wavefront from a point source whose surface is a sphere centred on the source	257
Fringe width (β)	Spacing between adjacent bright (or adjacent dark) fringes in Young's experiment, $\beta = \lambda D/d$	266
Central maximum (single slit)	The bright region between the first minima at $\theta = \pm\lambda/a$, of angular width $2\lambda/a$	267
Secondary maxima (single slit)	Weaker bright bands at $\theta \approx (n + ½)\ \lambda/a$	267
Snell's law (wave form)	$n_1 \sin i = n_2 \sin r$, derived from wavefront geometry	259
Speed–index relation	$n = c/v$	259

2.3 Diagrams / processes to remember

- **Fig. 10.1 (a),(b)** — Spherical wavefront from a point source; plane wavefront at large distance (p. 257).
- **Fig. 10.2** — Huygens' construction: spherical wavefront F1F2 → new wavefront G1G2 as envelope of secondary wavelets; backwave D1D2 absent (p. 257).
- **Fig. 10.3** — Huygens' construction for a plane wave propagating to the right; lines A1A2, B1B2 are rays (p. 258).
- **Fig. 10.4** — Refraction of plane wave AB at interface PP'; CE is refracted wavefront when $v2 < v1$ (bends toward normal) (p. 258).
- **Fig. 10.5** — Refraction at a rarer medium ($v2 > v1$); wavefront bends away from normal (p. 260).
- **Fig. 10.6** — Reflection of plane wave AB by surface MN; CE is reflected wavefront (p. 261).
- **Fig. 10.7 (a),(b),(c)** — Wavefront refraction by thin prism, by convex lens (focal point F), and reflection by concave mirror (p. 261).
- **Fig. 10.8** — Two needles oscillating in phase → coherent sources; nodal (N) and antinodal (A) lines on water surface (p. 262).
- **Fig. 10.9** — Constructive interference at point Q (path difference 2λ); destructive interference at point R (path difference 2.5λ) (p. 263).
- **Fig. 10.10** — Locus of points where $S1P - S2P = 0, \pm\lambda, \pm2\lambda, \pm3\lambda$ (p. 263).
- **Fig. 10.11** — Two sodium lamps illuminating two pinholes give no fringes (incoherent) (p. 265).

- **Fig. 10.12** — Young's double-slit arrangement; fringes on screen GG' (p. 265).
- **Fig. 10.13** — Computer-generated Young's fringes with d = 0.025 mm, D = 5 cm, λ = 5×10^{-5} cm (p. 266).
- **Fig. 10.14** — Single-slit geometry: slit LN of width a, midpoint M, path differences for diffraction (p. 267).
- **Fig. 10.15** — Intensity distribution + photograph of single-slit fringes; broad central maximum with weaker side maxima (p. 267).
- **Fig. 10.16** — Two razor blades held to form a single slit (home experiment) (p. 268).
- **Fig. 10.17** — Transverse string wave: y(x,t) = a sin(kx – ωt); linearly/plane polarised (p. 269).
- **Fig. 10.18** — Two polaroids P2 and P1: transmitted fraction varies as $\cos^2\theta$ as angle between axes goes from 0° to 90° (p. 271).

2.4 Common confusions / NTA trap points

- Corpuscular vs wave prediction on refraction: corpuscular says light is faster in denser medium, wave theory says slower — Foucault (1850) confirmed wave theory. Distractors often swap this.
- On refraction, **frequency stays the same** while wavelength and speed change. Students wrongly say wavelength is unchanged.
- Two independent identical sodium lamps are NOT coherent — their phases jump every ~10^{-10} s, so no fringes are seen. The trick in Young's setup is that S1 and S2 are derived from one primary source S.
- For **interference**: I_max = 4 I0 (when both sources contribute equal I0) and I_min = 0; with **incoherent** addition I = 2 I0 everywhere. Many students miss the factor of 4.
- Single-slit minima are at `a sin θ = nλ` (n ≠ 0). The condition `nλ` looks identical to the interference maxima condition — but here it's minima, and `n = 0` is excluded (it's the central maximum, not a minimum).
- Width of central maximum in single-slit diffraction is `2λ/a` (in angular terms) — i.e., from `θ = -λ/a` to `θ = +λ/a` — twice the spacing of subsequent minima. NTA loves this trap.
- Malus' law applies when light is already polarised. Unpolarised light through a single polaroid is reduced by exactly half, regardless of the angle of the polaroid.
- Fringe width $\beta = \lambda D/d$ depends on d (slit separation), not on a (slit width). Confusing the two parameters is a recurring NTA trap.
- Immersing Young's setup in water reduces wavelength by 1/n; fringe width shrinks (β/n), the central fringe stays put because the wavelength reduction is symmetric.
- Diffraction angle is large only when a ≈ λ. For a ≫ λ (e.g. ordinary slit and visible light), the central maximum is very narrow and the pattern resembles geometric shadow.

- Both interference and diffraction conserve total energy — bright maxima borrow intensity from where the minima fall; nothing is "lost" at dark fringes.

2.5 Key formulas table

Quantity	Symbol / Formula	NCERT reference
Snell's law (wave optics)	$n_1 \sin i = n_2 \sin r$	§10.3.1, Eq. 10.3, p. 259
Refractive index	$n = c/v$	§10.3.1, p. 259
Critical angle	$\sin i_c = n_2/n_1$	§10.3.2, Eq. 10.8, p. 260
Frequency unchanged in refraction	$\nu = v/\lambda$ = constant	§10.3.1, p. 259–260
Path difference (Young) — bright	$S_1P - S_2P = n\lambda$	§10.4, Eq. 10.9, p. 263
Path difference (Young) — dark	$S_1P - S_2P = (n + ½)\lambda$	§10.4, Eq. 10.10, p. 264
Intensity (two-source)	$I = 4 I_0 \cos^2(\phi/2)$	§10.4, Eq. 10.11, p. 264
Incoherent superposition	$I = 2 I_0$	§10.4, Eq. 10.12, p. 264
Bright fringe position	$x_n = n \lambda D/d$	§10.5, Eq. 10.13, p. 266
Dark fringe position	$x_n = (n + ½) \lambda D/d$	§10.5, Eq. 10.14, p. 266
Fringe width	$\beta = \lambda D/d$	§10.5, p. 266
Single-slit minima	$a \sin \theta = n\lambda$, $n = \pm1, \pm2, \cdots$	§10.6.1, p. 267
Single-slit secondary maxima	$a \sin \theta = (n + ½)\lambda$	§10.6.1, p. 267
Angular width of central maximum	$2\lambda/a$	§10.6.1, p. 267
Linear width of central maximum	$2\lambda D/a$	§10.6.1, p. 267
Polarised wave (1-D)	$y(x, t) = a \sin(kx - \omega t)$	§10.7, Eq. 10.15, p. 269
Unpolarised light through one polaroid	$I = I_0/2$	§10.7, p. 271
Malus' law	$I = I_0 \cos^2\theta$	§10.7, Eq. 10.18, p. 270
Crossed polaroids (with middle one at θ)	$I = (I_0/4) \sin^2(2\theta)$	Ex. 10.2, p. 271
Fringe width in medium n	$\beta_m = \beta/n$ (wavelength becomes λ/n)	implied, §10.3.1 + §10.5

🎯 Practice MCQs

📊 PYQ Alignment

Wave Optics is a high-yield unit in CUET Physics, contributing roughly 10-12 MCQs across the 2023-25 papers. The most repeated formats are direct numerical plug-ins on fringe width $\beta = \lambda D/d$ (Young's experiment), single-slit central-maximum width $2\lambda D/a$, and Malus' law $I = I_0 \cos^2\theta$, alongside conceptual statement-based questions on Huygens' principle, the difference between coherent and incoherent sources ($I = 4I_0$ vs $I = 2I_0$), and the transverse nature of light established by polarisation.

CUET 2025 — Actual PYQs from this chapter

Q.36 (CUET 2025) In Young’s double slit experiment: Slit separation = 1.5 mm Screen distance = 1.2 m Wavelength = 600 nm Fringe width will be:

- A) 0.48 mm B) 4.5 mm C) 4.8 mm D) 4.2 mm Tests: Young's double-slit experiment — fringe width $\beta = \lambda D/d$ Answer: Not in extracted key

Q.38 (CUET 2025) A polaroid sheet is rotated between two crossed polarizers. Maximum transmitted intensity occurs when angle between first polarizer and sheet is:

- A) $\pi/2$ B) $\pi/4$ C) π D) $\pi/3$ Tests: Malus's law / polariser between crossed polarisers Answer: Not in extracted key

CUET 2024 — Actual PYQs from this chapter

Q.22 (CUET 2024) Single slit diffraction: Slit width = 0.1 mm Screen distance = 50 cm Central maxima width = 5 mm Wavelength:

- A) 2.5×10^{-7} m B) 4×10^{-7} m C) 5×10^{-7} m D) 7.5×10^{-7} m Tests: Single-slit diffraction — wavelength from central-max width Answer: Not in extracted key

Q.46 (CUET 2024) Two slits 0.1 mm apart, screen distance 2 m, wavelength 500 nm. Fringe width:

- A) 1 cm B) 0.15 cm C) 15 cm D) 0.1 cm Tests: Young's double-slit — fringe width $\beta = \lambda D/d$ Answer: Not in extracted key

CUET 2023 — Actual PYQs from this chapter

Q.27 (CUET 2023) A slit of width (a) is illuminated with light of wavelength (\lambda). The angular width of the first diffraction maximum is:

- A) (\frac{2\lambda}{\sqrt{3}a}) B) (\frac{\lambda}{\sqrt{3}a}) C) (\frac{\sqrt{3}\lambda}{a}) D) (\frac{\sqrt{3}\lambda}{2a}) Tests: Single-slit diffraction — angular width of central maximum Answer: Not in extracted key

Q.28 (CUET 2023) In Young's double-slit experiment, light of wavelength 640 nm produces fringes of width 0.8 mm. Fringe width using wavelength 720 nm will be:

- A) 2.4 mm B) 2.7 mm C) 0.9 mm D) 0.3 mm Tests: Young's double-slit experiment — fringe width $\beta = \lambda D/d$ Answer: Not in extracted key

Q.32 (CUET 2023) The type of wavefront emerging from a distant light source is:

- A) Cylindrical B) Plane C) Diverging spherical D) Converging spherical Tests: Wavefront from a distant point source — plane wavefront Answer: Not in extracted key