FREE NOTES · NCERT + JEE/NEET LEVEL

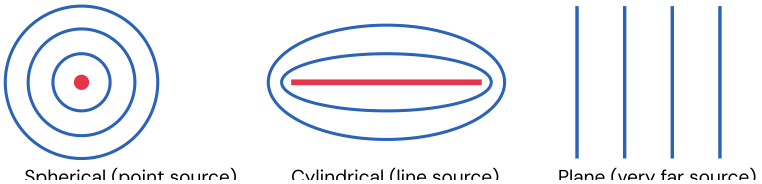
Wave Optics

Wavefronts, Huygens principle, coherent sources, interference, Young's double slit, diffraction, resolving power and polarisation (Malus and Brewster). With diagrams and solved numericals.

01 Wavefront
02 Huygens principle
03 Coherent sources
04 Interference
05 Young's double slit experiment (YDSE)
06 Diffraction (single slit)
07 Resolving power
08 Polarisation
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10 Solved numericals
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01 Wavefront

A surface on which all points are **in the same phase**. Light rays are always perpendicular to the wavefront.



Three kinds of wavefront

02 Huygens principle

- Every point on a wavefront acts as a new (secondary) source, sending out wavelets in all directions at the speed of light.
- A little later, the surface touching these wavelets (the envelope) is the new wavefront.

WHAT IT PROVES

The laws of reflection (i = r) and Snell's law. In refraction $\sin i/\sin r = v_1/v_2 = n_2/n_1$, i.e. light travels **slower** in a denser medium (Newton's corpuscular theory predicted the opposite and was wrong).

03 Coherent sources

Two sources with a **constant phase difference** (and the same frequency). Only then is a stable interference pattern seen.

WHY AREN'T TWO SEPARATE BULBS COHERENT?

In a bulb millions of atoms emit randomly and the phase changes every ~10^{-10} s. So coherent sources are made by splitting one source into two (Young's two slits, Lloyd's mirror) or by using a laser.

04 Interference

When two coherent waves overlap, some places become bright (constructive) and some dark (destructive).

$$I = I_1 + I_2 + 2\sqrt{(I_1 I_2)}\cos\varphi$$

Phase difference $\varphi = (2\pi/\lambda) \times$ path difference

	Constructive (bright)	Destructive (dark)
Path difference	$n\lambda$	$(2n-1)\lambda/2$
Phase difference	$2n\pi$	$(2n-1)\pi$
Intensity	$(\sqrt{I_1}+\sqrt{I_2})^2$	$(\sqrt{I_1}-\sqrt{I_2})^2$

Equal intensities I_o: maximum $4I_o$, minimum 0. Energy is not destroyed, only redistributed.

05 Young's double slit experiment (YDSE)

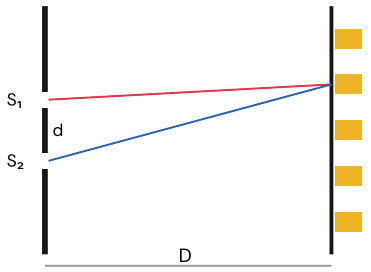
Path difference $= d \sin\theta \approx yd/D$

Bright fringe: $y_n = n\lambda D/d$

Dark fringe: $y_n = (2n-1)\lambda D/(2d)$

$$\text{Fringe width } \beta = \lambda D/d$$

d = slit separation, D = slit-to-screen distance. Angular width = λ/d.



Equally spaced bright and dark bands on the screen

Change	Fringe width β
Blue light instead of red	Decreases (smaller λ)
Slits farther apart (larger d)	Decreases
Screen farther (larger D)	Increases
Whole setup in water (n)	β/n
White light	Central fringe white, others coloured

A thin sheet (thickness t, index n) over one slit shifts the pattern toward that slit by $(n-1)tD/d$. Fringe width is unchanged.

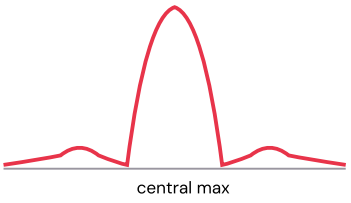
06 Diffraction (single slit)

The bending of light around the edges of an obstacle or a small opening. Noticeable when the opening is comparable to λ.

Minima: $a \sin\theta = n\lambda$

Width of central maximum $= 2\lambda D/a$

a = slit width. The central bright band is the widest and brightest; the others fade quickly. A narrower slit gives a wider pattern.



Intensity is greatest at the centre

Interference	Diffraction
Two separate coherent sources	Different parts of one wavefront
All fringes equally wide	Central wide, others narrow
Bright fringes equally intense	Intensity falls off quickly

Fresnel distance $z_F = a^2/\lambda$: below it ray optics holds; beyond it diffraction becomes noticeable.

07 Resolving power

The ability to see two close objects as separate. Diffraction sets a limit for every instrument.

Telescope: minimum angle $\Delta\theta = 1.22\,\lambda/D$

Microscope: $d_{min} = 1.22\,\lambda/(2n \sin\beta)$

A larger telescope lens/mirror (D) ⇒ better resolution. In a microscope, a shorter λ (electron microscope!) ⇒ better.

08 Polarisation

In ordinary light the electric field vibrates in all directions (unpolarised). After a polaroid it vibrates in one direction only: **plane polarised**. This proves light is a **transverse** wave (sound cannot be polarised).

MALUS'S LAW

$$I = I_0 \cos^2\theta$$

Unpolarised light through the first polaroid ⇒ $I_o/2$. θ = angle between the two polaroids' axes. θ = 90° (crossed) ⇒ 0.

BREWSTER'S LAW

$$\tan i_B = n$$

At this angle the reflected light is completely polarised, and the reflected and refracted rays are at 90°. Glass (1.5): $i_B \approx 56°$.

Uses: sunglasses (reduce glare), 3D movie glasses, LCD screens, camera filters.

09 JEE Extra + Tricks

JEE LEVEL

- YDSE: $\beta = \lambda D/d$; in a medium β/n; slab of thickness t in one path shifts pattern by $(n - 1)tD/d$ (towards the slab).
- Intensity $I = 4I_o\cos^2(\varphi/2)$; with unequal intensities $I_{max}/I_{min} = ((\sqrt{I_1} + \sqrt{I_2})/(\sqrt{I_1} - \sqrt{I_2}))^2$.
- Single slit: minima at $a\sin\theta = n\lambda$; central maximum width $2\lambda D/a$ (twice others).
- Malus's law $I = I_o\cos^2\theta$; unpolarised light through a polaroid: $I_o/2$.
- Brewster's law $\tan i_p = n$; reflected and refracted rays are perpendicular.
- Resolving power: microscope $\propto 1/\lambda$; telescope $\propto D/\lambda$.

10 Solved numericals

Q1. YDSE: d = 0.5 mm, D = 1 m, λ = 600 nm. Fringe width?
$\beta = 600 \times 10^{-9} \times 1/(5 \times 10^{-4}) = 1.2 \times 10^{-3}$ m. **Ans: 1.2 mm**

Q2. In the same setup, how far is the 3rd bright fringe from the centre?
$y_3 = 3\beta = 3.6$ mm. **Ans: 3.6 mm**

Q3. Two waves have intensities in the ratio 9 : 1. $I_{max} : I_{min}$?
$(3 + 1)^2 : (3 - 1)^2 = 16 : 4 = 4 : 1$. **Ans: 4 : 1**

Q4. Single slit a = 0.2 mm, λ = 500 nm, D = 2 m. Width of the central maximum?
$2\lambda D/a = 2 \times 5 \times 10^{-7} \times 2/(2 \times 10^{-4}) = 10^{-2}$ m. **Ans: 1 cm**

Q5. Unpolarised light (I_o) passes through two polaroids with axes at 60°. Final intensity?
After the first $I_o/2$, then × $\cos^2 60° = ¼ \Rightarrow I_o/8$. **Ans: $I_o/8$**

Q6. Brewster angle is 60°. Refractive index?
$n = \tan 60° = \sqrt{3} \approx 1.73$. **Ans: √3**

11 Common mistakes

- Applying $\cos^2$ directly to unpolarised light in Malus's law (halve it first).
- Writing the central diffraction width as λD/a (it is 2λD/a).
- Thinking fringe width increases in water (it decreases by n).
- Thinking energy is "destroyed" in interference (it is redistributed).
- Not converting mm and nm to metres.

12 Formula sheet

Phase vs path	$\varphi = (2\pi/\lambda)\,\Delta x$
Resultant intensity	$I = I_1 + I_2 + 2\sqrt{(I_1 I_2)}\cos\varphi$
Fringe width	$\beta = \lambda D/d$
Bright / dark	$n\lambda D/d$ / $(2n-1)\lambda D/2d$
Sheet shift	$(n-1)tD/d$
Single slit minima	$a\sin\theta = n\lambda$
Central max width	$2\lambda D/a$
Resolving limit	$1.22\lambda/D$
Malus	$I = I_0\cos^2\theta$
Brewster	$\tan i_B = n$

13 Practice questions

1. In YDSE d is halved and D doubled. β?
2. A third polaroid is placed at 45° between two crossed polaroids. Intensity (from unpolarised I_o)?
3. Two waves of equal intensity I_o with phase difference 60°. Resultant?
4. A single slit is widened. Central maximum?

ANSWERS

1) 4 times · 2) $I_o/2 \times ½ \times ½ = I_o/8$ · 3) $2I_o(1 + \cos 60°) = 3I_o$ · 4) Becomes narrower

14 Quick revision: 5 minutes before the exam

HUYGENS

- Every point = secondary source.
- Light is slower in a denser medium.
- Coherent: constant phase difference.

INTERFERENCE

- Bright $n\lambda$, dark $(2n - 1)\lambda/2$.
- $\beta = \lambda D/d$; β/n in water.
- $I_{max} = (\sqrt{I_1} + \sqrt{I_2})^2$.

DIFFRACTION

- $a \sin\theta = n\lambda$ (minima).
- Central width $2\lambda D/a$.
- Resolving limit $1.22\lambda/D$.

POLARISATION

- Light is transverse.
- $I = I_o \cos^2\theta$; unpolarised ⇒ $I_o/2$.
- $\tan i_B = n$; $r + i = 90°$.

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