Wave phenomena

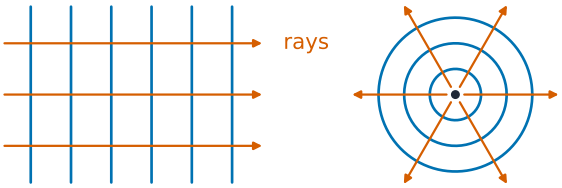
C.3 · SL and AHL

Why can you hear round a corner but not see?

How much a wave spreads depends on its wavelength compared with the gap.

- Sound bends round a doorway; light hardly does.
- One wave model explains mirrors, lenses, fibres and fringes.
- This unit: boundaries $\rightarrow$ **refraction** $\rightarrow$ **diffraction** $\rightarrow$ **interference**.

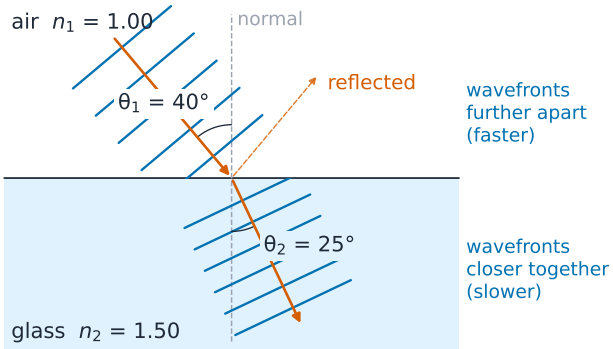
Wavefronts and rays



- A **wavefront** joins points in phase; crests are one wavelength apart.
- Rays show the direction of travel, at right angles to the wavefronts.

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Refraction on a wavefront diagram



- Slower medium means shorter wavelength; frequency is unchanged.
- The **ray** bends towards the **normal** when the wave slows.

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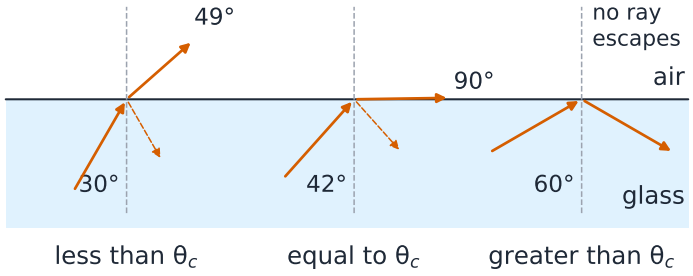
Snell's law

- Air to glass at 40° gives 25°.
- Water has $n = 1.33$, so light travels at 2.26×10^8 m s^{-1}.

$$\frac{n_1}{n_2} = \frac{\sin\theta_2}{\sin\theta_1} = \frac{v_2}{v_1}$$

Measure angles from the **normal**; $n = c/v$.

Total internal reflection



- Glass to air has $\theta_c = 42°$; diamond 24°.
- Needs a lower n beyond the **boundary** and an angle above θ_c.

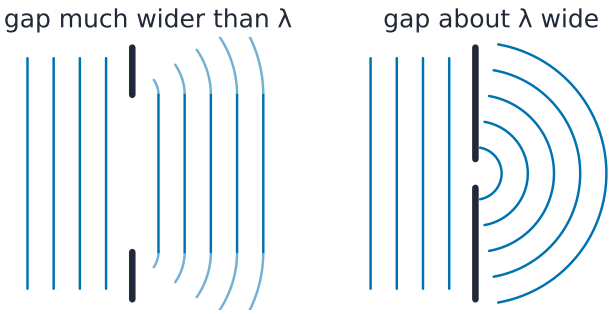
The critical angle

- An **optical fibre** core of 1.48 in cladding of 1.46 has $\theta_c = 81°$.
- Light skims along the fibre, reflected every time.

$$\sin\theta_c = \frac{n_2}{n_1}$$

Only from a higher to a lower **refractive index**.

Diffraction



- Strong when the gap is about one wavelength wide.
- Speech spreads substantially around a doorway; light spreads too little to form a useful view around it.

Superposition

Crest meets crest

Displacements add.

A **pulse** twice as tall for an instant.

Crest meets trough

Equal pulses cancel.

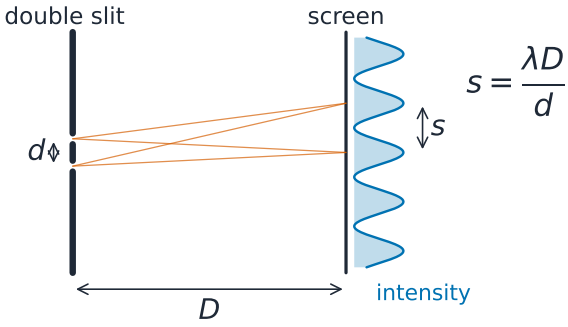
The rope is flat for an instant.

Constructive and destructive interference

Path difference	**Result**
$n\lambda$	constructive, maximum
$(n+\frac{1}{2})\lambda$	destructive, minimum

For **coherent** in-phase sources. Complete cancellation also requires equal amplitudes.

Young's double slit



- 633 nm, $d = 0.50$ mm, $D = 2.0$ m gives $s = 2.5$ mm.
- Measure across several **fringe** spacings, then divide by the number of intervals.

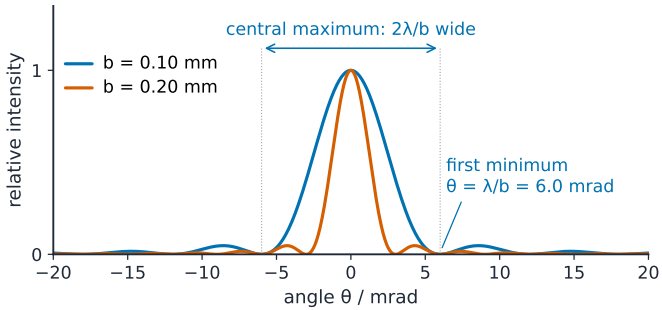
Check: fringe spacing

Your turn

Initially the double-slit fringe separation is 2.0 mm. Slit separation is halved while wavelength and screen distance stay fixed. What is the new fringe separation?

A. 0.5 mm
B. 1.0 mm
C. 2.0 mm
D. 4.0 mm

Single-slit diffraction



- 600 nm through 0.10 mm gives 6.0 mrad, 12 mm at 2.0 m.
- A narrower slit spreads the pattern more; the plotted peaks are normalized independently.

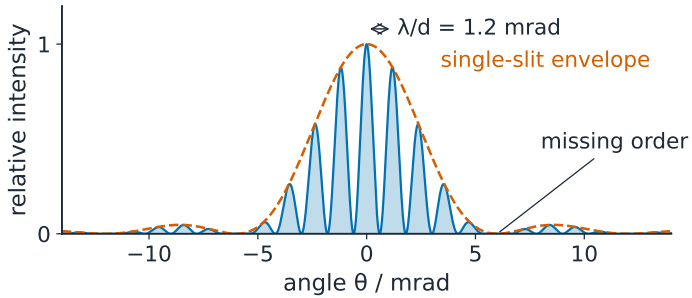
The first minimum

- The central maximum runs from $-\lambda/b$ to $+\lambda/b$.
- It is twice as wide as each side maximum.

$$\theta = \frac{\lambda}{b}$$

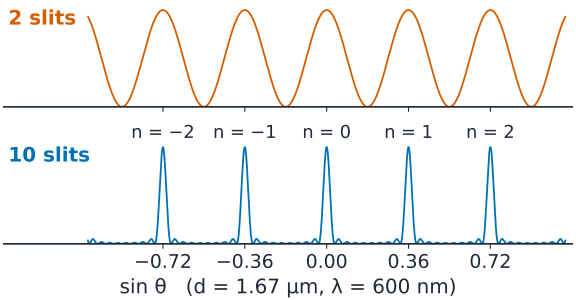
θ is in radians.

Fringes under an envelope



- Slit separation d sets the **fringe** spacing; slit width b sets the **envelope**.
- $d = 5b$ means order 5 is missing and 9 fringes fit in the centre.

Diffraction gratings



- More slits give narrower principal maxima; at fixed illumination per slit, their peaks are brighter.
- 600 lines per mm and 600 nm give 21° and 46°; no third order.

The grating equation

- White light gives a white zero order and spectra in the others.
- Violet is nearest the centre; higher orders overlap.

$$n\lambda = d\sin\theta$$

The highest order is the largest whole $n \leq d/\lambda$.

Exam tips

> Write the **path difference** in wavelengths before you decide.

- Angles are measured from the **normal**.
- **Total internal reflection** needs both conditions.
- Interference needs coherent sources.

Check yourself

Try these

Find the critical angle for light from water of refractive index 1.33 into air of index 1.00.

Find λ when fringes are 1.8 mm apart, 1.5 m from slits 0.40 mm apart.

HL. Find the wavelength when 300 lines per mm give a second order at 20.0°.