Wave phenomena

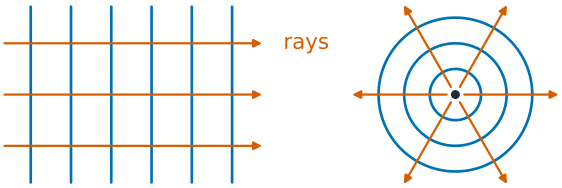
C.3 · SL and AHL

Why can you hear round a corner but not see?

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

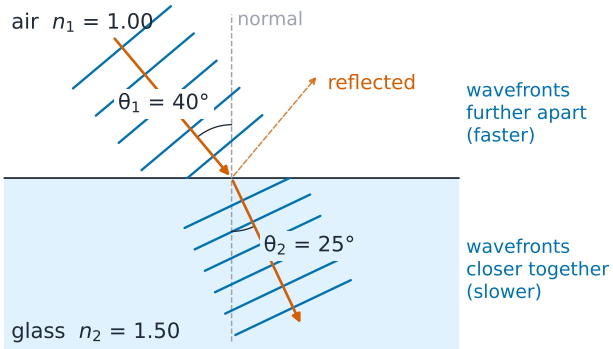
- Sound bends round a doorway; light hardly does.
- One wave model explains mirrors, lenses, fibres and fringes.
- This unit: boundaries $\rightarrow$ **refraction** $\rightarrow$ **diffraction** $\rightarrow$ **interference**.

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.

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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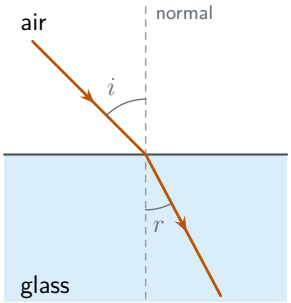
Investigating refraction

1. **Trace.** Outline the glass block and mark the incident and refracted **ray** paths. Keep beams away from eyes.
2. **Measure.** Draw the entry **normal**; measure both angles from it. Repeat at several incident angles and compare sine ratios.
3. **Waves.** In a ripple-tank image, measure across several wavelengths and divide by their number to reduce fractional reading uncertainty.

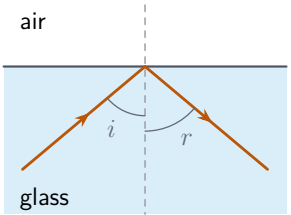
Decision

The source frequency stays fixed across the stationary **boundary**.

Refraction or total internal reflection



entering glass the ray slows and bends *towards* the normal: $r < i$



inside the glass, i greater than the critical angle: *all* the light reflects, $r = i$

Total internal reflection needs a slower-to-faster **boundary**

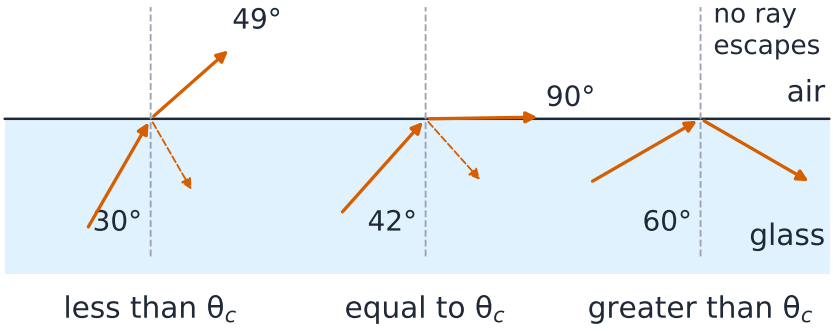
Snell's law

- 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 $\theta_c = 81^\circ$.
- Light skims along the fibre, reflected every time.

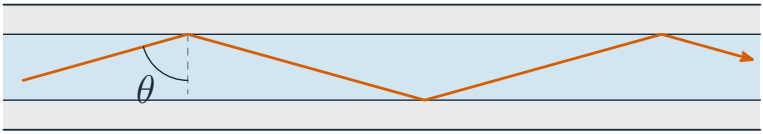
$$\sin\theta_c = \frac{n_2}{n_1}$$

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

Light trapped in an optical fibre

cladding, $n = 1.46$

core, $n = 1.48$

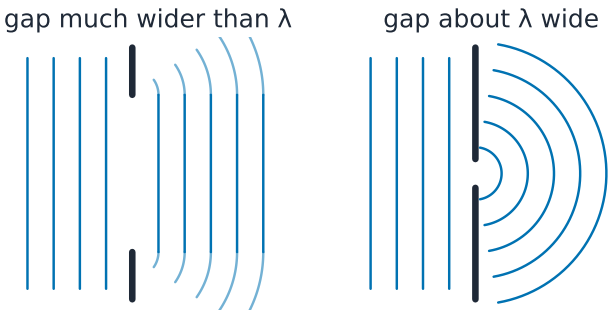


cladding

θ > critical angle (81°): total internal reflection at every bounce

A **ray** nearly along the fibre reflects totally at every bounce

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.

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Superposition

Crest meets crest

Displacements add.

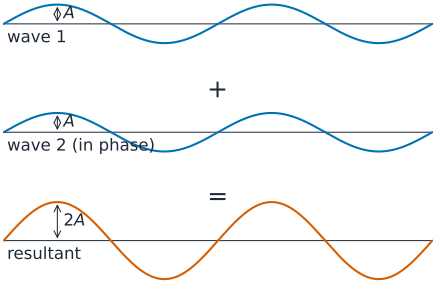
A **pulse** twice as tall for an instant.

Crest meets trough

Equal pulses cancel.

The rope is flat for an instant.

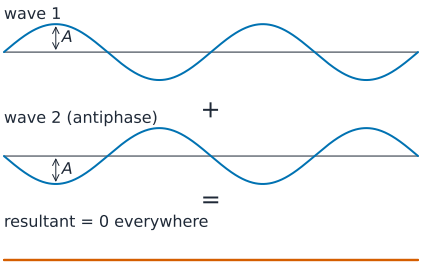
Constructive interference



constructive (in phase): amplitudes add $\rightarrow 2A$

Crest meets crest

Destructive interference



destructive (out of phase by $\lambda/2$): cancel if equal A

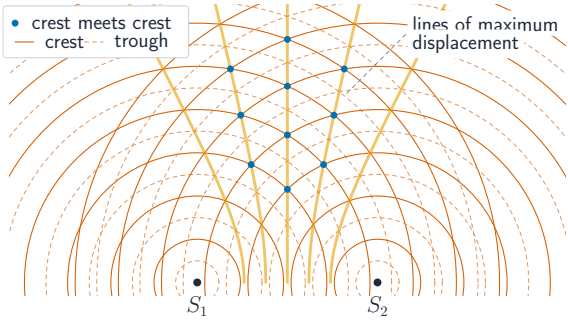
Crest meets trough

Constructive and destructive interference

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

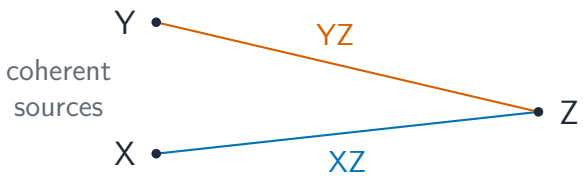
For **coherent** in-phase sources. Complete cancellation also requires equal amplitudes.

Two-source interference



The sources must be **coherent**

Path difference decides



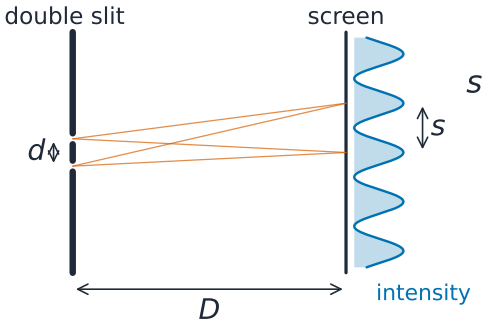
path difference $= \mathrm{XZ} - \mathrm{YZ}$

$= n\lambda$: in phase, maximum

$= (n + \frac{1}{2})\lambda$: antiphase, minimum

For sources in phase

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.

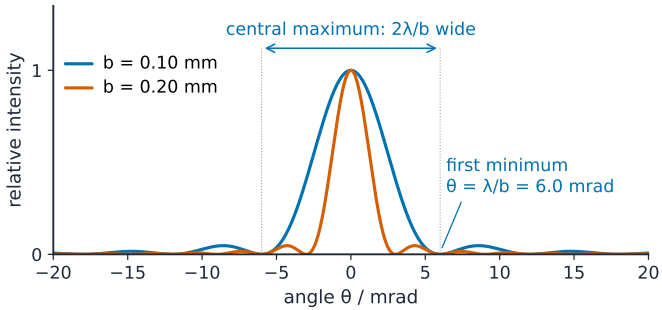
Check: fringe spacing

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.

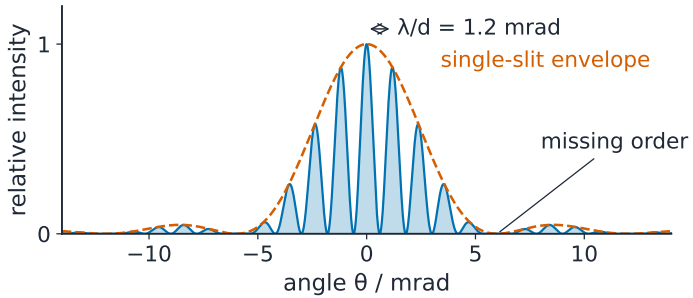
The first minimum

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

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

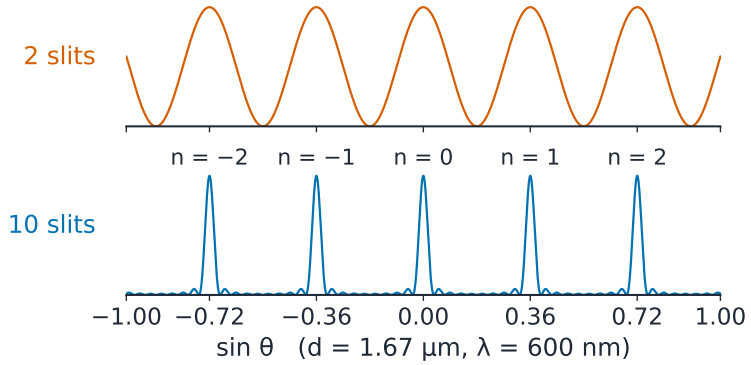
θ is in radians.

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 sharper peaks at the same angles. Fixed light per slit gives brighter peaks. Curves are normalized.

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The grating equation

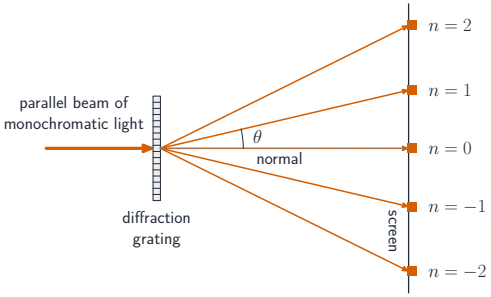
1. **Known. Normal** incidence; $\lambda = 600$ nm; 600 lines/mm gives $d = 1/600000$ m.
2. **Equation.** $n\lambda = d\sin\theta$, so $\theta = \sin^{-1}(n\lambda/d)$.
3. **Orders 1 and 2.** $\sin\theta_1 = 0.36 \Rightarrow 21.1°$; $\sin\theta_2 = 0.72 \Rightarrow 46.1°$.
4. **Limit.** Order 3 needs $\sin\theta = 1.08$: impossible. The highest whole order is 2.

Decision

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

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

A diffraction grating



More slits give sharper, brighter maxima

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°.