A LEVEL PHYSICS 9702 · AS LEVEL · TOPIC 8 · ~9 MIN READ

Superposition

The principle of superposition, how stationary waves form and how to find λ from nodes, experiments with strings, microwaves and air columns, diffraction, interference and coherence, the double slit λ = ax/D and the diffraction grating d sin θ = nλ.

Superposition | Stationary waves | Nodes & antinodes | Microwaves, strings, air columns | Diffraction | Interference & coherence | Double slit λ = ax/D | Diffraction grating

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Paper tag = **where it is examined** DATA & FORMULAE given in the exam C1 A1 B1 how marks are awarded

highlight = comes up again and again Test yourself at the end

IN 30 SECONDS

- **Superposition:** where two waves meet, the resultant displacement is the vector sum of the individual displacements.
- **A stationary wave** forms when two waves of the same frequency (and similar amplitude) travel in opposite directions, usually a wave and its reflection. Node to node is λ/2.
- **Diffraction** is the spreading of a wave through a gap or round an edge. It is most noticeable when the gap is about the same size as the wavelength.
- **Interference fringes** need **coherent** sources: a constant phase difference (so the same frequency).
- **Double slit:** λ = ax/D. **Grating:** d sin θ = nλ, with d = 1/(lines per metre).

BY THE END YOU CAN

- State and apply the principle of superposition.
- Explain how stationary waves form and find λ from node or antinode positions.
- Describe stationary-wave experiments with microwaves, strings and air columns.
- Describe diffraction and how it depends on the gap width.
- Explain interference and coherence and the conditions for observable fringes.
- Use λ = ax/D and d sin θ = nλ, and describe how a grating measures wavelength.

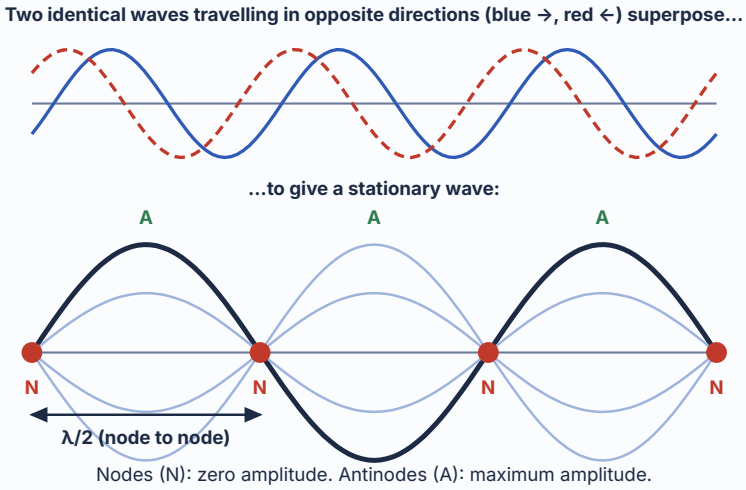
1 Superposition and stationary waves

Definitions

Principle of superposition — when two or more waves meet at a point, the resultant displacement is the (vector) sum of the displacements of the individual waves.

Node — a point on a stationary wave with zero amplitude (always at rest).

Antinode — a point on a stationary wave with maximum amplitude.



Nodes (N): zero amplitude. Antinodes (A): maximum amplitude.

Two waves travelling in opposite directions superpose to give fixed nodes and antinodes.

How a stationary wave forms

- **A wave travels to a boundary and is reflected.** The incident and reflected waves have the same frequency, speed and (nearly) the same amplitude, and travel in opposite directions.
- **They superpose.** At some points they always cancel (nodes); at others they reinforce to give maximum amplitude (antinodes).
- **Write all three ideas:** reflection, superposition (or interference), and same frequency/speed in opposite directions. In 2024 answers were too generic, and some wrongly mentioned "coherence".

	Progressive wave	Stationary wave
Energy	transferred along the wave	not transferred (stored)
Amplitude	the same for every point	varies from zero (node) to maximum (antinode)
Phase	changes continuously along the wave	all points between adjacent nodes are in phase; across a node, antiphase
Wavelength	distance between adjacent points in phase	twice the node-to-node distance

Three experiments

- **Stretched string:** a vibration generator drives a string over a pulley with a hanging mass. Adjust the frequency to see 1, 2, 3... loops. Each loop is $\lambda/2$; $v = f\lambda$.
- **Microwaves:** a transmitter faces a metal plate. Move a detector along the line between them: the reading rises and falls. Successive minima (nodes) are $\lambda/2$ apart.
- **Air column:** a tube closed at one end (or a tube in water) resonates with a tuning fork or loudspeaker. There is a node at the closed end and an antinode near the open end. Two successive resonance lengths differ by $\lambda/2$, which avoids the end correction.

WORKED EXAMPLE

A string 1.2 m long, fixed at both ends, vibrates in three loops at 150 Hz. Find the wave speed.

1. $3 \times \lambda/2 = 1.2 \Rightarrow \lambda = 0.80$ m **C1**
2. **$v = f\lambda = 150 \times 0.80 = 120$ m s^{-1}** **A1**

WORKED EXAMPLE

Microwaves reflect from a metal plate. A detector finds successive minima 1.4 cm apart. Find the frequency.

1. $\lambda/2 = 1.4$ cm $\Rightarrow \lambda = 2.8$ cm C1
2. $f = c/\lambda = 3.0 \times 10^8/0.028 = 1.1 \times 10^{10}$ Hz A1

WORKED EXAMPLE

A tube closed at one end resonates at 500 Hz at lengths 0.16 m and 0.50 m. Find the speed of sound.

1. successive resonances differ by $\lambda/2$: $\lambda = 2 \times 0.34 = 0.68$ m C1
2. $v = 500 \times 0.68 = 340$ m s^{-1} A1

COMMON MISTAKE

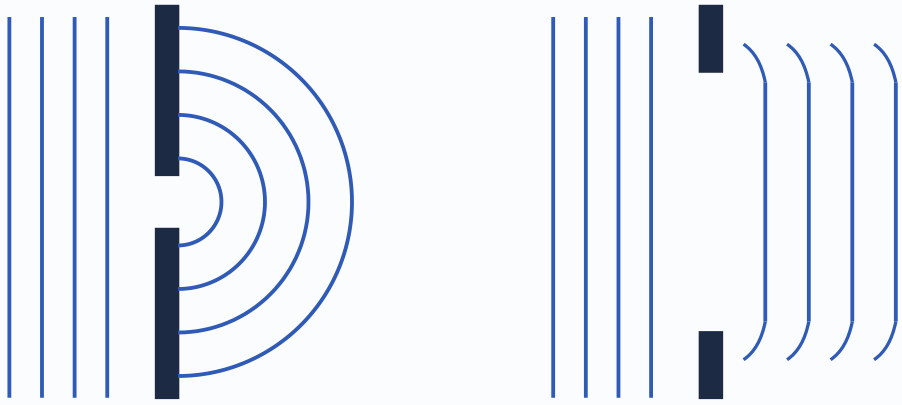
Taking the distance between two points as λ instead of λ/2. Common in 2024 Paper 1. Node to node (or antinode to antinode) is half a wavelength.

2 Diffraction

Spreading through a gap

Diffraction — the spreading of a wave as it passes through a gap or around the edge of an obstacle.

Diffraction: waves spread out after passing through a gap



gap ≈ λ: strong spreading | **gap ≫ λ: little spreading**

Diffraction is greatest when the gap width is close to the wavelength.

- **Ripple tank demonstration:** plane waves pass through a gap. With the gap about one wavelength wide, the emerging wavefronts are nearly circular; with a wide gap, they stay mostly straight with a little curving at the edges. Wavelength and speed are unchanged by diffraction.

3 Interference

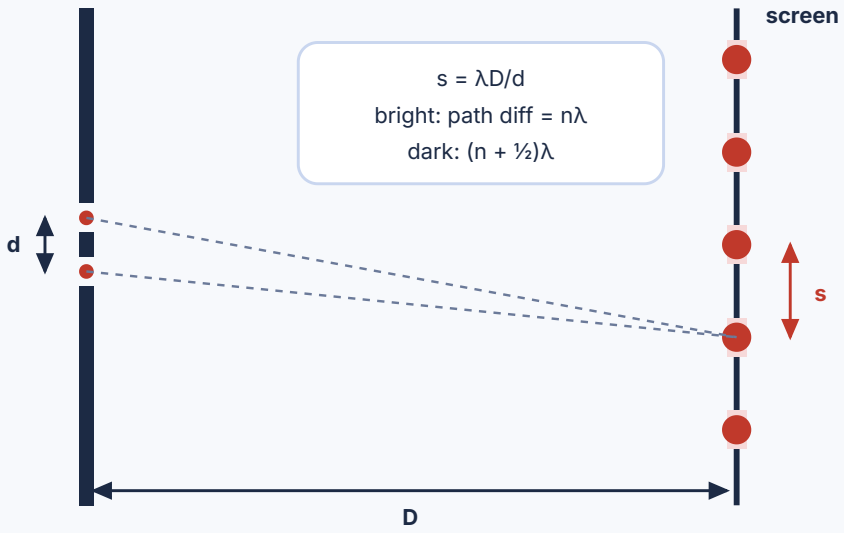
Coherence and conditions

Interference — the superposition of waves from two (or more) coherent sources, giving a stable pattern of maxima and minima.

Coherent — having a constant phase difference (which requires the same frequency).

- **Conditions for observable fringes:** coherent sources; similar amplitudes (so minima are dark); the waves overlap (diffraction at the slits makes this happen); slit separation not too large compared with λ so fringes are resolved.
- **Path difference (sources in phase):** constructive (maximum) when the path difference is nλ; destructive (minimum) when it is (n + ½)λ.
- **Demonstrations:** two dippers in a ripple tank (water); two loudspeakers driven by the same signal generator (sound); a laser through a double slit (light); microwaves through two gaps in a metal sheet.

The double slit



Young's double slit: fringe separation x on a screen a distance D from slits with separation a.

$$\lambda = ax/D$$ LEARN IT

a = slit separation, x = fringe separation, D = slit–screen distance (D ≫ a)

- **Measure x across many fringes** and divide (e.g. 10 fringe spacings) to reduce the percentage uncertainty.

WORKED EXAMPLE

Light passes through slits 0.50 mm apart. On a screen 2.4 m away, 10 fringe spacings measure 30 mm. Find λ.

1. x = 30/10 = 3.0 mm C1
2. **λ = ax/D = 0.50 × 10⁻³ × 3.0 × 10⁻³/2.4 = 6.3 × 10⁻⁷ m** A1

4 The diffraction grating

$d \sin\theta = n\lambda$

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

d = slit spacing = 1/N (N = lines per metre); n = order

- **Using a grating to measure λ:** shine monochromatic light normally onto the grating; measure the angle θ of a known order (measure both sides and halve 2θ to reduce error); λ = d sin θ/n. Higher orders give larger angles and smaller percentage uncertainty.
- **Highest order:** sin θ ≤ 1, so n ≤ d/λ. Round **down**. Total number of maxima = 2n_max + 1 (including the zero order).

WORKED EXAMPLE

A grating has 600 lines per mm and is illuminated normally with light of wavelength 550 nm. Find the angle between the 2nd and 3rd order maxima, and the highest order.

1. $d = 1/(600 \times 10^3) = 1.67 \times 10^{-6}$ m C1
2. $\theta_2 = \sin^{-1}(2 \times 550 \times 10^{-9}/1.67 \times 10^{-6}) = 41.3°$; $\theta_3 = \sin^{-1}(0.990) = 81.9°$ C1
3. angle between = **40.6°** A1
4. **$n \le d/\lambda = 3.03 \Rightarrow$ highest order 3** A1

COMMON MISTAKE

Mixing up N and d, giving the angle of one order when the angle between two was asked, or using sin 180° for the limit instead of sin 90°. All three are in the 2024 reports.

LINKING QUESTION

Superposition needs the wave terms from Waves; electron diffraction is evidence for wave behaviour of particles in Quantum physics; and the grating's line spectra link to energy levels in the same note.

Test yourself — cover the answers first

QUICK CHECK

1. State the principle of superposition.
2. What is the distance between adjacent nodes?
3. Define coherence.
4. What path difference gives a minimum for in-phase sources?
5. A grating has 300 lines per mm. What is d?

EXAM-STYLE

6. Explain how a stationary wave is formed on a stretched string fixed at both ends.
7. Red light of wavelength 600 nm gives a second-order maximum at 52° with a grating. Find the number of lines per millimetre.
8. In a double-slit experiment, state the effect on the fringe separation of (a) doubling D, (b) using blue light instead of red, (c) halving the slit separation.

Show answers

1. resultant displacement = vector sum of individual displacements
2. λ/2
3. a constant phase difference (same frequency)
4. (n + ½)λ
5. 3.3×10^{-6} m
6. the wave travels to the end and is reflected; incident and reflected waves (same frequency, speed and similar amplitude) travel in opposite directions and superpose; nodes where they always cancel (including the fixed ends), antinodes between
7. $d = 2 \times 600 \times 10^{-9}/\sin 52° = 1.52 \times 10^{-6}$ m ⇒ 660 lines per mm
8. (a) doubles (b) decreases (shorter λ) (c) doubles

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