8.1 Superposition and stationary waves

Name: _____ Class: _____ Date: _____ **Total: 24 marks**

KEY WORDS superposition • stationary wave • node • antinode • fundamental

Objective

Answer exam questions on **superposition** and **stationary waves**: how a stationary wave forms, its **nodes** and **antinodes**, the experiments with microwaves, strings and air columns, and finding a wavelength from the nodes. Syllabus 8.1, learning outcomes 1 to 4.

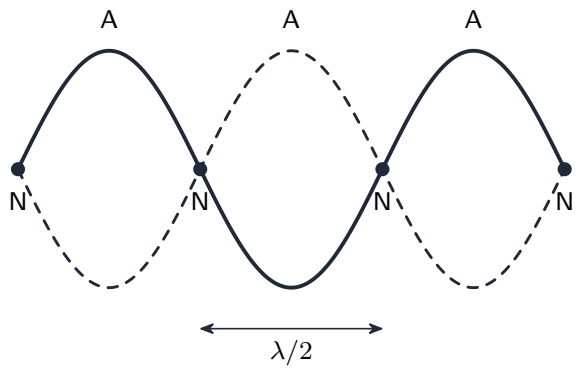
You must be able to:

- state the principle of superposition, and use it for waves in phase and in antiphase
- explain how a stationary wave forms, and compare it with a progressive wave
- identify nodes and antinodes, and find the wavelength from their positions
- describe the stationary-wave experiments with microwaves, a stretched string and an air column

1 Key knowledge and worked examples

Key knowledge: superposition and stationary waves

- **principle of superposition** (2 marks): when two or more waves meet at a point, the resultant displacement is the **sum** of the individual displacements
- two waves in phase add (constructive, amplitude $A_1 + A_2$); in antiphase they subtract (destructive, $|A_1 - A_2|$); since $I \propto A^2$, two equal waves in phase give four times the intensity
- **forming a stationary wave** (3 marks): two progressive waves of the **same frequency** (and speed and amplitude) travel in **opposite directions** and superpose; usually one is the **reflection** of the other

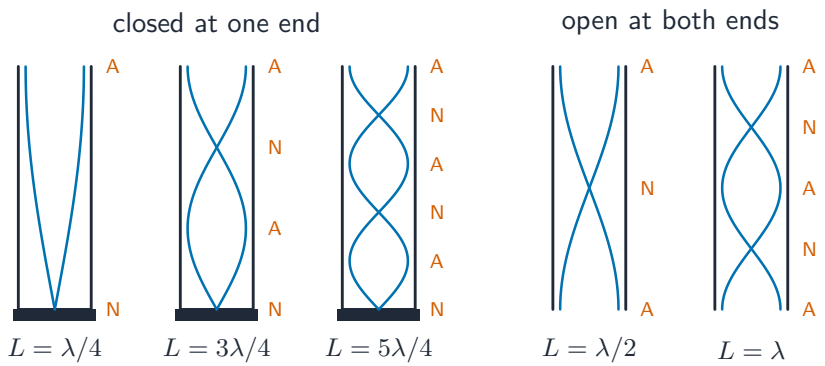


	Progressive wave	Stationary wave
energy	transferred along the wave	**not** transferred along it
amplitude	the same for every point	zero at **nodes**, greatest at **antinodes**
phase	changes continuously along the wave	all points between neighbouring nodes **in phase**; points in neighbouring loops in **antiphase**
wavelength	crest to crest	**twice** the distance between neighbouring nodes

Adjacent nodes are $\lambda/2$ apart; a node and its neighbouring antinode are $\lambda/4$ apart.

■ Key knowledge: the three experiments

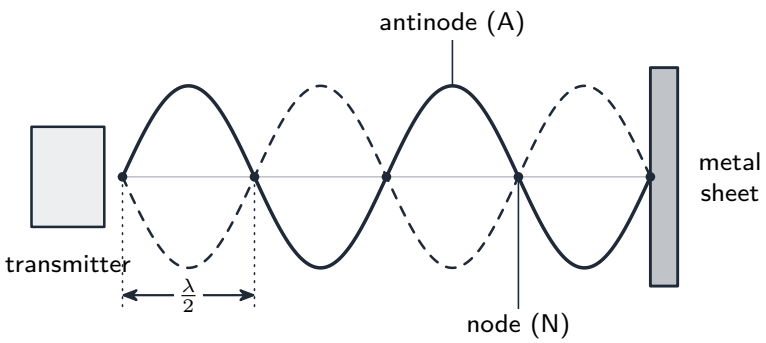
Set-up	What forms the stationary wave	Where the nodes are
microwaves: transmitter facing a metal sheet, a detector moved between them	the waves reflected by the sheet overlap the incoming waves	where the detector reading is a minimum: neighbouring minima are $\lambda/2$ apart
stretched string: a vibration generator at one end, over a pulley to masses	waves reflect at the fixed ends	at both fixed ends; n loops fit the length: $L = n\lambda/2$
air column: a loudspeaker or tuning fork at the open end of a tube	sound reflects at the end of the tube	a **closed** end is a node, an **open** end an antinode



Air columns: a closed end is a node, an open end an antinode

- a closed pipe resonates first when $L = \dfrac{\lambda}{4}$, then $\dfrac{3\lambda}{4}$; a pipe open at both ends first when $L = \dfrac{\lambda}{2}$
- the lowest frequency that fits is the **fundamental**; then $v = f\lambda$ gives the wave speed

■ Worked example: microwaves and a metal sheet



A detector moved between the transmitter and the sheet finds neighbouring minima 25 mm apart.

1. **Wavelength** – node to node is half a wavelength, $\dfrac{\lambda}{2} = 25$ mm, so $\lambda = 2 \times 25$ mm $= 0.050$ m.
2. **Frequency** – microwaves travel at c; wave equation, $f = \dfrac{c}{\lambda} = \dfrac{3.0 \times 10^8}{0.050} = 6.0 \times 10^9$ Hz.

■ **Worked example: a stretched string**

A string of length 1.20 m, fixed at both ends, shows three loops when vibrated at 150 Hz.

1. **Wavelength** – three loops fill the length: $L = 3 \times \frac{\lambda}{2}$, so $\lambda = \frac{2L}{3} = \frac{2 \times 1.20}{3} = 0.80$ m.
2. **Wave speed** – $v = f\lambda = 150 \times 0.80 = 120\ \frac{\text{m}}{\text{s}}$.
3. **Fundamental** – one loop, $\lambda = 2.40$ m: $f = \frac{v}{\lambda} = \frac{120}{2.40} = 50$ Hz.

■ **Worked example: an air column**

A tuning fork of frequency 512 Hz is held over a tube closed at the bottom. The air column resonates when it is 16.6 cm long, and next at 50.0 cm.

1. **Wavelength** – between the two resonances the column grows by half a wavelength: $\frac{\lambda}{2} = 50.0 - 16.6 = 33.4$ cm, so $\lambda = 0.668$ m.
2. **Speed of sound** – wave equation, $v = f\lambda = 512 \times 0.668 = 342\ \frac{\text{m}}{\text{s}}$.

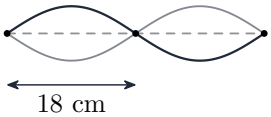
2 Practice

Now apply the methods above.

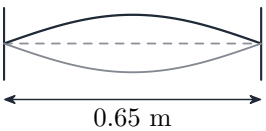
2.1 State the **principle of superposition**. [2]

superposition

2.2 On a stationary wave, neighbouring nodes are 18 cm apart. State the wavelength. [1]



2.3 A guitar string 0.65 m long vibrates in its fundamental mode at 196 Hz. Calculate the speed of the waves on the string. [2]

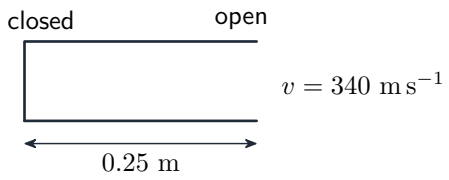


$f = 196$ Hz

2.4 State **two** differences between a stationary wave and a progressive wave. [2]

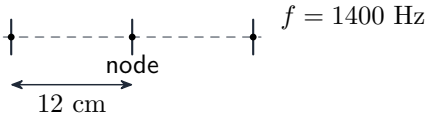
stationary progressive

2.5 A pipe closed at one end is 0.25 m long. The speed of sound is 340 $\frac{\text{m}}{\text{s}}$. Calculate the frequency of its fundamental. [2]



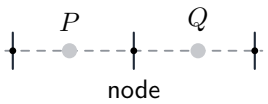
3 Exam-style questions

3.1 Neighbouring nodes of a stationary sound wave are 12 cm apart. The frequency is 1400 Hz. What is the speed of sound? [1]



- **A** 168 $\frac{\text{m}}{\text{s}}$
- **B** 336 $\frac{\text{m}}{\text{s}}$
- **C** 672 $\frac{\text{m}}{\text{s}}$
- **D** 1.2×10^4 $\frac{\text{m}}{\text{s}}$

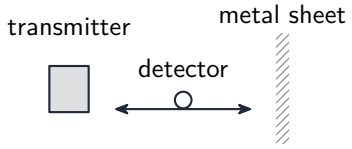
3.2 Two points on a stationary wave lie in neighbouring loops. What is the phase difference between their oscillations? [1]



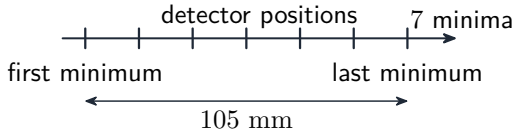
- **A** 0°
- **B** 45°
- **C** 90°
- **D** 180°

3.3 A microwave transmitter faces a flat metal sheet. A detector is moved along the line between them, and the reading rises and falls.

(a) **Explain** how a stationary wave forms between the transmitter and the sheet. [3]



(b) The detector passes through 7 neighbouring minima over a distance of 105 mm, measured from the first minimum to the last. **Determine** the wavelength of the microwaves. [2]

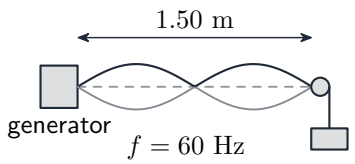


(c) Calculate the frequency of the microwaves. [2]

3.4 A string of length 1.50 m is stretched between a vibration generator and a pulley. At a frequency of 60 Hz it vibrates with two loops.

(a) State the positions of the nodes on the string. [1]

(b) Calculate the speed of the waves on the string. [2]



(c) Calculate the frequency at which the string vibrates with three loops. [2]

(d) State the phase difference between the oscillations of a point in the first loop and a point in the second loop. [1]