AQA AS Stationary Waves and Harmonics solutions

Matching solutions and teaching prompts for the class review

Specification points covered

• 3.3.1.3(a) Nodes and antinodes on a string. • 3.3.1.3(b) Use $f = (1/2\ell)\sqrt{(T/\mu)}$. • 3.3.1.3(c) Formation from equal-frequency opposite waves. • 3.3.1.3(d) Graphical explanation of stationary waves.	• 3.3.1.3(e) Stationary waves in strings, microwaves and sound. • 3.3.1.3(f) Harmonics on strings. • 3.3.1.3(g) AQA harmonic terminology.

Teaching focus

Insist on precise particle, wave and energy language as well as correct calculations.
Use each common-error prompt to correct the pupil's model or reasoning, not only the final answer.

1. How the pattern forms

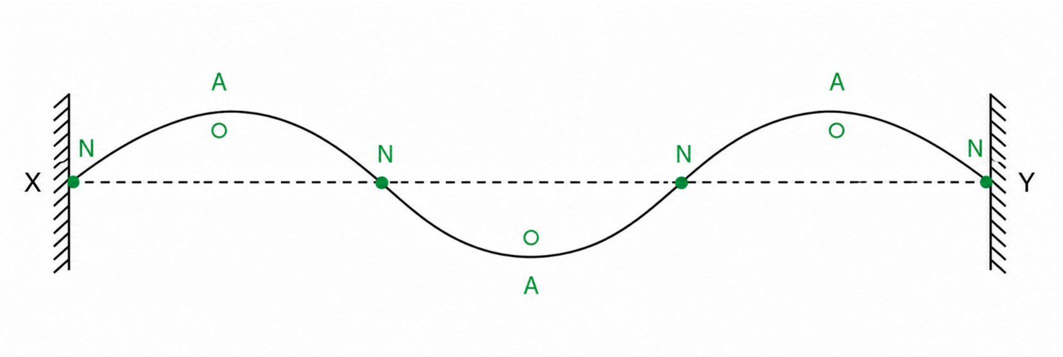
1. Two waves travel along a wind-turbine support cable in opposite directions. State the conditions required for them to form a stationary wave and explain the origin of nodes and antinodes. [3 marks]

Answer / mark points: The waves must have the same frequency and normally the same amplitude and travel in opposite directions. Superposition gives permanent destructive-interference positions called nodes and maximum-amplitude positions called antinodes.

Teacher prompt / common error: A stationary wave is formed by superposition, not by a single reflected wave alone.

2. Reading the cable pattern

2. The diagram shows the vibration pattern on a 6.00 m cable fixed at X and Y. State (a) the number of nodes, (b) the number of antinodes, (c) the harmonic shown and (d) the wavelength. [4 marks]



Answer / mark points: (a) Four nodes, including X and Y and two internal nodes. (b) Three antinodes. (c) Third harmonic. (d) Three half-wavelengths fit in 6.00 m: $3\lambda/2 = 6.00$, so $\lambda = 4.00$ m.
Teacher prompt / common error: Count fixed endpoints as nodes and use the number of half-wavelengths, not the number of internal nodes.

3. Compare the phase and amplitude of (a) two points within the same loop and (b) points in adjacent loops. State the amplitude at a node. [3 marks]

Answer / mark points: Points in one loop oscillate in phase but generally with different amplitudes depending on position. Points in adjacent loops oscillate in antiphase, a phase difference of π rad or 180°. A node has zero amplitude.
Teacher prompt / common error: Amplitude varies with position; phase is the same only within one loop.

3. Cable calculations

4. The pattern in the diagram has frequency 12.0 Hz. Calculate the wave speed along the cable. [2 marks]

Answer / mark points: $v = f\lambda = 12.0 \times 4.00 = 48.0$ m s^{-1}.	
Teacher prompt / common error: Use the wavelength inferred from the whole cable pattern.	

5. The cable has mass per unit length 3.20 kg m^{-1}. Calculate the tension in the cable when the wave speed has the value found in Question 4. [3 marks]

Answer / mark points: $v = \sqrt{(T/\mu)}$, so $T = \mu v^2 = 3.20 \times 48.0^2 = 7.37 \times 10^3$ N.	
Teacher prompt / common error: Rearrange $v = \sqrt{(T/\mu)}$ before substituting and square the speed.	

6. Ice increases the cable's mass per unit length by a factor of 1.44 while length and tension stay constant. Calculate the new frequency of the same harmonic. [3 marks]

Answer / mark points: For fixed T and ℓ, f is proportional to $1/\sqrt{\mu}$. New $f = 12.0/\sqrt{1.44} = 10.0$ Hz.	
Teacher prompt / common error: Frequency is inversely proportional to the square root of μ.	

7. The first harmonic of the unloaded cable is 6.0 Hz. The monitoring system detects a strong response at 18.0 Hz. Identify the harmonic and describe its loop pattern. [2 marks]

Answer / mark points: 18.0/6.0 = 3, so it is the third harmonic. It has three loops, four nodes and three antinodes.	
Teacher prompt / common error: The nth harmonic has n loops on a string fixed at both ends.	

4. Applying nodes and antinodes

8. An engineer proposes fitting a damper at the cable midpoint. Explain why this strongly suppresses the first harmonic but can leave the second harmonic much less affected. [3 marks]

Answer / mark points: The cable midpoint is an antinode in the first harmonic, so a damper there removes energy from a large motion. The midpoint is a node in the second harmonic, so its displacement is zero and the damper couples weakly to that mode.

Teacher prompt / common error: Judge the damper by local displacement: antinode large, node zero.

9. A microwave inspection chamber has adjacent detector minima separated by 6.10 cm. Calculate the microwave wavelength and frequency. [3 marks]

Answer / mark points: Adjacent minima are separated by $\lambda/2$. Therefore $\lambda = 2 \times 0.0610 = 0.122$ m. $f = c/\lambda = 3.00 \times 10^8/0.122 = 2.46 \times 10^9$ Hz.

Teacher prompt / common error: Adjacent minima are half a wavelength apart in the standing pattern.

10. In a sound-tube demonstration, adjacent powder heaps occur at displacement nodes 3.40 cm apart. The sound speed is 340 m s^{-1}. Calculate the wavelength and frequency. [3 marks]

Answer / mark points: Adjacent displacement nodes are $\lambda/2$ apart. $\lambda = 2 \times 0.0340 = 0.0680$ m. $f = v/\lambda = 340/0.0680 = 5.00 \times 10^3$ Hz.

Teacher prompt / common error: Powder heaps identify displacement nodes; adjacent nodes are $\lambda/2$ apart.

11. Compare a stationary wave with either travelling wave that forms it. Include amplitude, phase and net energy transfer. [3 marks]

Answer / mark points: The stationary wave has position-dependent amplitude, from zero at nodes to maximum at antinodes; points within a loop are in phase and adjacent loops are in antiphase. A component travelling wave has the same amplitude at every position and progressive phase change with distance. The stationary pattern has no net energy transfer along the cable, while each travelling wave transfers energy.

Teacher prompt / common error: Do not say energy stays at the antinodes. State that there is no net energy transfer along a stationary wave.

5. Testing the model

12. Design a method to test $f = (1/2\ell)\sqrt{T/\mu}$ for the cable material using a vibration generator, pulley and hanging masses. Include measurements, control variables, a graph and safety. [6 marks]

Answer / mark points: A high-level method: measure mass and length of a sample to obtain μ; set a measured vibrating length ℓ; pass the cable over a low-friction pulley and use T = mg; drive it and adjust frequency to the first harmonic, identified by one loop and nodes at both ends; repeat frequency readings and vary hanging mass over a safe range while keeping ℓ and μ constant; plot f^2 against T and expect a straight line through the origin; compare gradient with $1/(4\ell^2\mu)$. Clamp the apparatus, keep clear of falling masses and do not exceed the cable's safe load. Award any six distinct points including the graph.
Teacher prompt / common error: A valid test varies tension and keeps vibrating length and mass per unit length controlled.

13. For a fixed length and cable, explain why a graph of f^2 against T should be a straight line through the origin and state what its gradient equals. [3 marks]

Answer / mark points: Squaring $f = (1/2\ell)\sqrt{T/\mu}$ gives $f^2 = T/(4\ell^2\mu)$. With ℓ and μ fixed, this has the form y = mx, so the graph is linear through the origin and gradient = $1/(4\ell^2\mu)$.
Teacher prompt / common error: Derive the linear form before naming the gradient.

Language and method check

Award independent, creditworthy physics steps; do not award extra marks for repeated statements.
Accept equivalent methods when the physical reasoning, units and final precision remain consistent.