3.3 Waves: 1-hour Pack

AQA 7408 · Calculator allowed · about 60 minutes

Total Marks

Name: _____ Date: ____ / ____ / _____

Answer ALL questions. Show all your working.

1 Required practical: a student sets up a stretched string of length 0.80 m between a vibration generator and a pulley, with a mass hung over the pulley to provide tension. The mass per unit length of the string is 4.0×10^{-4} kg/m. Use the Physics Equations Sheet. Take g = 9.81 m/s^2. Use v = $\sqrt{T/μ}$, where T is the tension in the string and μ is the mass per unit length.

(a) A mass of 250 g is hung from the string. Calculate the tension T in the string. **(2)**

(b) Calculate the speed of the transverse wave on the string. **(3)**

(c) The string vibrates in its fundamental mode as a standing wave, with the string length of 0.80 m equal to half a wavelength. Calculate the frequency of the vibration generator needed to produce this fundamental standing wave. **(3)**

(d) The student then increases the tension in the string by hanging a heavier mass, while keeping the string length and the number of antinodes the same. Explain the effect this has on the frequency needed to maintain a standing wave pattern with the same number of antinodes. **(3)**

(e) State what is meant by a 'node' and by an 'antinode' on a stationary (standing) wave. **(2)**

(Total for Question 1 is 13 marks)

© Revision Library | revisionlibrary.co.uk

2 A wind instrument is modelled as a pipe of length 0.60 m, open at both ends. For a pipe open at both ends, stationary waves form when the pipe length is a whole number of half wavelengths: $L = n \times (\lambda/2)$, where $n = 1, 2, 3 \ldots$ The speed of sound in air depends on temperature according to $v = 331 + 0.60 \times \theta$, where θ is the temperature in degrees Celsius and v is in m/s.

(a) State what is meant by the 'fundamental frequency' of a stationary wave system such as this pipe. **(1)**

(b) Calculate the speed of sound in the pipe when the air temperature is 18°C. **(2)**

(c) Calculate the frequency of the fundamental (n = 1) note produced by the pipe at this temperature. **(3)**

(d) Calculate the frequency of the third harmonic (n = 3) at this temperature. **(2)**

(e) On a cold day the temperature drops to -5°C. Show that the fundamental frequency of the pipe changes by less than 5%, compared with its value at 18°C, assuming the pipe length does not change. **(4)**

(Total for Question 2 is 12 marks)

---

3 Interference and diffraction experiments, such as Young's double-slit experiment and diffraction through a grating, provide strong evidence for the wave nature of light. However, the photoelectric effect, in which electrons are only emitted from a metal surface above a threshold frequency of incident light regardless of its intensity, cannot be explained by a purely wave-based model and instead supports a photon (particle) model of light. Evaluate how evidence from wave phenomena and evidence from the photoelectric effect together support the modern view that light exhibits wave-particle duality, referring to specific features of each type of evidence in your answer.

(Total for Question 3 is 6 marks)

© Revision Library | revisionlibrary.co.uk

4 REQUIRED PRACTICAL. A student determines the speed of sound in air using a signal generator, a loudspeaker and two microphones connected to a double-beam oscilloscope. The loudspeaker is driven at a fixed frequency of 2500 Hz. One microphone is fixed; the second is moved directly away from the loudspeaker along the line joining them until the two oscilloscope traces are back in phase for the eighth time. The total distance moved by the second microphone is measured as 1.056 m.

(a) Explain why the student measures the total distance moved for eight complete cycles back into phase, rather than measuring the distance for just one wavelength. **(2)**

(b) Calculate the wavelength of the sound wave. **(2)**

(c) Calculate the speed of sound in air from this result. **(2)**

(d) The ruler used to measure the 1.056 m distance has an uncertainty of ± 1 mm, and the frequency of the signal generator has a negligible uncertainty. Calculate the percentage uncertainty and hence the absolute uncertainty in the calculated speed of sound. **(3)**

(e) The accepted speed of sound in air at 20°C is 343 m/s. Suggest two reasons why the student's calculated value is lower than this. **(2)**

(Total for Question 4 is 11 marks)

© Revision Library | revisionlibrary.co.uk

Mark scheme · 3.3 Waves: 1-hour Pack

Question 1

(a) T = mg = 0.250 x 9.81 **M1**

(a) 2.45 N (awrt 2.4-2.5 N) **A1**

(a) Answer: 2.45 N

(b) correct substitution: $v = \sqrt{2.4525/4.0 \times 10^{-4}}$ **M1**

(b) evaluates ratio inside the square root: 6131 (awrt) **M1**

(b) 78.3 m/s (awrt 78-79 m/s, ft from (a)) **A1**

(b) Answer: 78.3 m/s

(c) wavelength = 2 x 0.80 = 1.60 m **M1**

(c) correct substitution: f = v/λ = 78.3/1.60 **M1**

(c) 48.9 Hz (awrt 48-49 Hz, ft from (b)) **A1**

(c) Answer: 48.9 Hz

(d) increasing the tension T increases the wave speed v, since $v = \sqrt{T/μ}$ **B1**

(d) the wavelength is unchanged, since the string length and number of antinodes are the same **B1**

(d) since f = v/λ and λ is unchanged, an increase in v means the frequency needed increases oe **B1**

(d) Answer: The frequency needed increases, because increasing the tension increases the wave speed while the wavelength (fixed by the string length and mode) stays the same.

(e) a node is a point on the wave with zero (permanently no) displacement/amplitude **B1**

(e) an antinode is a point on the wave with maximum amplitude of oscillation **B1**

(e) Answer: Node: point of zero displacement/amplitude. Antinode: point of maximum amplitude.

Question 2

(a) the lowest frequency (n = 1) at which a stationary wave pattern can be formed in the system oe **B1**

(a) Answer: The lowest frequency (n = 1) at which a stationary wave can be formed in the pipe.

(b) correct substitution: v = 331 + 0.60 x 18 **M1**

(b) 342 m/s (awrt, cao) **A1**

(b) Answer: 342 m/s

(c) wavelength = 2 x L/n = 2 x 0.60/1 = 1.20 m **M1**

(c) correct substitution: f = v/λ = 341.8/1.20 **M1**

(c) 285 Hz (awrt 284-285 Hz, ft from (b)) **A1**

(c) Answer: 285 Hz

(d) recognises harmonics of an open-open pipe are integer multiples of the fundamental: f3 = 3 x f1, or recalculates wavelength = 2 x 0.60/3 = 0.40 m **M1**

(d) 855 Hz (awrt 854-855 Hz, ft from (c)) **A1**

(d) Answer: 855 Hz

(e) v at -5°C = 331 + 0.60 x (-5) = 328 m/s **M1**

(e) f1 at -5°C = 328/1.20 = 273 Hz (awrt) **M1**

(e) percentage change = (284.8 - 273.3)/284.8 x 100 **M1**

(e) = 4.0%, which is less than 5% (cso) **A1**

(e) Answer: The fundamental frequency changes by about 4.0%, which is less than 5%, confirming the statement.

Question 3

Level 3 Detailed and well-linked evaluation that correctly explains how interference and diffraction require superposition of waves (path difference, constructive/destructive interference) and could not occur for classical particles, AND explains why the photoelectric effect (existence of a threshold frequency, instantaneous emission, and kinetic energy of electrons depending on frequency not intensity) cannot be explained by a wave model but is explained by discrete photons of energy E = hf. Reaches a clear, justified conclusion that light must be treated as having both wave and particle character (wave-particle duality), used in different contexts. **5-6**

Level 2 Correctly describes at least one piece of wave evidence and at least one feature of the photoelectric effect, with some explanation of why each supports its respective model, but the argument linking them to a duality conclusion is only partially developed or contains minor inaccuracies. **3-4**

Level 1 Basic or one-sided answer: describes either wave evidence or photon evidence in isolation, with little or no attempt to connect the two forms of evidence or reach a conclusion about duality. **1-2**

Indicative content:

- Wave evidence: interference and diffraction require superposition of waves and depend on path difference; regions of constructive and destructive interference (bright and dark fringes) can only be explained if light behaves as a wave.
- A stream of classical particles would not produce a stable interference pattern with alternating maxima and minima; the wave model correctly predicts fringe spacing from wavelength, slit separation and distance to screen.
- Photoelectric evidence: emission of electrons occurs only above a threshold frequency, independent of intensity, and emission is effectively instantaneous even at very low intensity.
- A wave model predicts that energy should accumulate over time at any frequency given sufficient intensity, eventually releasing electrons; this is not observed, so the wave model fails here.
- The photon model (E = hf) explains the threshold frequency as the minimum photon energy needed to overcome the work function, and explains why increasing intensity (more photons) increases the rate of emission but not the maximum kinetic energy of each photoelectron, which depends only on frequency.
- Conclusion: light must be described using both models depending on the phenomenon being explained (wave-particle duality); neither a purely wave model nor a purely particle model alone accounts for all observed behaviour of light.

© Revision Library | revisionlibrary.co.uk

Question 4

(a) measuring across several wavelengths and dividing by the number of wavelengths means the absolute uncertainty in the ruler reading is spread over a much larger distance **B1**

(a) this reduces the percentage uncertainty in the value obtained for a single wavelength, compared with measuring just one wavelength directly oe **B1**

(a) Answer: Measuring across eight wavelengths and dividing by 8 spreads the fixed absolute uncertainty of the ruler over a much larger measured distance, reducing the percentage uncertainty in the wavelength.

(b) wavelength = total distance / number of wavelengths = 1.056 / 8 **M1**

(b) λ = 0.132 m cao **A1**

(b) Answer: 0.132 m

(c) use v = f λ = 2500 x 0.132 **M1**

(c) v = 330 m/s cao **A1**

(c) Answer: 330 m/s

(d) percentage uncertainty in distance = (0.001/1.056) x 100 = 0.095% **M1**

(d) since frequency uncertainty is negligible, this is also the percentage uncertainty in the speed **M1**

(d) absolute uncertainty = (0.095/100) x 330 = 0.31 m/s, so v = (330.0 ± 0.3) m/s cao **A1**

(d) Answer: ± 0.3 m/s

(e) the speed of sound in air increases with temperature, so the laboratory air was likely at a lower temperature than 20°C oe **B1**

(e) alternatively, a systematic error such as the student misjudging when the traces were exactly back in phase (a small consistent offset in the distance measured) would also explain a discrepancy oe **B1**

(e) Answer: The laboratory air was probably at a temperature below 20°C, since the speed of sound in air increases with temperature; a systematic timing/alignment error in judging when the traces were exactly in phase is also a plausible cause.

© Revision Library | revisionlibrary.co.uk