3.3 Waves: 2-hour Pack

AQA 7408 · Calculator allowed · about 120 minutes

Total Marks

Name: _____ Date: ____ / ____ / _____

Answer ALL questions. Show all your working.

1 Required practical: a monochromatic light source of wavelength 589 nm (from a sodium lamp) shines through a pair of double slits separated by 0.40 mm, producing an interference pattern on a screen 2.50 m from the slits. Use the equation w = (λ x D)/s, where w is the fringe spacing, D is the slit-to-screen distance and s is the slit separation.

(a) Calculate the fringe spacing, w, observed on the screen. **(3)**

(b) Show that about 14 bright fringes would be seen across a central 5.0 cm width of the screen. **(3)**

(c) State two conditions necessary for the light passing through the two slits to produce a stable, observable interference pattern. **(2)**

(d) State what is meant by the 'path difference' between two waves arriving at a point. **(1)**

(e) The sodium lamp is replaced with a red laser of longer wavelength, with the slit separation and screen distance unchanged. State and explain the effect on the fringe spacing. **(2)**

(Total for Question 1 is 11 marks)

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2 Required practical: a resonance tube, closed at one end, is used to measure the speed of sound. A tuning fork of frequency 512 Hz is held above the open end, and the air column length is increased from zero until the first resonance (loudest sound) is heard, at a length of 0.158 m. For a closed pipe at first resonance, $L = \lambda/4$.

(a) Calculate the wavelength of the sound in the tube at this first resonance. **(2)**

(b) Use $v = f \times \lambda$ to calculate the speed of sound in air found in this experiment. **(2)**

(c) A second resonance is found at a greater air column length. Using $L = (3 \times \lambda)/4$ for this second resonance, calculate the length at which it occurs. **(2)**

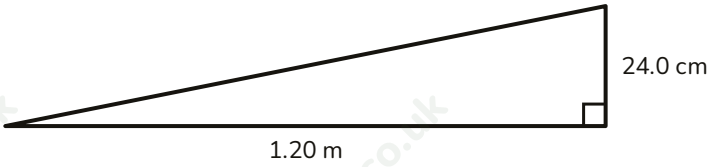
(d) State what is meant by 'resonance' occurring in the air column of the tube. **(1)**

(e) The student repeats the experiment several times and finds the measured speed of sound varies between 320 and 328 m/s, whereas the accepted value at room temperature is 343 m/s. Evaluate possible sources of error in this method and suggest improvements that could be made to obtain a more accurate value for the speed of sound. **(6)**

(Total for Question 2 is 13 marks)

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3 Required practical: a student directs a laser beam through a diffraction grating with 300 lines per mm onto a screen 1.20 m away. The first-order maximum is observed at a distance of 24.0 cm from the central (zeroth-order) maximum on the screen. Use $d \sin(\theta) = n \times \lambda$, where d is the grating spacing.



(a) Calculate the grating spacing, d, in metres. **(2)**

(b) Using the small right-angled triangle formed by the screen distance and the position of the first-order maximum, calculate the angle θ for the first-order maximum. **(3)**

(c) Calculate the wavelength of the laser light, using $d \sin(\theta) = n \times \lambda$ with $n = 1$. **(3)**

(d) State one advantage of using a diffraction grating, rather than a double slit, to determine the wavelength of light. **(1)**

(e) The student then uses a grating with 600 lines per mm instead of 300 lines per mm, keeping the laser and the screen distance the same. Explain, without further calculation, how the position of the first-order maximum on the screen would change. **(2)**

(Total for Question 3 is 11 marks)

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4 Standing waves on a string. A guitar string of length 0.65 m has mass per unit length 1.2×10^{-3} kg/m and is under a tension of 145 N.

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

(b) The string vibrates in its fundamental mode. Calculate the fundamental frequency. **(2)**

(c) The string is then made to vibrate at its third harmonic. Calculate this frequency and state the number of antinodes present on the string. **(2)**

(Total for Question 4 is 7 marks)

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5 A diffraction grating with 600 lines per mm is illuminated normally with light of wavelength 632.8 nm from a helium-neon laser.

(a) Calculate the grating spacing d in metres. **(1)**

(b) Calculate the angle at which the first-order maximum is observed. **(3)**

(c) Determine the highest order of diffraction maximum that can be observed with this grating and this wavelength, showing your reasoning. **(3)**

(Total for Question 5 is 7 marks)

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6 A point source emits sound waves uniformly in all directions. At a distance of 2.0 m from the source, the intensity of the sound is 4.5×10^{-3} W/m^2.

(a) State how the intensity of sound from a point source varies with distance from the source. **(1)**

(b) Calculate the intensity of the sound at a distance of 6.0 m from the source. **(3)**

(c) Using the relationship between intensity and amplitude, calculate the ratio of the wave amplitude at 6.0 m to the amplitude at 2.0 m. **(3)**

(Total for Question 6 is 7 marks)

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7 A student measures the wavelength of a laser using two independent methods. Method 1: a double-slit arrangement with slit separation $s = 2.5 \times 10^{-4}$ m and slit-to-screen distance D = 3.00 m, giving a measured fringe spacing $w = 7.60 \times 10^{-3}$ m, using $w = (\lambda \times D)/s$. Method 2: a diffraction grating with 600 lines per mm, using $d \sin(\theta) = n \times \lambda$.

(a) Calculate the wavelength obtained from the double-slit method (Method 1). **(2)**

(b) The student estimates the percentage uncertainty in the measured fringe spacing w to be 3.0%, with the percentage uncertainties in s and D negligible in comparison. Calculate the absolute uncertainty in the wavelength found in part (a). **(3)**

(c) The diffraction grating (Method 2) is then used with the same laser. Calculate the angle of the second-order (n = 2) maximum, using the wavelength found in part (a). **(3)**

(d) State one advantage of averaging fringe widths measured across ten fringe spacings, rather than measuring a single fringe spacing, when determining w. **(1)**

(e) Evaluate which of the two methods (double slit or diffraction grating) is likely to give the more precise value of the wavelength, using your understanding of the experimental measurements involved. **(3)**

(Total for Question 7 is 12 marks)

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8 Young's double-slit experiment. A laser illuminates two slits of separation 0.45 mm. The resulting fringe pattern is observed on a screen 1.85 m from the slits. The fringe spacing is measured as 2.28 mm.

(a) Calculate the wavelength of the laser light, giving your answer in nm to 3 significant figures. **(4)**

(b) The fringe spacing was measured to ± 0.05 mm, the slit separation to ± 0.01 mm and the slit-to-screen distance to ± 0.02 m. Calculate the percentage uncertainty in the calculated wavelength. **(3)**

(c) Use your answers to (a) and (b) to state the wavelength with its absolute uncertainty, to an appropriate number of significant figures. **(2)**

(Total for Question 8 is 9 marks)

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9 Unpolarised light of intensity 840 W/m^2 is incident on a polarising filter, then on a second polarising filter whose transmission axis is at 35 degrees to the first.

(a) Calculate the intensity of light transmitted through both filters. **(4)**

(b) Calculate the angle between the transmission axes of the two filters that would be needed to reduce the intensity after the second filter to 10% of the intensity leaving the first filter. **(3)**

(Total for Question 9 is 7 marks)

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Mark scheme · 3.3 Waves: 2-hour Pack

Question 1

(a) converts units correctly: $\lambda = 589 \times 10^{-9}$ m, $s = 0.40 \times 10^{-3}$ m — **M1**

(a) correct substitution: $w = (589 \times 10^{-9} \times 2.50)/(0.40 \times 10^{-3})$ — **M1**

(a) 3.68×10^{-3} m (awrt 3.7 mm) — **A1**

(a) Answer: 3.68 mm (3.68×10^{-3} m)

(b) converts width to metres: 5.0 cm = 0.050 m — **M1**

(b) number of fringes = $0.050/(3.68 \times 10^{-3})$ — **M1**

(b) = 13.6, so about 14 bright fringes fit across the width (cso, ft from (a)) — **A1**

(b) Answer: About 14 bright fringes.

(c) the two sources (slits) must be coherent (constant phase difference) oe — **B1**

(c) the light from the two slits must have the same frequency/wavelength (and be monochromatic, of similar amplitude) oe — **B1**

(c) Answer: Coherence (constant phase difference); same frequency/wavelength.

(d) the extra distance travelled by one wave compared with the other, from the sources to that point oe — **B1**

(d) Answer: The extra distance travelled by one wave compared with the other, to reach the same point.

(e) the fringe spacing increases — **B1**

(e) since $w = (\lambda \times D)/s$, with D and s unchanged, a larger λ gives a larger w oe — **B1**

(e) Answer: The fringe spacing increases, because w is directly proportional to wavelength when D and s are fixed.

Question 2

(a) $\lambda = 4 \times L = 4 \times 0.158$ — **M1**

(a) 0.632 m (cao) — **A1**

(a) Answer: 0.632 m

(b) correct substitution: $v = 512 \times 0.632$ — **M1**

(b) 324 m/s (awrt 323-324 m/s, ft from (a)) — **A1**

(b) Answer: 324 m/s

(c) correct substitution: $L = (3 \times 0.632)/4$ — **M1**

(c) 0.474 m (awrt, ft from (a)) — **A1**

(c) Answer: 0.474 m

(d) the air column vibrates with maximum amplitude, forming a stationary wave, when driven at (one of) its natural frequencies oe — **B1**

(d) Answer: The air column vibrates with maximum amplitude (forming a stationary wave) when driven at one of its natural frequencies.

(e) **L3** Detailed, coherent evaluation of multiple sources of error (including at least one systematic and one random error), each clearly linked to a valid, practical improvement. Physics used accurately throughout. — **5-6**

(e) **L2** Sound evaluation of some sources of error, with improvements suggested, though links between error and improvement may be incomplete or only partially explained. — **3-4**

(e) **L1** Basic, general statements about accuracy or error, with limited explanation and little or no clear link to this specific experiment. — **1-2**

(e) **L0** No creditable content. — **0**

(e) Indicative content:

- There is a systematic error (end correction): the antinode at the open end of the tube actually occurs slightly beyond the tube opening, so the measured length L underestimates the true resonating length, giving a systematic underestimate of the wavelength and speed.
- This end correction can be reduced/eliminated by finding a second (or higher) resonance and using the difference between resonant lengths (which is always half a wavelength) rather than a single length measurement.
- Judging the exact position of resonance (loudest sound) by ear is imprecise and introduces random error; a microphone and oscilloscope, or a data logger with a sound sensor, could be used to detect the maximum amplitude more objectively and precisely.
- The speed of sound depends on air temperature; if room temperature was not measured or was different from the assumed value, this would cause a systematic difference from the accepted value of 343 m/s.
- Repeating the length measurement several times at each resonance and averaging reduces the effect of random error in judging the resonance position.
- Using a signal generator and loudspeaker instead of a tuning fork would allow a wider range of precise, known frequencies to be tested, improving the reliability of the method.

(e) Answer: Credit awarded via levels of response using the indicative content (end correction, resonance judgement, temperature effects, repeats/averaging, use of sensors/data logger).

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Question 3

(a) d = 1/300 mm = 3.33 x 10^{-3} mm **M1**

(a) 3.33 x 10^{-6} m (awrt, cao) **A1**

(a) Answer: 3.33 x 10^{-6} m

(b) tan(θ) = x/L = 0.240/1.20 **M1**

(b) = 0.200, and takes inverse tan **M1**

(b) 11.3 degrees (awrt 11.2-11.3 degrees) **A1**

(b) Answer: 11.3 degrees

(c) sin(11.3 degrees) = 0.196 (awrt) **M1**

(c) correct rearrangement and substitution: λ = (3.33 x 10^{-6} x 0.196)/1 **M1**

(c) 6.5 x 10^{-7} m (awrt 650-655 nm, ft from (a) and (b)) **A1**

(c) Answer: 6.5 x 10^{-7} m (about 654 nm)

(d) the grating produces sharper/narrower and brighter maxima than a double slit, allowing the angle (and hence wavelength) to be measured more precisely oe **B1**

(d) Answer: A diffraction grating produces sharper, brighter maxima, allowing a more precise measurement of the angle and hence the wavelength.

(e) the grating spacing d halves (there are twice as many lines per mm) **B1**

(e) since sin(θ) = (n x λ)/d, a smaller d gives a larger sin(θ) and hence a larger angle, so the first-order maximum moves further from the centre oe **B1**

(e) Answer: The first-order maximum moves further from the centre, because halving d roughly doubles sin(θ), increasing the diffraction angle.

Question 4

(a) quote v = $\sqrt{T / \μ}$ **M1**

(a) substitute v = $\sqrt{145 / 1.2 \times 10^{-3}}$ **M1**

(a) v = 348 m/s (accept 347-348) cao **A1**

(a) Answer: 348 m/s

(b) use f = v / 2L with L = 0.65 m and v from (a) **M1**

(b) f = 267 Hz (accept 266-268) cao **A1**

(b) Answer: 267 Hz

(c) f3 = 3 x f1 = 802 Hz (accept 799-804 following through from (b)) **A1**

(c) 3 antinodes (and 4 nodes) oe **B1**

(c) Answer: f3 = 802 Hz; 3 antinodes.

Question 5

(a) d = 1 / (600 x 10^{3}) = 1.67 x 10^{-6} m cao **B1**

(a) Answer: 1.67 x 10^{-6} m

(b) quote d sin(θ) = n λ with n = 1 **M1**

(b) substitute sin(θ) = 632.8 x 10^{-9} / 1.67 x 10^{-6} **M1**

(b) θ = 22.3 degrees cao **A1**

(b) Answer: 22.3 degrees

(c) recognise the maximum order occurs when sin(θ) = 1, so n(max) = d / λ **M1**

(c) calculate d / λ = 1.67 x 10^{-6} / 632.8 x 10^{-9} = 2.63 **M1**

(c) n = 2 is the highest order observed, since n = 3 would require sin(θ) = 1.14 which is impossible cao **A1**

(c) Answer: n = 2

Question 6

(a) intensity is inversely proportional to the square of the distance from the source (inverse square law) oe **B1**

(a) Answer: Intensity is inversely proportional to the square of the distance from the source.

(b) use I2 = I1 x (r1/r2)^2 **M1**

(b) substitute I2 = 4.5 x 10^{-3} x (2.0/6.0)^2 **M1**

(b) I2 = 5.0 x 10^{-4} W/m^2 cao **A1**

(b) Answer: 5.0 x 10^{-4} W/m^2

(c) quote I proportional to A^2, so A2/A1 = $\sqrt{I2/I1}$ **M1**

(c) substitute A2/A1 = $\sqrt{5.0 \times 10^{-4} / 4.5 \times 10^{-3}}$ **M1**

(c) A2 : A1 = 1 : 3 (ratio = 0.333) cao **A1**

(c) Answer: A2 : A1 = 1 : 3

Question 7

(a) correct substitution: λ = (w x s)/D = (7.60 x 10^{-3} x 2.5 x 10^{-4})/3.00 **M1**

(a) 6.33 x 10^{-7} m (awrt 633 nm, cao) **A1**

(a) Answer: 6.33 x 10^{-7} m (633 nm)

(b) recognises that since λ = w x s/D and the uncertainties in s and D are negligible, the percentage uncertainty in λ equals the percentage uncertainty in w (3.0%) **M1**

(b) calculates 3.0% of the wavelength found in (a): 0.030 x 6.33 x 10^{-7} **M1**

(b) ± 1.9 x 10^{-8} m (awrt, ft from (a)) **A1**

(b) Answer: ± 1.9 x 10^{-8} m (about ± 19 nm)

(c) d = 1/600 mm = 1.67 x 10^{-6} m **M1**

(c) correct substitution: sin(θ) = (2 x 6.33 x 10^{-7})/(1.67 x 10^{-6}) **M1**

(c) 49.5 degrees (awrt 49.4-49.6 degrees, ft from (a)) **A1**

(c) Answer: 49.5 degrees

(d) it reduces the percentage (random) uncertainty in w, since any fixed error in locating the fringe edges is divided by the number of fringe widths spanned oe **B1**

(d) Answer: It reduces the percentage uncertainty in the fringe spacing, since a fixed measurement error is spread over many fringe widths.

(e) the diffraction grating is likely to give the more precise value, because it produces sharper and brighter maxima than a double slit oe **B1**

(e) double-slit fringes are dimmer and wider, making it harder to judge the exact centre of each fringe precisely, increasing the random uncertainty in w oe **B1**

(e) valid overall conclusion linking this to a smaller percentage uncertainty in the wavelength obtained from the grating method oe **B1**

(e) Answer: The diffraction grating method is likely to be more precise, since its sharp, bright maxima allow the angle to be measured more precisely than the wider, dimmer double-slit fringes.

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Question 8

(a) quote fringe spacing $w = \lambda D / a$ **M1**

(a) rearrange to $\lambda = w a / D$ **M1**

(a) substitute $\lambda = (2.28 \times 10^{-3} \times 4.5 \times 10^{-4}) / 1.85$ **M1**

(a) $\lambda = 555$ nm cao **A1**

(a) Answer: 555 nm

(b) calculate each percentage uncertainty: $w = 0.05/2.28 \times 100 = 2.19\%$, $a = 0.01/0.45 \times 100 = 2.22\%$, $D = 0.02/1.85 \times 100 = 1.08\%$ **M1**

(b) recognise that for a product/quotient the percentage uncertainties are added **M1**

(b) total percentage uncertainty = 5.5% cao **A1**

(b) Answer: 5.5%

(c) absolute uncertainty = 5.5% of 555 nm = 30 nm (accept 30-31) **M1**

(c) $\lambda = (555 \pm 30)$ nm cao, uncertainty to 1-2 sig figs **A1**

(c) Answer: (555 ± 30) nm

Question 9

(a) recognise the first filter transmits half the unpolarised intensity: $I1 = 840/2 = 420$ W/m^2 **M1**

(a) quote Malus's law $I = I1 \cos^2(\theta)$ **M1**

(a) substitute $I = 420 \times \cos^2(35 \text{ degrees})$ **M1**

(a) $I = 282$ W/m^2 (accept 280-283) cao **A1**

(a) Answer: 282 W/m^2

(b) set $\cos^2(\theta) = 0.10$ **M1**

(b) $\theta = \arccos(\sqrt{0.10})$ **M1**

(b) $\theta = 71.6$ degrees cao **A1**

(b) Answer: 71.6 degrees

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