3.1 Measurements and their Errors: Test Pack

AQA 7408 · Calculator allowed · about 70 minutes

Total Marks

Name: _____ Date: ____ / ____ / _____

Answer ALL questions. Show all your working.

1 SI units, prefixes and estimation are the basis of every physical quantity used in this course.

(a) State the SI base unit of: (i) thermodynamic temperature, (ii) amount of substance, (iii) luminous intensity. **(3)**

(b) A telecommunications signal has a frequency of 2.4 GHz. Write this frequency in hertz, using standard form. **(1)**

(c) Estimate, to one significant figure, the mass of a single mosquito in kilograms. State the order of magnitude of your estimate. **(2)**

(Total for Question 1 is 6 marks)

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2 A rectangular metal plate has a measured length $L = 12.0 \pm 0.1$ cm and width $W = 8.0 \pm 0.1$ cm.

(a) Calculate the percentage uncertainty in L and the percentage uncertainty in W. **(2)**

(b) Calculate the area of the plate and express it with its absolute uncertainty. **(4)**

(c) The perimeter of the plate is found using $P = 2(L + W)$. Calculate the absolute uncertainty in the perimeter. **(2)**

(Total for Question 2 is 8 marks)

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3 Required practical: A student determines the resistivity of a metal wire. The wire's diameter is measured at several points along its length using a micrometer of resolution 0.01 mm, giving a mean diameter d = 0.32 mm. The wire's length is l = 0.800 ± 0.001 m. A graph of potential difference V against current I for the wire gives a straight line through the origin of gradient R = 2.40 ± 0.05 ohm, where R is the resistance of the wire. Resistivity is given by $\rho = R \times A / l$, where A is the cross-sectional area of the wire.

(a) Explain why the student measures the wire's diameter at several points along its length and uses the mean value in the calculation. **(2)**

(b) Calculate the cross-sectional area, A, of the wire, using $A = \pi \times d^2 / 4$ and d = 0.32 mm. Give your answer in m^2. **(3)**

(c) The micrometer used has a resolution of 0.01 mm. Calculate the percentage uncertainty in the cross-sectional area, A. **(3)**

(d) Given R = 2.40 ± 0.05 ohm and l = 0.800 ± 0.001 m, calculate the percentage uncertainty in the resistivity, $\rho = R \times A / l$. **(3)**

(e) Calculate the resistivity of the wire and express your answer with its absolute uncertainty, to an appropriate number of significant figures. **(4)**

(f) Evaluate how the student could improve the experimental procedure to reduce the overall percentage uncertainty in the calculated resistivity, referring to the measurements taken in this experiment. **(6)**

(Total for Question 3 is 21 marks)

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4 Required practical: A student investigates how the pressure, P, of a fixed mass of gas at constant volume varies with temperature. The gas is held in a sealed rigid flask connected to a pressure sensor, and is heated in a water bath. The student records the following pressure at five temperatures: $\theta = 20.0°C$, $P = 107$ kPa; $\theta = 40.0°C$, $P = 114$ kPa; $\theta = 60.0°C$, $P = 121$ kPa; $\theta = 80.0°C$, $P = 128$ kPa; $\theta = 100.0°C$, $P = 135$ kPa. A best-fit straight line through these points has a gradient of 0.350 kPa per °C and a pressure-axis intercept of 100 kPa. The steepest and shallowest straight lines that can still be drawn through all the error bars on the data points have gradients of 0.380 kPa per °C and 0.320 kPa per °C, and pressure-axis intercepts of 92 kPa and 108 kPa, respectively.

(a) Calculate the percentage uncertainty in the gradient of the best-fit line. **(3)**

(b) Using the same method, calculate the percentage uncertainty in the pressure-axis intercept of the best-fit line. **(3)**

(c) Using the gradient and intercept of the best-fit line, calculate the temperature, in °C, at which the extrapolated line predicts the pressure would fall to zero. This value is an experimental estimate of absolute zero. **(3)**

(d) The extrapolated temperature in part (c) is found from a quotient of the intercept and the gradient. Using your percentage uncertainties from parts (a) and (b), calculate the absolute uncertainty in this extrapolated temperature, and comment on whether the accepted value of absolute zero (-273°C) is consistent with the student's result. **(3)**

(Total for Question 4 is 12 marks)

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Mark scheme · 3.1 Measurements and their Errors: Test Pack

Question 1

(a) kelvin, K **B1**

(a) mole, mol **B1**

(a) candela, cd **B1**

(a) Answer: (i) kelvin (K); (ii) mole (mol); (iii) candela (cd).

(b) 2.4 x 10^{9} Hz (cao) **B1**

(b) Answer: 2.4 x 10^{9} Hz

(c) any sensible estimate in the range 1 x 10^{-6} kg to 5 x 10^{-6} kg **B1**

(c) correctly states the order of magnitude of their estimate (e.g. 10^{-6} kg) oe **B1**

(c) Answer: Approximately 2 x 10^{-6} kg; order of magnitude 10^{-6} kg (any value from 1 x 10^{-6} kg to 5 x 10^{-6} kg with a correctly stated matching order of magnitude is acceptable).

Question 2

(a) percentage uncertainty in L = (0.1/12.0) x 100 = 0.83% **B1**

(a) percentage uncertainty in W = (0.1/8.0) x 100 = 1.25% (accept 1.3%) **B1**

(a) Answer: L: 0.83%; W: 1.25%

(b) Area = 12.0 x 8.0 = 96.0 cm^2 **M1**

(b) for multiplication, percentage uncertainties are added: %unc(Area) = 0.83% + 1.25% = 2.08% (ft from a) **M1**

(b) absolute uncertainty = 96.0 x 0.0208 = 2.0 cm^2 **M1**

(b) Area = 96 ± 2 cm^2 (cao) **A1**

(b) Answer: Area = (96 ± 2) cm^2

(c) for a sum, absolute uncertainties are added: uncertainty in (L+W) = 0.1 + 0.1 = 0.2 cm **M1**

(c) multiplying by the constant 2 also multiplies the absolute uncertainty by 2: uncertainty in P = 0.4 cm (cao) **A1**

(c) Answer: ± 0.4 cm (P = 40.0 ± 0.4 cm)

Question 3

(a) the wire's diameter is not perfectly uniform along its length, so a single reading is subject to random variation **B1**

(a) taking a mean of several readings reduces the effect of this random variation, giving a more precise/representative value of the diameter **B1**

(a) Answer: A wire is not perfectly uniform in thickness, so measuring at several points and averaging reduces the effect of random variation and gives a more precise mean diameter.

(b) converts diameter to metres: d = 3.2 x 10^{-4} m **M1**

(b) correct substitution and evaluation: A = π x (3.2 x 10^{-4})^2 / 4 = 8.04 x 10^{-8} m^2 **M1**

(b) 8.0 x 10^{-8} m^2 (awrt, to 2 s.f., matching the precision of d) **A1**

(b) Answer: A = 8.0 x 10^{-8} m^2

(c) absolute uncertainty in d = half the resolution = ± 0.005 mm **M1**

(c) percentage uncertainty in d = (0.005/0.32) x 100 = 1.6% **M1**

(c) since A depends on d^2, percentage uncertainty in A = 2 x 1.6% = 3.1% (ft) **A1**

(c) Answer: 3.1%

(d) percentage uncertainty in R = (0.05/2.40) x 100 = 2.1% **M1**

(d) percentage uncertainty in l = (0.001/0.800) x 100 = 0.13% **M1**

(d) for a product/quotient, percentage uncertainties add: %unc(ρ) = 2.1% + 3.1% + 0.13% = 5.3% (ft from c) **A1**

(d) Answer: 5.3%

(e) correct substitution: ρ = (2.40 x 8.04 x 10^{-8}) / 0.800 **M1**

(e) ρ = 2.41 x 10^{-7} ohm m (or awrt, ft from b) **M1**

(e) absolute uncertainty = 2.41 x 10^{-7} x 0.053 = 1.3 x 10^{-8} ohm m (ft from d) **M1**

(e) ρ = (2.4 ± 0.1) x 10^{-7} ohm m (awrt, appropriate s.f.) **A1**

(e) Answer: ρ = (2.4 ± 0.1) x 10^{-7} ohm m

(f) **L3** A full, coherent evaluation that correctly identifies the diameter measurement as the dominant source of uncertainty (because it is doubled when calculating the area), proposes at least two valid, correctly justified improvements linked to specific measurements in the experiment, and reaches a clear, justified conclusion about which change would have the greatest effect. **5-6**

(f) **L2** The answer identifies at least one valid improvement and links it correctly to a reduction in percentage uncertainty, but the evaluation is incomplete, lacks full justification, or does not identify the dominant source of uncertainty. **3-4**

(f) **L1** A basic suggestion for improving the experiment (e.g. use better equipment) with little or no justification linking it to percentage uncertainty. **1-2**

(f) **L0** No relevant content, or the answer does not relate to the question. **0**

(f) Indicative content:

- The diameter measurement contributes the largest percentage uncertainty to the resistivity because it is squared in the area calculation (its percentage uncertainty is doubled), so it is the dominant source of overall uncertainty.
- Using a micrometer/digital micrometer with a smaller resolution (e.g. 0.001 mm) would reduce the absolute and hence percentage uncertainty in the diameter.
- Measuring the diameter at several points and in perpendicular directions at each point (to check for a non-circular cross-section) and averaging reduces random error further.
- Using a longer length of wire (while keeping the same absolute uncertainty in the length measurement) reduces the percentage uncertainty in l, since percentage uncertainty falls as the measured value increases for a fixed absolute uncertainty.
- Reading the length with a set square against the metre rule (avoiding parallax error) reduces the absolute uncertainty in l.
- Taking several sets of V and I readings and using the gradient of the V-I graph (rather than a single pair of readings) reduces the effect of random error in R.
- Conclusion: reducing the uncertainty in the diameter measurement gives the greatest improvement in the overall percentage uncertainty in resistivity, since it is the largest single contributor and is doubled in the calculation.

(f) Answer: Improving the diameter measurement (e.g. finer-resolution micrometer, more readings at different points/orientations, averaging) gives the greatest reduction in overall percentage uncertainty, since the diameter's percentage uncertainty is doubled in the area calculation and is the dominant contributor (3.1% of the total 5.3%).

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Question 4

(a) uncertainty in gradient = half the difference between the steepest and shallowest gradients = (0.380 - 0.320)/2 = 0.030 kPa per °C **M1**

(a) percentage uncertainty = (0.030/0.350) x 100 **M1**

(a) 8.6% (awrt) **A1**

(a) Answer: 8.6%

(b) uncertainty in intercept = half the difference between the two extreme intercepts = (108 - 92)/2 = 8 kPa **M1**

(b) percentage uncertainty = (8/100) x 100 **M1**

(b) 8.0% (cao) **A1**

(b) Answer: 8.0%

(c) rearranges P = intercept + gradient x θ with P = 0 to give θ = -intercept/gradient **M1**

(c) substitutes θ = -100/0.350 **M1**

(c) -286°C (awrt, accept -285 to -286) **A1**

(c) Answer: -286°C

(d) for a quotient, percentage uncertainties add: %unc(θ) = %unc(intercept) + %unc(gradient) = 8.0 + 8.6 = 16.6% (ft) **M1**

(d) absolute uncertainty = 286 x (16.6/100) = 47°C (ft), giving a range of roughly -333°C to -239°C **M1**

(d) the accepted value of -273°C lies within this range, so the result is consistent with the accepted value, although the large uncertainty reflects how imprecise it is to extrapolate a short section of line so far beyond the measured data oe **A1**

(d) Answer: Uncertainty is approximately ± 47°C, giving a range of about -333°C to -239°C; since -273°C lies within this range, the result is consistent with the accepted value.

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