3.9 A-Level Physics: Required Practicals and Uncertainties

Total Marks

AQA 7408 · Calculator allowed · about 125 minutes · Write-in edition

Name: _____ Date: ____ / ____ / _____

Answer ALL questions. Show all your working.

1 A student is preparing to determine the resistivity of a length of constantan wire. Before assembling the circuit, they use a digital micrometer screw gauge to measure the diameter of the wire at several points along its length.

(a) With the micrometer's jaws fully closed, it reads +0.02 mm instead of zero. State the type of error this represents, and state how the student should use this reading to correct each subsequent measurement of the wire's diameter. **(2)**

(b) After correcting for the zero error, the student measures the diameter at five points along the wire and obtains: 0.54 mm, 0.56 mm, 0.55 mm, 0.53 mm, 0.57 mm. Calculate the mean diameter. **(1)**

(c) Calculate the absolute uncertainty in the mean diameter, taking it as half the range of the five readings. **(2)**

(d) Calculate the percentage uncertainty in the mean diameter, and explain why the percentage uncertainty in the cross-sectional area $A = \pi \times d^2 / 4$ is twice this value. **(3)**

(Total for Question 1 is 8 marks)

2 A student investigates how the period T of a simple pendulum depends on its length L, to test the relationship $T = k L^n$ and, from it, to find a value for g.

L (m): 0.20, 0.40, 0.60, 0.80, 1.00

T (s): 0.897, 1.269, 1.554, 1.794, 2.006

log10(L): -0.699, -0.398, -0.222, -0.097, 0

log10(T): -0.047, 0.103, 0.191, 0.254, 0.302

(a) Show that taking logarithms of both sides of $T = k L^n$ gives a straight-line relationship between log10(T) and log10(L), and state what the gradient and the y-intercept of this line represent. **(3)**

(b) Show that, taking $g = 9.81 \text{ m s}^{-2}$ and using the Physics Equations Sheet equation for the period of a simple pendulum, T = 1.55 s (3 significant figures) when L = 0.600 m. **(2)**

(c) The line of best fit through the log10(T) against log10(L) data has gradient 0.500 and y-intercept 0.302. Determine the value of n, and hence use the y-intercept to find k and a value for g. (Hint: since $T = k L^n$ with $n = 0.5$, $k = 2\pi / \sqrt{g}$.) **(5)**

(d) Explain why the period is timed over many oscillations (e.g. 20) rather than a single swing, and suggest, without changing the apparatus, one way the percentage uncertainty in the final value of g could be further reduced. **(3)**

(Total for Question 2 is 13 marks)

3 In question 6, a student calculated a percentage uncertainty of 4.8% in the Young modulus of copper, based only on the uncertainty in the gradient of their stress-strain graph. Evaluate whether the overall percentage uncertainty in the final value of the Young modulus is likely to be greater than or smaller than this 4.8%, and suggest specific improvements to the method that would most effectively reduce the overall uncertainty in the result.

(Total for Question 3 is 6 marks)

4 The wire from question 1 (mean diameter 0.550 mm, length L = 0.800 m, measured with a metre ruler to ± 0.001 m) is now connected into a circuit. The student measures its resistance as R = 3.42 ohm ± 0.05 ohm.

(a) Calculate the cross-sectional area A of the wire, in m^2, using the mean diameter found in question 1. **(2)**

(b) Use resistivity = R x A / L to calculate the resistivity of the wire. **(2)**

(c) The percentage uncertainty in R is 1.5%, in L is 0.13%, and in d is 3.6% (from Q1(d)). Calculate the percentage uncertainty in the resistivity, given that resistivity depends on d^2. **(3)**

(d) Calculate the absolute uncertainty in the resistivity, and state the resistivity with its uncertainty to an appropriate number of significant figures. **(2)**

(Total for Question 4 is 9 marks)

5 A student determines g by a free-fall method. A steel ball bearing is held by an electromagnet a measured distance s above a trapdoor switch. Releasing the electromagnet starts an electronic timer, which stops when the ball strikes the trapdoor, giving the fall time t. The results are:
s (m): 0.200, 0.400, 0.600, 0.800, 1.000
t (s): 0.202, 0.286, 0.350, 0.404, 0.451
t^2 (s^2): 0.0408, 0.0818, ?, 0.163, 0.203

s (m)	t (s)	t^2 (s^2)
0.200	0.202	0.0408
0.400	0.286	0.0818
0.600	0.350	?
0.800	0.404	0.163
1.000	0.451	0.203

(a) Using $s = (1/2)\, g\, t^2$ (from the Physics Equations Sheet), explain why plotting a graph of s against t^2 gives a more reliable value of g than calculating g from a single pair of s and t values. **(2)**

(b) Show that $t^2 = 0.123\ s^2$ (3 significant figures) for s = 0.600 m, using the tabulated value of t. **(2)**

(c) The gradient of the line of best fit through the s against t^2 data is 4.93 m s^{-2}. Calculate g. **(2)**

(d) The uncertainty in the gradient, found from the steepest and shallowest lines that fit within the error bars, is ± 0.15 m s^{-2}. Calculate the percentage uncertainty and the absolute uncertainty in g, and state g with its uncertainty to an appropriate number of significant figures. **(3)**

(e) The accepted value of g is 9.81 m s^{-2}. State, with a reason, whether the student's result is consistent with this value, and suggest one systematic error that could affect the free-fall method, stating its likely effect on the calculated value of g. **(3)**

(Total for Question 5 is 12 marks)

6 A student determines the Young modulus of a copper wire using a simple technique: a long test wire (original length L0 = 2.500 m, mean diameter 0.28 mm, percentage uncertainty in diameter 7.1%) is clamped at one end, passed over a pulley, and loaded with slotted masses at the other end, with extension measured against a fixed reference marker.

(a) Calculate the cross-sectional area of the wire, and state the percentage uncertainty in this area. **(3)**

(b) The gradient of the student's stress-strain graph (the Young modulus) is 1.25 x 10^{11} Pa, with an uncertainty (from the steepest and shallowest lines of best fit) of ± 0.06 x 10^{11} Pa. Calculate the percentage uncertainty in the Young modulus. **(2)**

(c) State three precautions used in this experiment to improve the reliability or precision of the result, other than repeating readings. **(3)**

(d) A second, thicker wire made from the same copper is tested using the same method. Predict, with a reason, whether the gradient of its stress-strain graph would differ from that of the first wire. **(2)**

(Total for Question 6 is 10 marks)

7 A student investigates stationary waves on a stretched string. A vibration generator at one end and a fixed pulley at the other keep a constant tension in the string; for each length L between the generator and the pulley, the student adjusts the frequency until a clear standing-wave pattern (one loop) is seen, and records the resonant frequency f.

L (m): 0.20, 0.30, 0.40, 0.50, 0.60

f (Hz): 150, 100, 75, 60, 50

(a) Explain, in terms of superposition of waves, how a stationary wave pattern is produced on the string. **(2)**

(b) Using f = v / (2L) (from the Physics Equations Sheet, for the fundamental mode), calculate f x L for each pair of values in the table, and comment on what this shows about the relationship between f and L. **(3)**

(c) The student plots f (y-axis) against 1/L (x-axis). State the shape of this graph and what physical quantity is given by its gradient. **(2)**

(d) The wave speed on a stretched string is given by $v = \sqrt{T/\μ}$ (Physics Equations Sheet), where T is the tension and μ is the mass per unit length. Using $v = 60\ m\ s^{-1}$ found in part (b) and a tension of T = 4.5 N, calculate μ. **(3)**

(e) State and explain the effect on the resonant frequency, for a fixed length L, of increasing the tension in the string. **(2)**

(Total for Question 7 is 12 marks)

8 A student investigates the I-V characteristic of a 6 V filament lamp, using a variable power supply with an ammeter in series and a voltmeter across the lamp.
V (V): 0.50, 1.00, 1.50, 2.00, 2.50
I (A): 0.20, 0.32, 0.39, 0.44, 0.48

(a) Describe the shape of the I-V graph for the filament lamp, and explain this shape in terms of the resistance of the filament. **(3)**

(b) Calculate the resistance of the lamp when V = 2.00 V. **(2)**

(c) The voltmeter has a percentage uncertainty of 1.0% and the ammeter a percentage uncertainty of 2.5% at this reading. Calculate the percentage and absolute uncertainty in the resistance found in part (b), and state the result to an appropriate number of significant figures. **(3)**

(d) Both the ammeter and voltmeter have a small but non-zero resistance. Explain why, for a low-resistance component such as this lamp, connecting the voltmeter directly across the lamp only (so the ammeter also carries the voltmeter's own small current) introduces a smaller systematic error than the alternative arrangement. **(3)**

(Total for Question 8 is 11 marks)

9 A second student determines g using a simple pendulum, timing 20 oscillations for a single length of L = 1.000 m, obtaining g = 9.75 m s^{-2} with a percentage uncertainty of 1.8%. Compare this with the free-fall method of question 5, which gave g = (9.9 ± 0.3) m s^{-2}, a percentage uncertainty of about 3.0%.

(a) Compare the precision of the two methods, referring to their percentage uncertainties. **(2)**

(b) Given that the accepted value is g = 9.81 m s^{-2}, state which method's result is closer to the accepted value, then explain, using these two results, why a method can be precise but not accurate (or vice versa). **(3)**

(c) Suggest one modification to the pendulum method that would reduce a systematic error in its value of g. **(1)**

(Total for Question 9 is 6 marks)

Mark scheme · 3.9 A-Level Physics: Required Practicals and Uncertainties

Question 1

(a) this is a systematic (zero) error **B1**

(a) subtract 0.02 mm from every raw diameter reading taken with this micrometer oe **B1**

(a) Answer: Systematic (zero) error; subtract 0.02 mm from every raw reading.

(b) 0.550 mm cao **B1**

(b) Answer: 0.550 mm

(c) range = 0.57 - 0.53 = 0.04 mm, so half range = 0.02 mm (correct method) **M1**

(c) ± 0.02 mm cao **A1**

(c) Answer: ± 0.02 mm

(d) (0.02/0.550) x 100 (correct substitution) **M1**

(d) 3.6% (awrt 3.6) cao **A1**

(d) A depends on d^2 (d multiplied by itself), so when two quantities are multiplied their percentage uncertainties add, giving 2 x the percentage uncertainty in d oe **B1**

(d) Answer: 3.6%; percentage uncertainty in A = 2 x 3.6% = 7.3%, since A depends on d^2.

Question 2

(a) log10(T) = log10(k) + n log10(L) (correct application of log rules to $T = k L^n$) **M1**

(a) gradient of the log10(T) against log10(L) graph = n **A1**

(a) y-intercept (value of log10(T) at log10(L) = 0) = log10(k) **A1**

(a) Answer: log10(T) = log10(k) + n log10(L); gradient = n, y-intercept = log10(k).

(b) $T = 2\pi\sqrt{0.600/9.81}$ (correct substitution) **M1**

(b) 1.55 s cso (answer given) **A1**

(b) Answer: 1.55 s

(c) n = 0.500 (the gradient), confirming T is proportional to the square root of L **B1**

(c) $k = 10^{\text{y-intercept}}$ (correct rearrangement of log10(k) = y-intercept) **M1**

(c) k = 2.00 s $m^{-0.5}$ (awrt 2.00) cao **A1**

(c) rearranges $k = 2\pi / \sqrt{g}$ to give $g = (2\pi / k)^2$, and substitutes their k **M1**

(c) g = 9.9 m s^{-2} (accept any value in the range 9.7 to 10.0 m s^{-2}, due to rounding in k) **A1**

(c) Answer: n = 0.500; k = 2.00 s $m^{-0.5}$; g is approximately 9.9 m s^{-2} (accept 9.7 to 10.0 m s^{-2}).

(d) the fixed absolute uncertainty from human reaction time is divided by the number of oscillations timed, greatly reducing the percentage uncertainty in the period T oe **B1**

(d) use the largest practical range of pendulum lengths L (including the longest achievable length) when taking readings for the graph oe **B1**

(d) a longer L gives a longer T for the same fixed reaction-time uncertainty, reducing its percentage uncertainty, and a wider range of L values on the log-log graph reduces the effect of any single anomalous point on the gradient (and hence on g) oe **B1**

(d) Answer: Timing many oscillations divides the fixed reaction-time uncertainty across all of them, reducing its percentage effect; using the widest practical range of L (including longer lengths) further reduces the percentage uncertainty in g.

Question 3

Level 3 A coherent, logically structured evaluation that correctly identifies that the overall uncertainty should combine the uncertainties in the gradient, the cross-sectional area and the original length (not the gradient alone), explains why the diameter's uncertainty dominates (because it is doubled when squared to find area), links this clearly to specific, justified improvements to the method, and reaches a supported final judgement on how the overall uncertainty compares with 4.8%. Terminology is used accurately throughout. **5-6**

Level 2 Some correct reasoning that other sources of uncertainty (such as area or length) should be combined with the gradient uncertainty, and at least one relevant improvement is suggested and linked to a source of uncertainty, but the argument may be incomplete, one-sided, or not fully linked throughout. **3-4**

Level 1 Basic or isolated statements are made about sources of uncertainty and/or possible improvements, with little reasoning and little or no linkage between them. **1-2**

Level 0 No relevant content. **0**

Indicative content:

- The 4.8% figure only accounts for the uncertainty in the gradient of the stress-strain graph; the overall uncertainty in the Young modulus should also combine the percentage uncertainty in the cross-sectional area (14%, from question 6(a)) and in the original length L0, so the true overall uncertainty is considerably larger than 4.8% alone.
- The diameter measurement (via the micrometer) is likely the single largest contributor, because its percentage uncertainty is doubled when the diameter is squared to calculate the cross-sectional area.
- Improvement: measure the diameter at several points along the wire's length and at different orientations (rotating the wire) at each point, then average the readings and use half the range as the uncertainty, to reduce the uncertainty in the mean diameter used for the area calculation.
- Improvement: use a travelling microscope, or a vernier scale mounted between the test wire and a reference wire, rather than a simple marker and ruler, to measure the extension more precisely, since this reduces the absolute uncertainty in each individual extension reading.
- Improvement: take readings over a wider range of loads (a greater range of stress and strain values) so that the gradient of the line of best fit can be determined more precisely, reducing the percentage uncertainty contributed by the gradient itself.
- A systematic error such as initial slack in the wire before it becomes taut would reduce the measured extension at each load; this should be corrected for by applying a small initial tensioning load and treating the marker reading at that point as the new zero extension.
- An overall judgement should state that, since area and length uncertainties add to the gradient uncertainty (and the area uncertainty of 14% alone already exceeds 4.8%), the true combined percentage uncertainty in the Young modulus is very likely to be substantially greater than 4.8%.

Question 4

(a) $A = \pi \times (0.550 \times 10^{-3})^2 / 4$ (correct substitution, ft from Q1(b)) **M1**

(a) 2.38×10^{-7} m^2 (awrt 2.38) cao **A1**

(a) Answer: 2.38×10^{-7} m^2

(b) $\rho = 3.42 \times 2.38 \times 10^{-7} / 0.800$ (correct substitution, ft their A) **M1**

(b) 1.02×10^{-6} ohm m (awrt 1.02) cao **A1**

(b) Answer: 1.02×10^{-6} ohm m

(c) identifies that percentage uncertainties combine by addition for a product/quotient, with the d term doubled: %R + %L + 2 x %d **M1**

(c) 1.5 + 0.13 + 2(3.6) (correct substitution) **M1**

(c) 8.8% (awrt 8.8) cao **A1**

(c) Answer: 8.8%

(d) $0.088 \times 1.02 \times 10^{-6}$ (correct method, ft their percentage uncertainty and ρ) **M1**

(d) $\rho = (1.02 \pm 0.09) \times 10^{-6}$ ohm m oe **A1**

(d) Answer: $\rho = (1.02 \pm 0.09) \times 10^{-6}$ ohm m

Question 5

(a) using several data points and a line of best fit averages out random error/timing variation across all the readings, rather than relying on one possibly anomalous pair oe **B1**

(a) the gradient method also allows any anomalous points to be identified and excluded, and does not require the line to pass exactly through the origin, so it is not affected by a fixed (systematic) timing offset in the same way a single calculation would be oe **B1**

(a) Answer: Using the gradient of a graph of many points averages out random timing errors and allows anomalies to be spotted, unlike a single calculation.

(b) 0.350^2 (correct substitution of the tabulated t) **M1**

(b) 0.1225, which rounds to 0.123 s^2 cso (answer given; accept 0.122 if the more precise unrounded t is used) **A1**

(b) Answer: 0.123 s^2

(c) g = 2 x gradient (correct rearrangement of $s = (1/2)\, g\, t^2$) **M1**

(c) 9.86 m s^{-2} (awrt 9.86) cao **A1**

(c) Answer: 9.86 m s^{-2}

(d) percentage uncertainty in gradient = (0.15/4.93) x 100 = 3.0%; this is unchanged by doubling to find g, since multiplying by a constant does not change a percentage uncertainty **M1**

(d) absolute uncertainty = 0.030 x 9.86 = 0.3 m s^{-2} (awrt 0.3) **A1**

(d) g = (9.9 ± 0.3) m s^{-2} oe **B1**

(d) Answer: g = (9.9 ± 0.3) m s^{-2}

(e) the range (9.6 to 10.2) m s^{-2} includes 9.81 m s^{-2} oe **B1**

(e) so the result is consistent with the accepted value **B1**

(e) a valid systematic error with correct direction, e.g. air resistance on the ball reduces its true acceleration below g, making the measured/calculated g too low; or a delay between the electromagnet switching off and the ball actually starting to fall means the recorded t is too long, making the calculated g too low (any one, oe) **B1**

(e) Answer: Consistent, since 9.81 lies within (9.9 ± 0.3) m s^{-2}; e.g. air resistance would make the measured g too low.

Question 6

(a) $A = \pi \times (0.28 \times 10^{-3})^2 / 4$ (correct substitution) **M1**

(a) 6.16×10^{-8} m^2 (awrt 6.16) cao **A1**

(a) 14% (= 2 x 7.1%, since A depends on d^2) cao **B1**

(a) Answer: A = 6.16×10^{-8} m^2; percentage uncertainty = 14%

(b) (0.06/1.25) x 100 (correct substitution) **M1**

(b) 4.8% (awrt 4.8) cao **A1**

(b) Answer: 4.8%

(c) the wire is loaded and unloaded to check it returns to its original length (no permanent extension), confirming the elastic limit has not been exceeded oe **B1**

(c) a long, thin wire is used, which gives a larger, more easily measured extension for a given load, reducing the percentage uncertainty in the extension oe **B1**

(c) a second, unloaded reference wire of the same material is mounted alongside the test wire, so any sagging of the support or change in length due to a temperature change affects both wires equally and can be compensated for oe **B1**

(c) Answer: Check for elastic behaviour by unloading; use a long thin wire for a larger extension; use a reference wire to compensate for sagging/temperature effects.

(d) the gradient (Young modulus) would be the same/unchanged **B1**

(d) because dividing by cross-sectional area and original length in stress and strain already accounts for the wire's dimensions, so the Young modulus is a property of the material only, not of the sample's size oe **B1**

(d) Answer: The gradient (Young modulus) would be unchanged, since it is a property of the material, independent of the wire's dimensions.

Question 7

(a) a progressive wave travels along the string and is reflected at the fixed end (pulley), so two waves of the same frequency and amplitude travel in opposite directions along the string oe **B1**

(a) these waves superpose; at the resonant frequency this produces a stable pattern of fixed nodes (no displacement) and antinodes (maximum displacement) oe **B1**

(a) Answer: Waves travelling in opposite directions (incident and reflected) superpose to form a fixed pattern of nodes and antinodes.

(b) calculates f x L for at least three pairs: 0.20x150=30, 0.30x100=30, 0.40x75=30, 0.50x60=30, 0.60x50=30 **M1**

(b) all five products are equal (constant at 30 m s^{-1}, within experimental variation) **A1**

(b) this confirms f is inversely proportional to L (f = v/(2L)), with wave speed v = 2 x 30 = 60 m s^{-1} **A1**

(b) Answer: fL = 30 m/s for every row, confirming f is inversely proportional to L; wave speed v = 60 m/s

(c) a straight line through the origin **B1**

(c) gradient = v/2, so the wave speed v on the string is twice the gradient oe **B1**

(c) Answer: A straight line through the origin; gradient = v/2, so v is twice the gradient.

(d) rearranges to $\mu = T / v^2$ **M1**

(d) $4.5 / 60^2$ (correct substitution, ft their v) **M1**

(d) 1.25×10^{-3} kg m^{-1} (awrt 1.25) cao **A1**

(d) Answer: 1.25×10^{-3} kg m^{-1}

(e) increasing T increases v, since $v = \sqrt{T/\μ}$ **B1**

(e) with L fixed, f = v/(2L), so increasing v increases the resonant frequency f oe **B1**

(e) Answer: The resonant frequency increases, because increasing tension increases the wave speed v, and f = v/(2L) with L fixed.

Question 8

(a) the graph curves, with the gradient (proportional to 1/R) decreasing as V (and I) increase oe **B1**

(a) as current increases, the filament's temperature increases oe **B1**

(a) the increased temperature increases the amplitude of vibration of the lattice ions, increasing the frequency of collisions with the conduction (charge-carrying) electrons, which increases resistance oe **B1**

(a) Answer: The graph curves and flattens as V increases, because heating the filament raises its resistance (more ion vibration, more electron collisions).

(b) R = 2.00/0.44 (correct substitution) **M1**

(b) 4.5 ohm (awrt 4.5) cao **A1**

(b) Answer: 4.5 ohm

(c) %R = %V + %I = 1.0 + 2.5 = 3.5% (correct combining rule for a quotient) **M1**

(c) absolute uncertainty = 0.035 x 4.5 = 0.16 ohm (awrt 0.16, ft their R) **A1**

(c) R = (4.5 ± 0.2) ohm oe **B1**

(c) Answer: R = (4.5 ± 0.2) ohm

(d) a real ammeter has a small non-zero resistance and a real voltmeter has a large but finite (not infinite) resistance, so either arrangement introduces some systematic error oe **B1**

(d) with the voltmeter directly across the lamp, the ammeter reading is slightly too high (it includes the small current taken by the voltmeter), but since the voltmeter's resistance is very much greater than the lamp's resistance, this extra current is negligible oe **B1**

(d) in the alternative arrangement (ammeter directly next to the lamp, voltmeter across both), the voltmeter reading would include the (larger, comparable) voltage across the ammeter's own resistance, giving a proportionally bigger systematic error for a low-resistance component oe **B1**

(d) Answer: Placing the voltmeter directly across the (low-resistance) lamp gives only a negligible ammeter error, since the voltmeter's resistance is much greater than the lamp's; the alternative arrangement would add the ammeter's comparable resistance into the voltage reading.

Question 9

(a) the pendulum method (1.8%) has a smaller percentage uncertainty than the free-fall method (3.0%), so it is more precise **B1**

(a) valid supporting reason, e.g. timing 20 oscillations and dividing reduces the effect of the (fixed) reaction-time uncertainty far more than timing a single, much shorter, free-fall event oe **B1**

(a) Answer: The pendulum method is more precise (1.8% versus 3.0%), largely because timing many oscillations reduces the relative effect of reaction-time uncertainty.

(b) the pendulum result (9.75 m s^{-2}, 0.06 from 9.81) is closer to the accepted value than the free-fall result (9.9 m s^{-2}, 0.09 from 9.81), since 0.06 < 0.09; the difference is small, so a comment that they are comparable is also credited provided the correct differences (0.06 vs 0.09) are used **B1**

(b) precision describes the spread/repeatability of a set of measurements (a small percentage uncertainty means high precision), while accuracy describes how close a result is to the true value oe **B1**

(b) a method can give a small, consistent percentage uncertainty (be precise) yet still be inaccurate if there is an unaccounted systematic error affecting every reading in the same way, so precision alone does not guarantee accuracy oe **B1**

(b) Answer: The pendulum result (9.75 m s^{-2}) is closer to 9.81 m s^{-2} (0.06 away) than the free-fall result (9.9 m s^{-2}, 0.09 away). Precision (small % uncertainty) and accuracy (closeness to the true value) are different: a method can be precise yet inaccurate if it has an uncorrected systematic error, so a smaller % uncertainty does not guarantee a result closer to 9.81 m s^{-2}.

(c) any valid modification, e.g. keep the angle of swing small (less than about 10 degrees) so the motion approximates simple harmonic motion (the equation $T = 2\pi\sqrt{L/g}$ assumes small-angle oscillations); or measure L to the centre of mass of the bob rather than to its top or bottom oe **B1**

(c) Answer: Keep the swing angle small (under about 10 degrees) so the pendulum's motion satisfies the small-angle approximation used in $T = 2\pi\sqrt{L/g}$.