

Mark scheme – Making Measurements and Analysing Data

Question			Answer/Indicative content	Marks	Guidance
1			B	1	
			Total	1	
2			D	1	
			Total	1	
3			D	1	
			Total	1	
4			C	1	Examiner's Comments All of the questions showed a positive discrimination, and the less able candidates could access the easier questions. The questions in Section A do require careful reading and scrutiny. Candidates are advised to reflect carefully before recording their response in the box. Candidates must endeavour to use a variety of quick techniques when answering multiple choice questions. The candidates to demonstrate their knowledge and understanding of physics. Tested knowledge of how uncertainties compound when determining resistance of a filament lamp.
			Total	1	
5			D	1	
			Total	1	
6			C	1	Examiner's Comments There was an erratum issues for this question. The term precision was replaced with <i>uncertainty</i>. The performance of the candidates was as expected with most opting for the correct answer C. A very small number of candidates opted for D because this value had the smallest percentage uncertainty.
			Total	1	
7			D	1	
			Total	1	
8			D	1	
			Total	1	

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9			A	1	
			Total	1	
1 0			The gradient remains the same	B1	Note: This mark is for the idea that the gradient / slope (of the line) remains the same Allow: The line is (just) shifted (to the right) by the same amount (AW) Examiner's Comments This question on systematic errors favoured the top-end candidates; most of them appreciated that the gradient of the line would remain the same. The majority of the candidates were baffled and struggled to provide a creditable answer. Answers such as '<i>Systematic errors do not affect the experiment</i>' or '<i>Speed does not change when x changes</i>' demonstrated a poor understanding of the question and of systematic errors.
			Total	1	
1 1			D	1	
			Total	1	
1 2			C	1	Examiner's Comments In this question, candidates generally forgot that the practical skills guide recommends that uncertainties are usually given to one significant figure, ruling out option D. Furthermore, the length and width are both given to two significant figures, which means that the area should also be to two significant figures. The correct procedure is to add the percentage uncertainties in the length and width, which gives the percentage uncertainty in the area and hence the absolute uncertainty of 300 m. This question provided opportunities for middle-grade candidates.
			Total	1	
1 3			A	1	Examiner's Comments This question was based on understanding the term accuracy; a key concept in practical skills. The majority of the candidates got the correct answer A. The difference between the accepted value for g and the experimental value was greatest for A. The most popular distractor was B, where candidates took 'least accurate' to mean the value with the least percentage uncertainty. Some candidates even had the percentage uncertainties calculated for each of the options.
			Total	1	
1 4			D	1	
			Total	1	

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1 5			D	1	<u>Examiner's Comments</u> Most candidates understood that the percentage uncertainties, rather than the absolute uncertainties should be combined here. The percentage uncertainty in the length is 0.5% and the percentage uncertainty in the diameter is 0.2%. The most common incorrect response here was C, because this is what you get when you add the 2 percentage uncertainties. The percentage uncertainty in the diameter must be doubled, because the formula for the volume of the cylinder include diameter². This gives the correct answer D.
			Total	1	
1 6			D	1	
			Total	1	
1 7			C	1	
			Total	1	
1 8			D	1	
			Total	1	
1 9			Accuracy is (a quality denoting) the closeness of the measured value to the true value Precision is (a quality denoting) the closeness of agreement between measured values (obtained by repeated measurements)	B1 B1	Allow readings/results/data/values/measurements for <i>measured value</i>; actual/real/allowed/correct for <i>true</i> Allow measurements are close together/are similar/have small range/have low spread/have low scatter/have good agreement/are all close to the average <u>Examiner's Comments</u> This was generally well answered, although a few candidates reversed the definitions. Some candidates thought that the precision of an answer was determined by its number of significant figures.  AfL Centres should make sure that they are using the latest definitions, which can be found in <i>The Language of Measurement</i> (ASE 2010).
			Total	2	
2 0			$v \rightarrow \text{m s}^{-1}$ or $v^2 \rightarrow \text{m}^2 \text{s}^{-2}$ Clear algebra leading to base unit = kg m⁻¹	M1 A1	

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			Total	2	
2 1	a	i	To ensure whole cross-sectional area or end of the conducting putty is in contact with the metal plate (AW)	B1	Not good electrical contact / reduces contact resistance / surface area Examiner's Comments Conversely, candidates struggled with an explanation as to why large metal plates were used. Many candidates discussed the electrical properties of the metal plates rather than understanding the need of the experiment.
		ii	Use a (Vernier) caliper / micrometer (screw gauge)	B1	Allow ruler
		ii	Repeat measurements <u>along</u> the conducting putty	B1	Examiner's Comments Most candidates discussed measuring the diameter with a named instrument at different points along the putty.
	b	i	6.6	B1	Allow 6.56 Ignore 10^{-3} factor Examiner's Comments This part was answered well with the majority of the candidates recording the correct value to two significant figures. Some candidates made rounding errors or recorded spurious values.
		ii	$\left(\% \text{ uncertainty} = \frac{2 \times 0.001}{0.049} \times 100 = \right) 4.1 \%$	B1	Ignore significant figures Allow 4 % Examiner's Comments Most candidates were able to determine a percentage uncertainty although many did not multiply by 100. Some candidates thought that the nearest millimetre meant 0.01m instead of 0.001m. Some candidates did not realise that the percentage uncertainty in d needed to be multiplied by two.
	c	i	Plots the missing point to less than a half small square	B1	Allow ECF from (i) Penalise blob of half a small square or larger
		i	Draws <u>straight</u> line of best fit	B1	Allow ECF Expect to be balance of points about line of best-fit. Judge straightness by eye. Not a top point to bottom point line / not a top point to (2.0, 10) line Examiner's Comments The plotting of the missing point was accurately positioned by the majority of the candidates. There were major difficulties on drawing a suitable straight line of best fit; it is expected that there should be a balance of points about the line. Many lines could have been rotated. Lines that were drawn from the bottom plot to the top plot invariably had too many points below the line and were penalised. Some candidates did not draw straight lines.

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		ii	Gradient = $\frac{y_2 - y_1}{x_2 - x_1} = \frac{\Delta y}{\Delta x}$	M1	Not one R/L ² value using the line or a data point Ignore POT for M1
		ii	gradient = 5700 (5550 – 5850)	A1	Allow ± 150 for the value of gradient Ignore units Examiner's Comments This question tested the practical skills of candidates to determine the gradient from their results. To score these marks candidates had to show their method. A large number of candidates failed to realise that the x-axis had a factor of 10 ⁻³ . Other common errors were to assume that the graph commenced at (0, 0). Good candidates clearly demonstrated their method by indicating the points taken, made sure that the length of their gradient was at least half the length of their line and correctly substituted into Δy / Δx.
	d		$\rho = 5700 \times 1.9 \times 10^{-5}$ $\rho = 0.108$ <u>given to 2 or 3 sf</u> Ω m	C1 A1 B1	Note: ECF from (ii) Allow any subject for equation Not use of data points from table Examiner's Comments Candidates were expected to use the gradient that they had calculated in (ii) of the previous question part to determine a value for the resistivity; candidates who substituted a data point from the table did not score the first two marks. The final answer needed to be given to two or three significant figures. There was also a mark available for the correct unit; a good number of candidates scored this mark although a number of candidates did write the unit for density.
			Total	12	
2 2			$\frac{0.12}{1.20} (\times 100)$ or $\frac{0.24}{4.00} (\times 100)$ or $(k =) 2.78 \text{ (kg m}^{-1}\text{)}$ $[2 \times 0.1 + 0.06]$ or 0.26 or 26 % absolute uncertainty = 0.72 (kg m ⁻¹)	C1 C1 A1	Allow $(k_{\max} =) \frac{4.24}{1.08^2}$ and $(k_{\min} =) \frac{3.76}{1.32^2}$ or 3.635 and 2.158 Allow (range =) 1.48 Note: The answer must be given to 2 SF – as required by the question Ignore any value given for k on the answer line
			Total	3	
2 3			$T = 60/1600$ or $T = 3.75 \times 10^{-2} \text{ (s)}$ $(v = \pi \times 0.50/3.75 \times 10^{-2})$ speed = 42 (m s ⁻¹)	C1 A1	Allow: $f = 26.7$ or $\frac{1600}{60} \text{ (Hz)}$ or $\omega = 168 \text{ (s}^{-1}\text{)}$ Note: v must be to 2 or more SF

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			uncertainty = 3 (m s ⁻¹)	A1	Note: uncertainty must be to 1 SF Allow: ecf on candidate's value for speed i.e. uncertainty = candidate's value / 16 (to 1 SF) Allow for 2 marks max: 84 ± 5 (m s⁻¹) <u>Examiner's Comments</u> About half of the candidates got this item right or provided clear working to show where they were going. There was much confusion about which quantity was which. 1600 revolutions per minute refers to the frequency of the rotation, not the angular speed, angular frequency or the speed itself. The percentage error of the frequency was 6.25%, prior to rounding. Some candidates multiplied this by their value for the speed to get the correct absolute uncertainty, although good practice is to round uncertainties to 1 SF.
			Total	3	
2 4	a		Use a thermometer (with ± 1 °C) Stir water bath / avoid parallax (for glass thermometer)	B1 B1	Allow 'temperature sensor / gauge' Allow 'avoid touching sides of water bath with thermometer' Allow 'take temperature in several places / times and average' Allow idea of 'leave thermometer for long time (to reach thermal equilibrium)' Not idea of 'use thermometer with finer resolution' <u>Examiner's Comments</u> A large majority included a correct measuring device, such as a thermometer. Significantly fewer described a technique for accurate measurements such as stirring the water or taking the temperature at several points and calculating a mean temperature.
	b	i	Smaller (spacing between) divisions / increments (AW)	B1	Ignore any reference to accuracy or precision Allow 'less uncertainty' Allow better or smaller or greater or higher resolution <u>Examiner's Comments</u> Approximately half of the candidature made a correct comment regarding resolution or that the smaller intervals on the psi scale made it a sensible choice of scale.
		ii	$p = 37.0 \times 4.448 / (1000 \times 0.0254^2)$ 255 (kPa) uncertainty = 3 (kPa)	B1 B1	Allow clearly identified correct answer in table or in working area. Must be 3sf Must be 1sf Allow 255.1 ± 3.4 scores mark 1 <u>Examiner's Comments</u> The vast majority of candidates correctly calculated the pressure in kPa and stated that the absolute uncertainty was 3 kPa. A very small number of responses were rounded inappropriately.
	c	i	Point plotted at (44, 255)	B1	ECF from (b)(ii) Plot to with ± half a small square

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				Ignore checking error bars Examiner's Comments Most candidates correctly plotted the point with error bars. In this instance during marking Examiners were instructed to ignore the error bars as they were too difficult to view when scanned.
		Level 3 (5–6 marks) Clear explanation, description and determination <i>There is a well-developed line of reasoning which is clear and logically structured.</i> <i>The information presented is relevant and substantiated.</i> Level 2 (3–4 marks) Some explanation, description and determination Or Some explanation and clear determination ii <i>There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.</i> Level 1 (1–2 marks) Limited explanation or description or determination <i>The information is basic and communicated in an unstructured way. The information is supported by limited evidence and the relationship to the evidence may not be clear.</i> 0 marks No response or no response worthy of credit.	B1 × 6	Indicative scientific points may include: Explanation and Description • Absolute zero is the minimum possible temperature / at absolute zero KE is zero • At absolute zero p is zero • At absolute zero, the internal energy is minimum (allow 0) • Absolute zero should be (about) $-273\text{ }^{\circ}\text{C}$ • Reference to $pV = nRT$ or $pV = NkT$ or $p \propto T$ • A graph of p against θ is a straight line / straight line drawn on graph • Intercept of straight line with x-axis or θ-axis is absolute zero calculated by using $y = mx + c$ Determination • Gradient in the range 0.7 to 0.9 (kPa K^{-1}) • $y = mx + c$ used to determine the intercept c or absolute zero • Absolute zero in the range $-320\text{ }^{\circ}\text{C}$ to $-240\text{ }^{\circ}\text{C}$ Use only L1, L2 and L3 in RM Assessor. Examiner's Comments It was clear that the majority of candidates had either performed this experiment themselves or had otherwise seen it before. The concept of absolute zero was very successfully described and many knew that an extrapolation or calculation involving the equation of a straight line was required to find absolute zero as the x-intercept of the straight line. Common errors included mis-calculating the gradient, inability to rearrange the equation or inappropriate conversion to kelvin. Re-

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				plotting the graph was not required and merely wasted time for little reward.
	d	Draw the worst fit line (through all the error bars) (AW). Determine the new value for absolute zero and find the difference between the value in (c)(ii) and this new intercept. (AW)	B1 B1	Examiner's Comments Many candidates realised that drawing a line of worst fit was sensible. Far fewer were clear that using the line of worst fit to find a new x-intercept, leading to a spread in values for absolute zero was the correct procedure. Many incorrectly suggested finding the difference in gradients, or percentage differences in gradients.
	e	Cooling gas value of absolute zero is lower than (c)(ii) (Whilst cooling, the) temperature of gas lags behind the temperature of water (AW, ORA) Graph is shifted to the left Stir water / wait for temperatures to be the same / attempt at measuring temperature of gas directly (AW)	B1 B1 B1 B1	Allow: gradient is too shallow Allow: p measured is higher than expected for incorrect measurement of T (so affects the graph) (AW, ORA) Not insulation of water bath Not heat losses Examiner's Comments The first mark for this item was intended to be for a straightforward comparison that the repeated experiment yielded a lower value than that from part (c)(ii). Many candidates calculated a percentage difference yet did not refer to the direction of difference. Some candidates successfully suggested that the water would always be cooler than the gas and so the thermometer reading would be systematically lower than the true temperature of the gas. Rather fewer discussed that the pressure reading would therefore be higher than it should be for the thermometer reading. Very few candidates linked this idea to the effect on the graph, namely that the points would all be shifted to the left, causing a lower x-intercept or a less steep line of best fit. There were three acceptable experimental approaches to avoid this systematic error. Stirring the water and waiting until the gas and water equilibrated would have reduced the effects of the rapid cooling. A sensible approach employed by some candidates was to take the temperature of the gas directly using a thermometer or temperature inside the flask.
		Total	18	
25		$\frac{0.002}{0.1000} (\times 100) \text{ or } \frac{0.1}{1.4} (\times 100) \text{ or } g = \frac{1.4^2}{2 \times 0.100}$ ($2 \times 0.071 \dots + 0.02$) or 0.1628 ... or 16.3 %	C1 C1 A1 C1	Allow 1SF answers here for uncertainties Not $g = 9.8$ for this C1 mark; must see working Allow 0.16 or 16%

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			absolute uncertainty = $1.6 \text{ (m s}^{-2}\text{)}$ OR $g_{\max} = \frac{1.5^2}{2 \times 0.098} (= 11.48)_{\text{or}}$ $g_{\min} = \frac{1.3^2}{2 \times 0.102} (= 8.28)$ range = $3.2 \text{ (m s}^{-2}\text{)}$ absolute uncertainty = $1.6 \text{ (m s}^{-2}\text{)}$	C1 A1	Note: The answer must be given to 2 SF Ignore value of g given on the answer line, e.g. 9.8 ± 1.6 Note: The answer must be given to 2 SF
			Total	3	
2 6			(mean) = $1.87(2) \text{ (mm)}$ (range) = 0.04 mm (percentage uncertainty) = $\frac{0.02}{1.872}$ percentage uncertainty = 1 (%)	C1 C1 A1	Allow use of resolution of micrometer (gives percentage uncertainty of 0.5%) Allow use of maximum or minimum deviation from the mean Allow 2 or 3 SF answer
			Total	3	
2 7	a	i	$l = (v/4)(1/f) - k$ Correct comparison with $y = mx + c$	M1 A1	Correct manipulation of equation must be shown
		ii	large triangle used to determine gradient gradient calculated correctly $v = 320 \text{ (m s}^{-1}\text{)}$	B1 B1 B1	$\Delta x > 0.6 \times 10^{-3}\text{s}$ Expect between 80 and 82 $\text{(m s}^{-1}\text{)}$ Allow 320 ± 20; allow ECF from an incorrect gradient
	b	i	Value of $1/F$ determined correctly from graph $F = 350 \text{ (Hz)}$	C1 A1	Allow values between $2.83 \times 10^{-3}\text{s}$ and $2.84 \times 10^{-3}\text{s}$ Allow only alternative methods which use values from line of best fit
		ii	$(100 (\Delta F/F) =) 100 \Delta v/v$ $+ \frac{100 (\Delta l + \Delta k)}{(l + k)}$	B1 B1	
			Total	9	
2 8		i	A and B move in opposite directions	B1	Allow A is moving up and B is moving down (or vice versa) Allow they have a phase difference of 180° or $\pi \text{ (rad)}$ Allow they are in antiphase Examiner's Comments The majority of the candidates gave a good answer. Most realised that the particles at A and B will be moving in opposite directions or have a phase difference of 180°.
		ii	$\lambda = 0.80 \text{ (m)}$ $v = f\lambda$, $v = 75 \times 0.80$	C1	Allow 80 (cm) for this C1 mark

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		ii	$v = 60 \text{ (m s}^{-1}\text{)}$ $\text{absolute uncertainty} = \frac{2.0}{40} \times 60$	A1	Allow 1 mark for $30 \text{ (m s}^{-1}\text{)}$ from the C1A1 marks; $\lambda = 0.40 \text{ m}$ used Note $60 \pm 3 \text{ (m s}^{-1}\text{)}$ scores full marks Allow 2 marks for $6000 \pm 300 \text{ (m s}^{-1}\text{)}$; λ in cm (POT error) Allow 2 marks for $30 \pm 1.5 \text{ (m s}^{-1}\text{)}$; $\lambda = 0.40 \text{ m}$ used Examiner's Comments This was a notable success for the candidates; many correctly determined the wave speed to be 60 m s^{-1} . The absolute uncertainty of 3.0 m s^{-1} was correctly calculated by most of the top-end candidates. The most frequent incorrect values for the uncertainty were 0.02 m s^{-1} and 0.04 m s^{-1} . A significant number of the low-scoring candidates took the wavelength to be 0.40 m . This gave an answer of $(30 \pm 1.5) \text{ m s}^{-1}$. Examiners awarded two marks for such an answer.
		ii	absolute uncertainty = $3.0 \text{ (m s}^{-1}\text{)}$	A1	
			Total	4	
29	a	i	points on the line read to the nearest half square	B1	Allow Δy for $y_2 - y_1$ and Δx for $x_2 - x_1$
			size of triangle is greater than half the length of the drawn line and $\Delta y / \Delta x$	B1	$\Delta x \geq 0.1625$
		ii	$\left(\frac{9.81}{0.12}\right) = 81.75$ 82 N m^{-1} given to 2 or 3 significant figures	C1 A1	Allow ECF from (a)(i) Allow 81.8 N m^{-1} Note POT must be correct for given unit Allow kg s^{-2}
	b	i	steepest or shallowest line that passes through all the error bars	B1	
		ii	gradient determined: 0.10 m kg^{-1} or 0.13 m kg^{-1}	B1	Allow ECF from (b)(i)
			$\Delta \text{gradient (} 0.13 - 0.12 \text{ or } 0.12 - 0.10 \text{)}$ $\frac{\Delta \text{gradient}}{\text{gradient}} \times 100 = 8.3\% \text{ or } 17\%$ OR $\Delta k (82 - 75 \text{ or } 98 - 82)$ $\frac{\Delta k}{k} \times 100 = 8.5\% \quad \text{or} \quad 20\%$	C1 A1 C1 A1	Allow ECF from (b)(i) and (ii) Not 10% without justification Examiner's Comments In this question, most candidates clearly identified the points on the line that were to be used for the gradient calculation. High achieving candidates clearly showed their working when determining the percentage uncertainty.
			Total	8	
30	a		gradient = b and y-intercept = lg a	B1	

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	b	i	1.70;	B1	both values for the mark
		i	0.41 ± 0.03	B1	allow ecf to find uncertainty value
		ii	two points plotted correctly;	B1	ecf value and error bar of first point
		ii	line of best fit	B1	allow ecf from points plotted incorrectly
	c	i	$b = \text{gradient} = 1.60$	B1	allow 1.56 to 1.64; allow 1.6
		i	$y = 0.86 (\pm 0.01)$; $x = 1.98$ so y -intercept $= 0.86 - 1.6 \times 1.98 = -2.3(1)$	B1	ecf gradient in finding y -intercept
		i	$a = 10^{-2.3} = 0.005$	B1	
		ii	worst acceptable straight line	B1	steepest or shallowest possible line that passes through the error bars; should pass from top of top error bar to bottom of bottom error bar or bottom of top error bar to top of bottom error bar allow $(1.6) \pm 0.1$ or 0.2 where plausible working is shown
		ii	$b = \text{gradient of steepest line} = 1.75$ giving uncertainty ± 0.15	B1	
			Total	10	
3 1		i	$g = \frac{2s}{t^2} \quad / \quad g = \frac{2 \times 1.200}{0.50^2}$	C1	
		i	$g = 9.6 \text{ (m s}^{-2}\text{)}$	A1	
		ii	(% uncertainty in s) = 0.08 % or	C1	
		ii	(% uncertainty in t) = 4.00 %		
		ii	% uncertainty in $g = ((2 \times 4.00) + 0.08)$	C1	
		ii	% uncertainty in $g = 8.08 \text{ (%)}$	A1	Allow 8.1% or 8 %
			Total	4	
3 2			(force =) $2.2 \times 10^{-3} \times 9.81$ $2.2 \times 10^{-3} \times 9.81 = B \times 5.0 \times 0.060 (= 0.072 \text{ T})$ (absolute uncertainty =) $\frac{0.2}{6.0} + \frac{0.1}{5.0} (\times 0.072 = 0.0038 \text{ T})$ $B = 0.072 \pm 0.004$	C1	Allow calculation of percentage uncertainty = 5.3% Allow calculation of max $B (=0.0759 \text{ T})$ and min $B (=0.0683 \text{ T})$ Note B must be given to 2 SF and the uncertainty given to 1 SF. Special case: allow follow through from incorrect B calculation.
				C1	<u>Examiner's Comments</u>
				C1	This question is based around a common experiment used to determine the magnetic flux density of a pair of magnets and the experimental design should have been familiar to many candidates, along with the use of $F = BIL\sin\theta$ from the data booklet. The first mark is for identifying the magnitude of the force as being the change in the apparent weight on the balance. Several candidates simply used the reading with the wire, or did not change the mass unit to kg. However, those who managed to get the correct reading for the force generally went on to calculate the magnetic flux density correctly. The uncertainties for two readings were given, and most candidates correctly calculated a percentage uncertainty of 5.3%. The final answer required the correct number of significant figures. Some candidates either did not see this, or ignored it,
				A1	

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					leaving their final answer in different significant figures. It was noted that several candidates underlined this instruction and in general they tended to follow it. It is good practice to do this.
			Total	4	
3 3			Line of best fit drawn through the data points Gradient = 38 ($Ck \ln 2 = \text{gradient}$) $1.2 \times 10^{-3} \times k \times \ln 2 = 38$ $k = 4.6 \times 10^4 \text{ } (\Omega \text{ m}^{-1})$	B1 C1 C1 A1	Allow ± 2. Not calculated through use of a single point. Possible ECF from incorrect gradient Note: gradient of 40 gives 4.8×10^4 and gradient of 36 gives 4.3×10^4 <u>Examiner's Comments</u> This question is likely to be an unfamiliar scenario to many candidates and so required some careful reading. The first mark is for a single straight line of best fit; many candidates simply joined up the first and last point, which produced a line that did not produce an even distribution of points above and below. The gradient calculation was well done by most candidates, leading to a value within the tolerance. Although the given equation is likely to be unknown, most candidates were able to appreciate how to determine the value of k and did so successfully. Over half of the candidates were able to achieve full marks on this question.
			Total	4	
3 4		i	Systematic error / meter not zeroed (AW)	B1	Allow resistance due to crocodile clips / resistance of connecting wires / internal resistance (of cell in ohmmeter) / resistance of ohmmeter
		ii	Use a vernier calliper / micrometer to measure diameter of pencil lead (and hence <u>determine</u> A) $\rho = \text{gradient of line} \times A$ (Any subject) Any one from: $A = \frac{\pi d^2}{4}$ - Measure the diameter in several positions (and average) - Use a large 'triangle' to determine the gradient	B1 B1 B1	Allow vernier / calliper Allow use of 'slope' for gradient Allow $A = \pi r^2$ and $d = 2r$
			Total	4	
3 5	a		weight $\times y = Fx$ $(AL\rho g) \times y = Fx$ $y = \left(\frac{F}{AL\rho g} \right) x$	M1 M1 A0	Allow W or mg $Wy = Fx$ or $mg y = Fx$

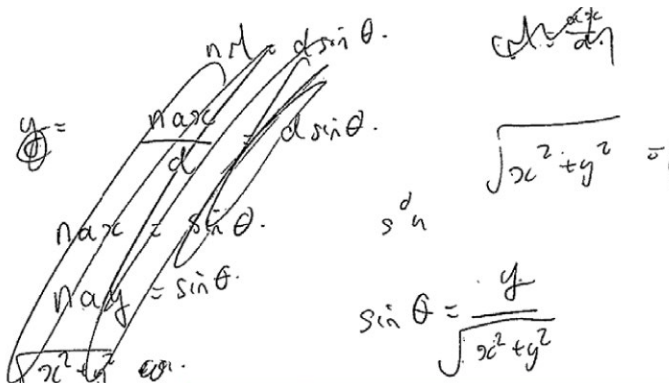
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	b	i	Straight line of best fit drawn through the data points Gradient = 1.5	B1 B1	Allow gradient in the range 1.40 -1.60
		ii	$\left(\frac{F}{ALpg}\right) = 1.5$ $\frac{6.8}{6.4 \times 10^{-5} \times 0.90 \times \rho \times 9.81} = 1.5$ $\rho = 8.0 \times 10^3 \text{ (kg m}^{-3}\text{)}$	C1 C1 A1	Allow ECF from (i) Allow 8×10^3 (1 SF answer) Note must be consistent with gradient value from (i)
			Total	7	
3 6	a		(change in) KE = (change in) GPE /AW $\frac{1}{2}(m + 0.8)v^2 = 0.6 \text{ mg}$ (and hence equation as shown on	M1 A1	allow $mgh = \frac{1}{2}Mv^2$ as long as it is clear that m and M are different, i.e. NOT $mgh = \frac{1}{2}mv^2$ allow linear motion equation $v^2 = u^2 + 2as$ and $F = Ma$ ($W \Rightarrow$) $mg = (m + 0.8)a$; $u = 0$ and $s = 0.6$ Examiner's Comments The challenge to candidates in answering this <i>show that</i> question was to produce a convincing proof. More chose to use constant acceleration equations and $F = ma$ rather than loss of potential energy equates to gain in kinetic energy. The difficulty in the former method was justifying the statement $F = mg = (m + 0.800) a$. Most just quoted that $a = mg / (m + 0.800)$ which immediately gave the relationship shown in the question. The difficulty with the second method was that most candidates wrote $mgh = \pm \frac{1}{2}mv^2$ as the first line of their answer. In the next line one m became $(m + 0.800)$ without explanation to give the required relationship. Only candidates who gave more explanation were credited the marks. The candidate who wrote this perfect answer (exemplar 7) solved the problem in the first method of solution by introducing the tension in the string (labelled T on Fig. 4.1). Exemplar 7 (a). Show that the relationship between v and m is $v^2 = \frac{1.20mg}{(m + 0.800)}$ where g is the acceleration of free fall. $T = 0.800a$ $mg - T = ma$ $mg = a[(0.800) + m]$ $s = 0.600$ $v = ?$ $a = ?$ $t = ?$ $v^2 = u^2 + 2as$ $v^2 = 2(0.600)$ $v^2 = \frac{1.20mg}{(0.800 + m)}$
	b	i	($v^2 =$) 4.93 ($\pm$) 0.22	B1 B1	allow 4.9 ($\pm$) 0.2 (same number of decimal places)
		ii	Point (and error bar) plotted correctly Line of best-fit drawn through all points shown (use protractor tool at 49°)	B1 B1	tolerance $\pm \frac{1}{2}$ small square; possible ecf from (b)(i) allow ecf from point plotted incorrectly or point omitted Examiner's Comments Most candidates calculated the value of v^2 to two decimal places successfully. Fewer were successful in giving the absolute

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				uncertainty as ± 0.22 . A popular distractor was ± 0.10 . On the graph of Fig. 4.2 only the correct position of the point was required to gain the mark. The length of the uncertainty bar was ignored. A significant number of candidates forgot to draw the line of best fit on the graph.
	c	i	$v^2 = \frac{1.20mg}{(m + 0.800)}$ compared with $y = mx + c$	B1 allow minimum of gradient = $v^2/[m/(m + 0.8)] = 1.2g$ or expect $y = v^2$ <u>and</u> $x = m/(m + 0.800)$ so gradient = $1.20g$ <u>Examiner's Comments</u> The common successful method employed by the majority was to compare the given equation with standard form for a straight line $y = mx + c$. A simple rearrangement of the relationship without any explanation was not considered to be adequate.
		ii	one acceptable worst-fit line drawn large triangle used to determine gradient Gradient (used to determine 'worst' g) absolute uncertainty given to one decimal place	B1 roughly between extremes of top and bottom error bars or by eye; consequential ecfs for rest of (ii) $\Delta x > 0.13$; B1 expect steepest 12.5 ± 0.2 or shallowest 10.3 ± 0.2 if point from bii not plotted steepest line is 12.9 answer from ± 0.8 to $1.1(m\ s^{-2})$; allow ecf from gradient value B1 <u>Examiner's Comments</u> To avoid the problem of various lengths of error bar, candidates were judged to have drawn an acceptable worst fit line if it passed through opposite ends of the top and bottom bars on their graphs. Almost all gained the mark for using a triangle to determine the gradient of the line which spanned more than 0.13 on the x – scale. Most candidates were able to gain credit for finding the gradient of their graph correctly. The determination of the absolute uncertainty to one decimal place then proved to be too difficult a challenge for the majority.
	d		card appears shorter or time measured shorter calculated speed of trolley larger gradient of graph steeper or $v^2 \propto g$ /AW so calculated g is greater	B1 N.B. each B mark is consequential on the previous statement; e.g. ecf max of 3 marks for correct consequences of stating card appears longer or time longer <u>Examiner's Comments</u> B1 Candidates gave full and usually clear answers to this part. There were four consequential marking points in this answer. Each candidate was given credit for every point that followed logically from the previous one, even when that previous one was incorrect. In the example (exemplar 8) shown here the candidate stated that the card appeared longer, which is incorrect. There were still three marks available for stating that the speed would appear lower and deducing that g would appear smaller. By this method most candidates were credited with at least half of the available marks. B1 Exemplar 8

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				The time taken to is increased. ✗ So constant velocity V decreases ✓ ECF $V = \frac{m}{m+80} \cdot 1.20g$ ECF Gradient would be smaller, therefore, the eq value of g would be smaller. ✓ ECF
			Total	15
3 7	a	$y = \sin(\theta) \sqrt{x^2 + y^2}$ compared with "$y=mx+c$"	B1	gradient = $\frac{\Delta y}{\Delta(\sqrt{x^2 + y^2})}$ with $\sin(\theta) = O/H$ Allow: gradient = $\frac{y}{(\sqrt{x^2 + y^2})}$ unless "c=0" seen. Not: Examiner's Comments Candidates found this item tricky even if they realised that $\sin(\theta) = y/\sqrt{x^2 + y^2}$ and then re-arranged the equation into a form comparable with the general equation of a straight line, "$y=mx+c$". Unless that comparison was clear, then the mark could not be credited. Exemplar 8  $\sqrt{x^2 + y^2} \sin \theta = y$ $C + 90m = y$ So $\sin \theta$ is the gradient is $\sin \theta$ as $\sin \theta$ is m in graph $y=mx+c$ © OCR 2018 The exemplar shows a clear way of demonstrating how to show that the gradient of the line of the graph should be $\sin(\theta)$.
	b i	(Straight line of best fit showing) <u>gradient</u> = 0.73 $(d \sin \theta = n\lambda)$ $\frac{1.0 \times 10^{-3}}{600} \times 0.73 = 2 \times \lambda$ $\lambda = 6.1 \times 10^{-7} \text{ (m)}$	C1 C1	Allow: gradient in range 0.70–0.76. Allow: evaluation of $\theta = 44$–50 (degrees) in place of gradient Allow: any subject Note: Gradient in range 0.70–0.76 gives λ in range (5.8 – 6.4) ×

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				A1	10^{-7} m <u>Examiner's Comments</u> Many candidates could plot the best fit straight line and attempted to calculate the gradient. Not many candidates after that point realised that the gradient had given them $\sin(\theta)$ and could make no further meaningful progress. Common errors included not calculating d correctly from the quoted number of lines mm^{-1} or, less frequently, was using a value different from 2 for n .
		ii	(Scales/distances are large compared with the absolute uncertainty so) <u>absolute uncertainty is too small</u> to be shown (reasonably on this graph's scale) (AW)	B1	Ignore: error too small <u>Examiner's Comments</u> 20 per cent of candidates did not attempt this item. Some candidates were on the right lines but very few mentioned about absolute uncertainty and that for these instruments and this graph, the absolute uncertainty was too small to view on this scale.
		ii i	(The values for λ or θ will be) less precise (as independent measurements less likely to agree) (AW)	B1	<u>Examiner's Comments</u> About two fifths of candidates appreciated that the precision would not be as good with a protractor, as repeated measurements would be less likely to cluster in close proximity. <i>Precision</i> The term 'precision' is defined on page 40 of the Practical Skills Handbook, along with other useful terms that attempt to describe the quality of data
			Total	6	
3 8		i	– 0.060 and 3.85 (Both to 2 sf after the decimal point)	B1	Allow – 0.06 or –0.0605 (the minus sign is required) Not: 0.06 Allow: 3.845(1) Note: Use of $\ln$ gives –0.14 and 8.854 for 0 marks. <u>Examiner's Comments</u> Although some candidates were confused by the appearance of 'lg', most candidates were not. This notation is on the specification and was used in the previous specification.
		ii	Missing data point plotted to $\pm$ half small square consistent with candidate's value. Straight best fit line drawn	B1 B1	Allow ECF from (b)(i) Allow ECF for incorrectly plotted point or data point from (i) omitted <u>Examiner's Comments</u> Providing the candidate had entered values in the tables, the data point was almost always plotted correctly. The best fit line caused

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				slightly more problems. Candidates should take a ruler into the examination and be careful about the positioning of the ruler for the fairest best fit straight line. The Practical Skills Handbook is helpful on this topic. Exemplar 3 $\frac{dy}{dx} = \frac{(4, -0.37) - (3.78, 0.076)}{3.78 - 4} = -2.02 \quad \checkmark$ In this example, the candidate's line has missed the final data point. The line of best fit for this item should just graze each of the given points.
	ii	(Triangle used to determine gradient and) gradient calculation is shown to be within range -1.90 to -2.20	B1	Examiner's Comments Most candidates correctly found the gradient of their best fit straight line.
	i	$\lg(g) = \lg(GM) - 2\lg(r)$ or $\lg(g) = -2\lg(r) + \lg(GM)$ seen Compared with $y = mx + c$, and hence gradient = -2	M1 A1	Allow: incorrect handling of negative g. Examiner's Comments Exemplar 4 The exemplar shows both an unsuccessful and a successful

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				approach. The crossed-out working was typical across many candidates, with incorrect maths and no handling of the 'GM' term. The successful approach was very clear mathematically, as well as making a clear comparison with the general equation for a straight line. Some candidates decided to find the gradient of their best fit line again, showing that they did not see the distinction between these two questions, despite the change in command verb.	
			Total	6	
3 9			Level 3 (5 - 6 marks) Clear procedure or correct determination of wavelength, plus reasonable estimation of uncertainty in λ or $(\sin) \theta$ <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3 – 4 marks) Description of procedure or correct determination of λ, but no estimation of uncertainty or Clear estimation of uncertainty in wavelength but limited description of procedure and/or determination of λ or $(\sin) \theta$ or Some description of procedure, an attempt to determine the wavelength, and an attempt to estimate uncertainty in some of the measurements (e.g. in x) <i>There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.</i> Level 1 (1 – 2 marks) A limited selection from the scientific points worthy of credit. <i>There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.</i> 0 marks No response or no response worthy of credit. <u>Frontal</u>	1 (AO 3)	Use level of response annotations in RM Assessor, e.g. L2 for 4 marks, L2⁺ for 3 marks, etc. <u>L1 maximum for any answers which use formula $\lambda = ax/D$</u> Indicative scientific points may include: Procedure • use formula $n\lambda = d\sin\theta$ • $n = 1$ since first order spectrum • find d using number of lines/mm = 300 mm⁻¹ • find θ using distance of grating from plastic ruler = 0.50 m and $x = 0.10$ m (not protractor) Determination of wavelength • calculate d ($= 10^{-3}/300$) = 3.3×10^{-6} m • use $x = 0.10$ m and distance to grating = 0.50 m to calculate $\tan \theta$ ($= 0.2$) • $\theta = 11.3^\circ$ • $\sin \theta = 0.196$ • alternatively, calculate hypotenuse of triangle (using Pythagoras's theorem) = 0.51 m, giving $\sin\theta$ ($= 0.10/2600^{1/2}$) = 0.196 • allow use of small angle rule ($\sin\theta \approx \tan\theta \approx \theta = 0.2$) • calculate λ ($= 0.196 \times 10^{-3}/300$) = 650 nm Estimation of uncertainty • negligible uncertainty in d (and n) • uncertainty in $\sin \theta$ is found using uncertainty in distance measurements • uncertainty in each distance measurement is ± 1.0 mm or ± 0.5 mm or ± 2.0 mm • maximum % uncertainty in $\tan \theta / \theta / \sin \theta = 3\%$ • so % uncertainty in $\lambda = \% \text{ uncertainty in } \sin \theta = 3\%$ <u>Examiner's Comments</u> Unfortunately, a significant number of candidates did not recognise the diffraction grating experiment here, confusing it with the double

				slit experiment and so using the formula $\lambda = ax/D$. This may be because the formula $n\lambda = d\sin\theta$ is in the astrophysics section of the formula sheet. Candidates who chose to use the correct formula $n\lambda = d\sin\theta$ were given for choosing the correct values for n, d and θ, for a correct calculation of λ, and for an accurate error analysis. Candidates who did not calculate λ could still gain full marks, as long as they gave accurate instructions as to how this could be done. Strong candidates successfully calculated a reasonable estimate of uncertainty in λ by combining the uncertainties in the distance measurements which had been used to find $\sin\theta$.
				AfL The experiment to measure the wavelength of light using a diffraction grating is PAG 5.1 and so is often carried out in Year 12. It may be beneficial to carry out this practical activity in Year 13 instead during the study of spectral lines, to reinforce use of the formula $n\lambda = d\sin\theta$.
				OCR support Being aware of the contents of the data, formulae and relationship booklet and its layout will support candidates, alleviating the need to recall numerical values of constants and allowing retrieval of correct formulae, or giving assurance that the student has recalled correctly.
				Exemplar 7 Red photons occur only at the 4th order (n)... there are 300 lines per millimeter, which is 300,000 per meter... the separation is... Need to measure the angle θ between the 3rd and 4th order to use equation... $d\sin\theta = n\lambda$, rearrange for λ A more fully dark room would be better as it's easier to determine what the colours are and see the light. Exemplar 7 illustrates many aspects of a Level 1 response. Although the correct formula has been identified, it will not give a correct value for λ because incorrect values for n, d and θ have been chosen. The response has been put at the bottom of Level 1 because, although there is an attempt at a logical structure, almost all of the information it contains is inaccurate and therefore not relevant.
			Total	6

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4 0	i	$hf = \phi + KE_{\text{(max)}}$ and kinetic energy = 0 (at f_0) (therefore $\phi = hf_0$)	B1	Examiner's Comments About a third of the candidates showed how Einstein's photoelectric equation led to the expression $\phi = hf_0$. The key in securing a mark was stating that the kinetic energy of the electrons is zero at the threshold frequency. Some candidates lost the mark for careless work such as writing $hf_0 = \phi + KE_{\text{max}}$.
	ii	Data point (to with $\frac{1}{2}$ small square) and a reasonable straight (best-fit) line drawn with a straight edge / ruler	B1	Not freehand / wobbly line Examiner's Comments Most candidates picked up the mark for plotting the data point and drawing a best fit line. Examiners were a lenient with the marking of the line of best fit. Candidates must use rulers and ensure an equal spread of data plots about their best fit lines.
	ii i	Correct conversion from eV to J using 1.6×10^{-19} (gradient = h) gradient determined and $h = (6.4 \text{ to } 7.4) \times 10^{-34} \text{ (J s)}$	B1 B1	Note this can be a single value of ϕ or $\Delta\phi$ Allow value of h must be given to 2 or 3 SF Examiner's Comments The determination of Planck constant h from the gradient of the best fit line was impeccably undertaken by the top-end candidates. A large triangle was used to determine the gradient of the best fit line. More than half of the candidates correctly converted the eV to J. The most common errors here were: - Using 1.0×10^{-19}, rather than 1.6×10^{-19} to convert eV to J. - Calculating the gradient using eV values. - Omitting the 10^{14} factor for the frequency.
	i v	Draw a worst-fit line (and determine gradient / h) (AW) % uncertainty = $(h \text{ from biii} - h \text{ from worst line}) \times 100 \div h \text{ from biii}$ or Calculate the average h using f_0 and ϕ (values) % uncertainty = $(\frac{1}{2} \text{ range} \div \text{average } h) \times 100$	B1 B1 B1 B1	Allow (line of) maximum / minimum gradient Ignore sign Allow gradient instead of h Examiner's Comments About one in ten candidates omitted this question. Many candidates realised that a worst-fit line had to be draw, with or without error bars, and then its gradient used to determine the percentage uncertainty in the experimental value for h. A significant number of

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				candidates gave answers in terms of percentage difference between their experimental value and the accepted value for Planck constant.
			Total	6
4 1	a		Level 3 (5–6 marks) Clear procedure, measurements and analysis <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3–4 marks) Some procedure, some measurements and some analysis. <i>There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.</i> Level 1 (1–2 marks) Limited procedure and limited measurements or limited analysis <i>The information is basic and communicated in an unstructured way. The information is supported by limited evidence and the relationship to the evidence may not be clear.</i> 0 marks No response or no response worthy of credit.	B1 x6 Indicative scientific points may include: Procedure - labelled diagram - long tube - method to determine <u>terminal</u> velocity - check for terminal velocity - safety precaution (tray to avoid spills / gloves / clamp tube) - method to remove sphere Measurements - measurement of diameter - use micrometer / calliper to measure diameter - averages diameter - measurements to determine v, e.g. stopwatch, ruler, light gate connected to timer, detailed use of video camera - repeats experiment for same r Analysis $r = d / 2$ - determination of terminal velocity - plot a graph of v against r^2 $K = \text{gradient}$. Examiner's Comments This question was the first level of response question on the paper. It involved candidates planning an investigation into the variation of terminal velocity and the radius of a sphere. Candidates were expected to draw a labelled diagram and there were many tubes with elastic bands drawn. To gain the highest marks candidates were expected to explain carefully how they would measure the terminal velocity and to include how they would check that the terminal velocity had been achieved. Candidates were also expected to explain how their results could be used to give to determine the constant K. Good candidates suggested an appropriate graph that should be plotted and explained how K could be determined from the gradient. In general answers were better this year than last year.
	b	i	Micrometer/(Vernier) caliper Repeat readings (in different directions) <u>and</u> average	B1 B1 Not ruler Examiner's Comments

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					Most candidates were able to suggest the use of a micrometer or caliper. A significant number of candidates did not state that they would repeat readings in different directions and calculate the mean value.
		ii	$\frac{4}{3}\pi(0.014)^3$ OR 1.15×10^{-5} $m = 650 \times 1.15 \times 10^{-5} = 7.47 \times 10^{-3}$ 0.0075 (kg)	M1 M1 A0	Allow $\frac{4}{3}\pi(1.4)^3$ Note must see correct POT Examiner's Comments Candidates were able to use the formula for a volume of a sphere and rearrange the equation for density. Some candidates were confused with the power of tens. Again, clear working was needed for the award of both marks.
		ii i	$1000 \times 1.15 \times 10^{-5} \times 9.81 = 0.11 \text{ N}$ OR $0.0075 \times 9.81 = 0.074 \text{ N}$ $F = 0.11 - 0.074 = 0.037 \text{ (N)}$ OR $9.81 (1000 - 650)$ or $1.15 \times 10^{-5} \times (1000 - 650)$ $F = 1.15 \times 10^{-5} \times 9.81 (1000 - 650)$ $= 0.039 \text{ (N)}$	C1 A1 C1 A1	Allow use of $7.47 \times 10^{-3} \text{ kg}$ from a ii Allow ecf from a ii Examiner's Comments Candidates found this question difficult. Many candidates gained one mark either for determining the weight of the sphere or for determining the upthrust correctly. Few candidates realised they needed to find the difference between the upthrust and the weight of the sphere.
			Total	12	
4 2	a	i	vertical component $= 30.0 \sin(70^\circ)$ or $30.0 \cos(20^\circ)$ vertical component $= 28.2 \text{ (m s}^{-1}\text{)}$	A1	Allow 2 SF answer of 28
		ii	Evidence of $v^2 = u^2 + 2as$ and $v = 0$ or $gh = \frac{1}{2} u^2$ $h = \frac{28.2^2}{2 \times 9.81}$ (Any subject)	C1 M1 A0	Allow v and u interchanged; a and g interchanged Allow use of candidate's answer for (a)(i) at this point Ignore sign Allow $h = \frac{28^2}{2 \times 9.81}$ or $(30 \sin(70)) / (2 \times 9.81)$ No ECF from (a)(i) for the second mark

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			$h = 40.5 \text{ (m)}$		
		ii i	The ball has horizontal motion / velocity (AW)	B1	Allow idea of horizontal e.g. sideways, forwards Not: 'moving' unqualified
		i v	(horizontal velocity =) $30.0 \cos 70^\circ$ or $10.2 \dots \text{ (m s}^{-1}\text{)}$ or $30.0 \sin 20^\circ$. $E_k = \frac{1}{2} \times 0.057 \times 10.26^2$ $E_k = 3.0 \text{ (J)}$	C1 A1	Allow 1 SF answer Not 22 (J), $v = 28$ used Not 23 (J), $v = 28.2$ used Not 140 (J), $v = 70$ used <u>Examiner's Comments</u> Part (i) was particularly well answered by 95% of all candidates. Nine out of ten candidates scored full marks in part (a)(ii), as they remembered that the question asks to <i>show</i> that the maximum height is around 40m. Working for this type of question is essential. In part (a)(iii), three quarters of all candidates correctly talked about the ball still having a horizontal velocity (which wasn't zero) and therefore still possessing some KE. The key to this part (a)(iv), remembered by most candidates, was to use the horizontal component of velocity to find the KE at the maximum height. Some used the initial speed and others used the initial vertical velocity component found in part (a)(i).
		b	Level 3 (5–6 marks) Clear description and analysis. <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3–4 marks) Some description and some analysis. <i>There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.</i> Level 1 (1–2 marks) Limited description and limited analysis or limited description	B1 x 6	Indicative scientific points may include: Description • Ruler used to determine x • Average readings to determine x • x recorded for various v • Suitable method for consistent v or varying v e.g. • Released from same point on a track • Ejected from a spring device with different compressions • Suitable method of determining point of impact e.g. • trial run to get eye in approximate correct position • carbon paper so that ball makes a mark on paper • scale in frame of video recording • tray of sand to catch ball • Suitable instrument used to determine v (light-gate / motion sensor / video techniques) or suitable description of inference of v from other measurements such as energy released from spring of known k and x • Ensuring the initial velocity of ball is horizontal

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			or limited analysis <i>There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.</i> 0 marks No response (NR) or no response worthy of credit (0).	Analysis • Horizontal velocity is constant • Time of fall is independent of v/horizontal velocity • Suggested relationship: e.g. $x \propto v$, x d.p. to V^2, etc • Plot a graph of x against v or graph consistent with candidate's suggested relationship • If relationship is correct, then a straight line through the origin. • Suggested relationship supported by correct physics or algebra. • Correct relationship supported by physics. Note: L1 is used to show 2 marks awarded and L1^ is used to show 1 mark awarded. <u>Examiner's Comments</u> Many candidates had plenty to say that was sensible. There was plenty of evidence that candidates had seen this experiment or had performed a similar one themselves. A few confused the question, instead describing how to find the time of flight or that the ball was falling vertically. Others described what they thought would happen to the vertical component of velocity when they changed the vertical distance that the ball dropped. Exemplar 2
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Use your knowledge of projectile motion to suggest the relationship between v and x . How can an experiment be safely conducted to test this relationship and how is the data analysed?

As in a projectile the horizontal velocity is constant given a is negligible then an equation of x could become $x = vt$ where x is a travelled v is velocity of ball and t is time of flight. Therefore for a constant time of flight it can be said $x \propto t$. To test this it is very hard to have a time of flight constant as this is to its time of freefall. To test this a ball would be on a table at varying speeds calculate this speed a light gate can be used passing through the center of the metal ball. As distance travelled is equal to the diameter of ball, measured by a ruler, speed can be calculated using distance/time. A light gate for safety the ball land in sand as not to shatter land on someone's foot. This also makes measuring x much easier as x is equal to the horizontal distance from edge of the table to the center of sand measured using a ruler. If t is taken to fall is kept constant by using a stop watch and x is by raising or lowering the light gate when v is plotted against x on a graph it can be seen to be linear and pass through the origin.

In the first paragraph, the candidate has made clear that the time of flight is constant and goes on to explain why. Towards the end of the response, this supports the prediction that $v \propto x$. In addition, the candidate takes time to explain how to obtain data for both the horizontal velocity and horizontal distance. It was pleasing to see light gates and motion sensors being employed, with the best answers explaining how to use the data provided by the sensors to

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					calculate the velocity of projection. The exemplar response also includes the correct analysis. There is a graph of v against x and the resulting best fit straight line through the origin supports the idea that these two variables are directly proportional. Too many candidates did not mention the crucial statement about the line going through the origin, limiting their response to a high L1 or low L2.
			Total	12	
4 3			*Level 3 (5–6 marks) Clear explanation and discussion <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3–4 marks) Some explanation and some discussion <i>There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.</i> Level 1 (1–2 marks) Limited explanation or limited discussion <i>The information is basic and communicated in an unstructured way. The information is supported by limited evidence and the relationship to the evidence may not be clear.</i> 0 marks No response or no response worthy of credit.	B1 × 6	Indicative scientific points may include: Explanation $hf = \Phi + KE_{\max}$ (any subject) - A graph of $KE_{\max}$ against f is a straight line graph with gradient = h (and intercept = $-\Phi$) - Draw a straight best-fit line through points and determine the gradient using a 'large triangle' Discussion of accuracy and precision % uncertainties are 4.8% for A and 9.1% for B - Data points widely spread out for B. (ORA) - For B the value of h is accurate because its closer to the real / actual value (but the results are not precise) - For A the value of h is precise because of the smaller % uncertainty (but the result is not accurate)
			Total	6	
4 4	a		Level 3 (5-6 marks) Clear evaluation of Fig. 22.1 and clear analysis <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is</i>	B1× 6	Use level of response annotations in RM Assessor, e.g. L2 for 4 marks, L2* for 3 marks, etc. Ignore incorrect references to the terms precision and accuracy Indicative scientific points may include: Evaluation of Fig. 22.1 - Comment on the line - The straight line misses one error bar / anomalous point ringed or indicated - Too few data points plotted - The triangle used to calculate the gradient is (too) small

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		<i>relevant and substantiated.</i> Level 2 (3-4 marks) Some evaluation of Fig. 22.1 and some analysis <i>There is a line of reasoning presented with some structure.</i> <i>The information presented is in the most part relevant and supported by some evidence.</i> Level 1 (1-2 marks) Limited evaluation of Fig. 22.1 or limited analysis <i>There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.</i> 0 marks <i>No response or no response worthy of credit.</i>	- Some plots should have been repeated / checked - No error bars for current 'Not regular intervals' (for current) - No origin shown (AW) Evaluation of analysis - The value of B is close to the accepted value - The difference of only 7% - No absolute or percentage uncertainty in B shown (AW) - Worst-fit line or maximum / minimum gradient line could have been used to determine the (absolute or percentage) uncertainty in B F against I graph should be a straight line or BL = gradient (any subject) Examiner's Comment This was the second level of response (LoR) question in the paper. It required evaluation of a graph drawn by a student and the analysis shown in the box on page 24. Most candidates realised that the graph had few data points, the triangle used for the gradient was too small and the line drawn totally missed one of the error bars. The analysis shown by the candidate did not include an absolute uncertainty in B, which made the statement written by the student lack credibility. Many candidates wrote about drawing doing a line of worst-fit and determining the percentage uncertainty. This was only possible if there were more data points and the error bars for the F values reduced by perhaps repeating the measurements. Once again, there was a good spread of marks amongst the three levels.
b	i	There is a changing / fluctuating (magnetic) field / flux (linkage) (magnetic) field / flux (linkage) in <u>core</u> and <u>secondary</u> (coil) Statement of Faraday's law: e.m.f. (induced) $\propto$ <u>rate</u> of change of (magnetic) flux <u>linkage</u>	Note: This changing flux can be anywhere Allow 'the direction of the field oscillates' Allow 'the core helps to link the flux to the secondary coil' M1 Allow 'equal to / =' Ignore 'cutting of flux' Not just $E = (-)\Delta(N\phi)/\Delta t$ A1 Examiner's Comment The topic electromagnetic induction always challenges candidates. Successful responses often showed correct use of technical terms such as <i>magnetic flux</i> or <i>flux linkage</i>. Most candidates scored a mark for correctly stating Faraday's law of electromagnetic induction. Many realised that an alternating current produced an alternating magnetic flux within the iron core and this change in flux produced an e.m.f. at the secondary coil. One of the popular misconceptions was that there was an alternating current (or induced e.m.f.) within the iron-core. A small number of candidates referred to electromagnetic field in their descriptions rather than magnetic field. B1

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			1 ($I_s =$) 24/12 or 2.0 (A) ($I_p =$) $\frac{20}{400} \times 2.0$ (current in primary =) 0.10 (A) or ($V_p =$) 12 $\times$ 20 or 240 (V) ii ($I_p =$) $\frac{24}{240}$ (current in primary =) 0.10 (A) 2 Idea of changing / increasing (magnetic) field / flux / current (in primary) at the start Eventually current and flux (linkage) are constant, therefore no e.m.f.	C1 A1 C1 A1 B1 B1	Allow 1 sf answer Allow 1 sf answer Note: Any labels used must be clearly defined Examiner's Comment This question on current in the primary coil was successfully answered by most candidates. The most favourable method was to calculate the current in the secondary and then the current in the primary coil. The turn-ratio equation and $P = VI$ were effortlessly used to arrive at the correct answer of 0.10 A. Full marks were rarely scored but many top-end candidates did manage to score a mark for suggesting that the lamp was lit for a short period of time at the start because '<i>there was a changing magnetic flux as the current increased from zero to a steady value</i>'. Too many answers focussed on the requirement of an alternating supply for an induced e.m.f. in the secondary coil and how a battery is not an alternating supply.
			Total	13	
4 5		i	A = $470/8.8 \times 10^{-13} = 5.3 \times 10^{14}$ (Bq) $\lambda = \ln 2/(88 \times 3.16 \times 10^7)$ (= 2.5×10^{-10} s⁻¹) ($A = \lambda N$); N (= $5.3 \times 10^{14} / 2.5 \times 10^{-10}$) = 2.1×10^{24}	C1 C1 A1	Mark is for correct calculation of A (in Bq or decays per s) Mark is for correct working to give λ in s⁻¹
		ii	$P = P_0 \exp(-\lambda t)$ $P = 470 \exp(-\ln 2 \times 100 / 88)$ $P = 210$ (W)	C1 C1 A1	Allow formula in terms of N or A Allow calculation in terms of N or A; allow ECF for N or A
			Total	6	
4 6	a	i	At point P: path difference between slits and screen is a whole / integer number of <u>wavelengths</u> (for constructive interference)	B1	Allow $n\lambda$ or λ Not phase difference Allow $(n + \frac{1}{2})\lambda$

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			At point Q: path difference between slits and screen is an <u>odd number of half wavelengths</u> (for destructive interference)	B1	Not $\lambda/2$ Examiner's Comments It was expected that candidates would describe the path difference in terms of the wavelength. Candidates often realised that the bright line would have a path difference of an integer number of wavelengths, this was often written as $n\lambda$. To explain the dark line many candidates struggled with the appropriate relationship in terms of λ or did not state an odd number of half wavelengths.
		ii	$x = 4.22 \text{ mm}$ 1 $\lambda = \frac{4.22 \times 10^{-3} \times 0.56 \times 10^{-3}}{5.25 \times 10^{-7} \text{ m}}$ $\frac{0.02}{4.5} \quad \text{or} \quad \frac{0.02}{0.56} \quad \text{or} \quad \frac{0.2}{42.2}$ $\left(\frac{0.02}{4.5} + \frac{0.02}{0.56} + \frac{0.2}{42.2} \right) \times 100 = 4.48 \%$ Alternative max / min method: 2 $\lambda_{\text{max}} = \frac{4.24 \times 10^{-3} \times 0.58 \times 10^{-3}}{4.48} = 5.49 \times$ and/or $\lambda_{\text{min}} = \frac{4.20 \times 10^{-3} \times 0.54 \times 10^{-3}}{4.52} = 5.02 \times$ $\frac{\Delta\lambda}{\lambda} \times 100 = 4.4\% \text{ or } 4.6\%$	C1 C1 A1 C1 A1 B1 B1	Note $x = 42.2 \text{ mm}$ or $4.2 \times 10^{-2} \text{ m}$ scores zero Note $x = 3.84, 4.77 \times 10^{-7} \text{ m}$ may score max 2 Allow 4% or 5% with evidence of working Ignore significant figures Examiner's Comments Although candidates correctly identified the correct equation, a large number of candidates did not determine the fringe spacing correctly. Some candidates used 42.2 cm, others divided 42.2 cm by 11, 15 or 20. Furthermore, some candidates did not convert the slit separation from millimetres to metres. Candidates were able to identify the equation from the Data, Formulae and Relationships Booklet. Most candidates were able to determine at least one percentage uncertainty for the individual quantities correctly. Mistakes were made either on determining the other quantities or adding the percentage uncertainties. Some candidates attempted a maximum / minimum method – the common error with this method was not dividing maximum by minimum or minimum by maximum.
	b	i	$\frac{6.63 \times 10^{-34} \times 3 \times 10^8}{5.25 \times 10^{-7}} = \frac{1.989 \times 10^{-25}}{5 \text{ b ii 1}} = 3.79 \times 10^{-19}$ $n = \frac{50 \times 10^{-3}}{3.79 \times 10^{-19}} = 2.5 \times 10^{23} \times 5 \text{ b ii 1} = 1.3 \times 10^{24}$	C1 A1	Allow ecf from bii Examiner's Comments Candidates found this question difficult. Many could not determine the energy of a photon correctly – an error carried forward was allowed from 5(b)(ii)1. The question also required candidates to realise that 50.0 mW is equivalent to 50.0 mJ s⁻¹. A common error was to divide the power by the charge on an electron.
		ii	2.6 eV = $2.6 \times 1.6 \times 10^{-19} = 4.16 \times 10^{-19} \text{ J}$ ORA	M1	Allow photon has 2.37 eV of energy

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			Energy of photon is less than work function so photoelectrons will not be emitted	A1	Allow conclusion based 5 c i Examiner's Comments To explain whether photoelectrons will be emitted, candidates needed to convert the work function measured in electron volt to joule. A clear conclusion was needed.
			Total	11	
4 7	a		$3.6 \pm 0.4 \text{ (m}^2 \text{ s}^{-2}\text{)}$	B1	
	b	i	Data point and error bar correctly plotted	B1	Allow ecf from previous part.
		ii	* Level 3 (5–6 marks) Detailed analysis of the graph clearly linked to the principle of conservation of energy, including determination of the value of g and the related uncertainty in the answer. <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3–4 marks) Analysis of the graph linked to kinetic energy and / or potential energy, with an attempt to find the value of g. Mention of where one would find uncertainties in the answer but without analysis. <i>There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.</i> Level 1 (1–2 marks) Line of best fit drawn and gradient attempted. Mention of energy and / or where uncertainties may occur. <i>The information is basic and communicated in an unstructured way. The information is supported by limited evidence and the relationship to the evidence may not be clear.</i> 0 marks No response or no response worthy of credit.	B1 × 6	Explanation - Principle of conservation of energy used to derive relationship. $mgh = \frac{1}{2}mv^2$ or $v^2 = 2gh$ - A graph of v^2 against h will be a straight line (through the origin). - Gradient of line = $2g$. Determination - Line of best fit drawn through all data points. - Gradient in the range 17 to 21 ($\text{m}^2 \text{ s}^{-2}$). g determined correctly from the gradient. Uncertainty - Worst line of fit drawn. - Correct attempt to determine the uncertainty.
			Total	8	
4 8	a	i	0.22 and 0.26	B1	

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		i	correct plotting of points on Fig. 2.2	B1	tolerance on each point ± 0.5 small scale division
		i	sensible line not through origin	B1	expect x-intercept at about 0.02
		ii	triangle with base at least half width of graph	B1	must have appropriate triangle on Fig. 2.2 or two sets of data lying on the line clearly shown
		ii	expected gradient close to 5	B1	ecf line; typical values $(1.4 - 0)/(0.30 - 0.02)$
	b	i	All points lie below the theoretical line	B1	accept quantitative answers e.g. error in s is half a square
		i	the error bars on each reading are not long enough to allow a worst line through the origin / AW	B1	and in t^2 is 3 to 4% as several readings averaged 2 marks for two valid points
		ii	s is too small	B1	Or s should be larger
		ii	same shift in all values so no change to gradient	B1	
		ii	t is too big	B1	
		ii	constant error in t leads to increasing error in t^2 so gradient is changed / steeper	B1	
		ii	sensible reason for t being too large	B1	e.g. electromagnet does not release instantaneously, trapdoor is stiff, faulty contacts, etc
		i	or s too small		e.g. scale on ruler does not start at the end / AW
			Total	12	
4 9		i	Straight-line of best fit drawn gradient = 170 (Hz m)	B1 B1	Allow value in range 160.0 to 180.0 <u>Examiner's Comments</u> The straight-lines of best fit were generally acceptable. A small number of candidates drew the lines using very thick or indistinct pencil leads. Large triangles were often used to determine the gradient of the lines. Only a very small number of candidates, mainly at the lower quartile, made errors with powers of ten and got an answer of 0.17 instead of 170.
		ii	$v = f\lambda$ or $\lambda = 2L$ or $v = 2fL$ (Any subject) Clear steps leading to gradient $= \frac{v}{2}$ using $y = mx$	C1 A1	Allow separation between adjacent nodes $= \frac{\lambda}{2}$ Allow gradient $= f \div (\lambda/2)^{-1} = f\lambda/2 = v/2$ <u>Examiner's Comments</u> Most candidates scored 1 mark for either quoting the wave equation $v = f\lambda$ or the wavelength being twice inter-nodal distance L. The analysis leading to the gradient $= v/2$ proved to be quite demanding for most of the candidates. The most frequent incorrect reasoning was that speed v was divided by 2 because the sound waves are reflected from the wall, and they had to travel twice the

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					distance there and back. Only the most able of the candidates scored full marks.
		ii i	$v = 2 \times 170$ $v = 340 \text{ (m s}^{-1}\text{)}$	B1	Possible ECF from (b)(i) Examiner's Comments Almost all candidates picked up 1 mark for multiplying their answer from (b)(i) by 2. This included those who also got an answer such as 0.17 in (b)(i). Error carried forward (ECF) rules were applied even when the speed of sound looked unrealistic.
			Decrease frequency / f (ORA) L / λ increases (so, smaller % uncertainty) (ORA) or i v Measure distance between several nodes / antinodes Distance measured is larger (so, smaller % uncertainty) or Use a small(er) microphone Easier to locate position of node / antinode (so, smaller % uncertainty)	M1 A1 M1 A1 M1 A1	Allow other sensible suggestions Allow increase wavelength / λ (ORA) Allow L increases (so, smaller % uncertainty) (ORA) Allow reduce reflection of sound (other than from the wall) Examiner's Comments This was a low-scoring question, with many candidates focussing on averaging results. Only a small number of candidates appreciated that lower frequency would give longer inter-nodal distance L, and this resulted in smaller percentage uncertainty.
			Total	7	
5 0		i	$(F = ma =) 190 \times 10^3 = 2.1 \times 10^5 \text{ a}$ $a = 0.90 \text{ (m s}^{-2}\text{)}$	M1 A0	$a = 0.905$ to 3 SF
		ii	$(v^2 = u^2 + 2as \text{ gives}) 36 = 2 \times 0.90 \times s$ $s = 20 \text{ (m)}$	C1 A1	Allow any valid suvat approach; allow ECF from (i) Note using $a = 1$ gives $s = 18\text{(m)}$
		1 ii i	$P = Fv$ One correct calculation e.g. $F = 100 \times 10^3$ and $v = 42$ gives $P = 4.2 \times 10^6 \text{ (W)}$ $Fv = \text{constant}$ 2 $(P = VI = 4.2\text{MW so}) 4.2 \times 10^6 = 25 \times 10^3 \times I$ $I = 170 \text{ (A)}$	B1 B1 B1 C1 A1	Equation must be seen (not inferred from working) Allow any corresponding values of F and v; working must be shown. No credit for finding area below curve Allow F is proportional to $1/v$ or graph is hyperbolic or correct calculation of Fv at <u>two</u> points (or more) Allow $P = 4\text{MW}$ or ECF from (iii)1 Expect answers between 160 - 170 (A)

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			Total	8	
5 1	a		Any <u>one</u> from: current, temperature, light intensity and amount of substance / matter	B1	Not: ampere, kelvin, candela and mole Not correct quantity with its unit, e.g. current in A or current (A) Examiner's Comment Most candidates could not state an unambiguous base quantity. There was no credit for a correctly named quantity accompanied by its S.I. unit, e.g. '<i>current in ampere</i>'. Some answers were just wrong; these include <i>force</i>, <i>charge</i>, <i>energy</i> and <i>kelvin</i>.
	b	i	$R = \frac{\rho L}{A} \quad \text{and} \quad A = \pi \left(\frac{d}{2} \right)^2$ $R_x = \frac{4\rho L}{\pi d^2} \quad \text{and} \quad R_y = \frac{8\rho L}{\pi d^2}$ $R = \frac{12\rho L}{\pi d^2}$ Clear steps leading to	M1 A1	Examiner's Comment Most candidates were familiar with the equations $R = \rho L / A$ and $A = \pi d^2 / 4$. The modal score here was two marks. Most scripts had well-structured answers and demonstrated excellent algebraic skills. A variety of techniques were employed to determine the total resistance of the two resistors in series.
		ii	1 Ruler / tape measure (for L) and micrometer (for d) $R = 2.3(4) (\Omega)$ $\frac{0.1}{9.5} \quad \text{or} \quad 2 \times \frac{0.003}{0.270}$ 2 $\frac{0.1}{9.5} + 2 \times \frac{0.003}{0.270}$ or 0.0327 or 3.27% absolute uncertainty in $R = 0.0327 \times 2.34 = 0.077$ $R = 2.3 \pm 0.1 (\Omega)$ 3 (The actual) R is large(r) because (the actual) d is small(er) or (the actual) A is small(er) or $R \propto 1/d^2$	B1 C1 C1 C1 A1 B1	Allow (vernier / digital) calipers or travelling microscope for micrometer Allow other correct methods for getting $2.3 \pm 0.1 (\Omega)$ Allow 2 or more sf for this C1 mark Note 0.0105 or 1.05% or 0.0222 or 2.22% scores this mark, allow 2sf or more Allow: $2.34 \pm 0.08 (\Omega)$ Note use of R_x or R_y instead of R can score the second and third C1 marks only Allow: The calculated R is small(er) because (the measured) A is large(r) or $R \propto 1/d^2$ Examiner's Comment Almost all candidates correctly identified the measuring instrument for L and d. Some answers were spoilt by mentioning both a ruler and a micrometer for measuring the length of the wire. This question produced a range of marks and discriminated well. According to the data shown in the table on page 13, the final value for the resistance R had to be given to 2 significant figures (SF), but an answer to 3 SF was also allowed. Top-end candidates produced flawless answers and quoted R as either $2.3 \pm 0.1 \Omega$ or $2.34 \pm 0.08 \Omega$. Some candidates successfully calculated the maximum and the

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					minimum values for R and then the absolute uncertainty from half the range. The most common mistakes being made were: - Omitting the factor of 2 when determining the percentage uncertainty in d^2. - Calculating the resistance of either resistor X or resistor Y. - Inconsistency between R and its absolute uncertainty, e.g. $R = 2.3 \pm 0.077 \Omega$. Some candidates realised that the actual value of R would be '<i>larger because d was smaller or $R \propto 1/d^2$</i>'. On most scripts, it was difficult to follow if the resistance was the actual one or the calculated one.
			Total	9	
5		i	1 A straight line of best-fit drawn passing through all error bars.	B1	
2		i	2 $V = V_0 e^{-t/CR}$, therefore $\frac{1}{2} = e^{-T/CR}$	M1	
		i	$\ln(0.5) = -T/CR$	M1	
		i	$T = -\ln(0.5)CR$	A0	
		i	3 gradient = $(-) \ln(0.5)C$	C1	
		i	gradient determined using a 'large triangle' and equal to $(-) 7.7 \times 10^{-4} \text{ (s } \Omega^{-1})$	C1	Allow gradient in the range 7.5 to 8.0×10^{-4}
		i	$C = \text{gradient}/\ln(0.5) = (-) 7.7 \times 10^{-4}/\ln(0.5)$ $C = 1.1 \times 10^{-3} \text{ (F)}$	A1	Possible ECF from value of gradient
		ii	Draw a worst-fit straight line through the error bars.	M1	
		ii	Correct description of how to determine the % uncertainty in C .	A1	Allow: $\frac{\text{difference between worst and best - fit gradients}}{\text{value of best gradient from (i)3}} \times 100$
			Total	8	
5		i	Line of best fit drawn	B1	Expect the extrapolated line to have a y-intercept in the range 0.60 to 0.85 and at least one data point on each side of the line Allow gradient of line in the range 2.60 to 3.00 Examiner's Comments
3			gradient = 2.8	B1	In (c)(i), the lines of best fit were generally very good, as were the gradient calculations with most candidates getting values in the range 2.60 to 3.00. Only a small number of candidates calculated the inverse of the gradient.

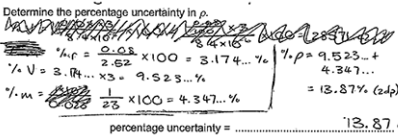
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			$E = I(r + R)$ and $R = \rho L/A$ ii $\frac{1}{I} = \frac{r}{E} + \frac{\rho}{AE}L$ (and comparison with $y = mx + c$ leads to gradient $\frac{\rho}{AE}$)	C1 A1	Allow $E = V + IR$ and $R = \rho L/A$ Examiner's Comments Most candidates struggled with (c)(ii). Less than 1 in 10 candidates successfully used the equations $E = V + Ir$ and $R = \frac{\rho L}{A}$ to derive the expression $\frac{1}{I} = \frac{\rho}{AE}L + \frac{r}{E}$, and then identified the gradient as $\frac{\rho}{AE}$ by comparison with the equation for a straight-line $y = mx + c$.
			($\rho = \text{gradient} \times AE$) ii $\rho = 2.8 \times \pi \times (0.19 \times 10^{-3})^2 \times 1.5$ i $\rho = 4.8 \times 10^{-7} (\Omega \text{ m})$	C1 A1	Possible ECF from (i) Note not using $A = \pi r^2$ is wrong physics (XP) Allow 1 mark for 1.9×10^{-6}, diameter used instead of radius Examiner's Comments Most candidates in (c)(iii) did exceptionally well to calculate the resistivity using the equation for the gradient. Calculations were generally well-structured, and the final answer showed good use of powers of ten and significant figures.
			The graph / points just shift horizontally (AW) i v The gradient is unchanged (and ρ will be the same)	B1 B1	Allow shifted to the right or left / 'systematic error' / zero error / change in length stays the same / 'no change in vertical values' Examiner's Comments Finally, (c)(iv) provided good discrimination with many of the top end candidates realising the gradient of the line was unaffected, the line was just shifted horizontally. 'Systematic error' and 'zero error' were allowed as alternative answers for the horizontal translation of the line.  Misconception There were some missed opportunities, with some candidates making the following mistakes. - In (c)(ii), ignoring the internal resistance r of the cell shown in the circuit of Fig. 18.1 to get the wrong expression $\frac{1}{I} = \frac{\rho}{AE}L$ - In (c)(iii), a small number of candidates either used 0.38 mm as the radius of the wire to get a resistivity of $1.9 \times 10^{-6} \Omega \text{ m}$ or forgot to convert the millimetres into metres to get a value of $0.48 \Omega \text{ m}$. - In (c)(iv), a significant number of low-end candidates, mentioned that resistivity of the wire did not depend on its physical dimensions, and therefore the resistivity value

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					calculated will be the same. There was no reasoning in terms of gradient = $\frac{\rho}{AE}$
			Total	8	
5 4	a	i	(Vernier) Calliper or micrometer (screw gauge)	B1	Not rule(r) <u>Examiner's Comments</u> This question was well answered with most candidates stating either Vernier calliper or a micrometer screw gauge.
		ii	2.52 ± 0.08	B1 B1	Allow (2.52-2.43 =) 0.09 or (2.59-2.52 =) 0.07 <u>Examiner's Comments</u> Most candidates correctly calculated the mean diameter of the ball. A much smaller proportion of the candidates determined the absolute uncertainty in the diameter correctly. In this case, the range was 0.16 cm, so the absolute uncertainty was 0.08 cm. Examiners allowed the maximum value minus average value or average value minus minimum value.  AfL When measurements are repeated the absolute uncertainty is given by: Absolute uncertainty = $\frac{1}{2} \times \text{range} = \frac{1}{2} \times (\text{maximum value} - \text{minimum value})$
		ii i	Volume = $\frac{4}{3} \times \pi \times (1.26 \times 10^{-2})^3$ = 8.379×10^{-6} $8.4 \times 10^{-6} \text{ m}^3$	M1 A0	$\frac{1}{6} \times \pi \times (2.52 \times 10^{-2})^3$ or $\frac{4}{3} \times \pi \times \left(\frac{2.52 \times 10^{-2}}{2}\right)^3$ <u>Examiner's Comments</u> This was another "show" question. Many candidates find dealing with standard form terms in their calculator difficult. Candidates needed to show clearly the conversion of the diameter in cm to radius in m. There was some evidence of candidate just adding a 10^{-6} power to their answer.
		i v	$\frac{0.023}{8.4 \times 10^{-6}}$ or 2738 2700 (kg m⁻³) or 2.7×10^3 (kg m⁻³)	C1 A1	Note 2745 if using calculator value from (iii) Note must be two significant figures Allow one mark for 2.7×10^6 (kg m⁻³)

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				Examiner's Comments In this question, most candidates were able to determine the density correctly although, a few candidates did not change the mass in gram to kilogram. A large number of candidates did not give their answer to an appropriate number of significant figures; the common answer being 2738 kg m⁻³. In this case, the mass was given to two significant figures and the volume was calculated from data give to three significant figures, thus the final answer should be given to the same number of significant figures as the least significant data, i.e. to two significant figures.
		v $\frac{1}{23}$ or $\frac{0.08}{2.52}$ or $\frac{0.24}{2.52}$ or 4.3% or 3.2% or 9.5% 14% (13.8%)	C1 A1	Allow ECF from (ii) – 3.6% or 10.7% for $\Delta d = 0.09$ Allow maximum/minimum methods Note 13% for $\Delta d = 0.07$ or 15% for $\Delta d = 0.09$ [ECF 5.5% for $\Delta d = 0.01$] Examiner's Comments The majority of candidates were able to determine the percentage uncertainty in the mass correctly. Fewer candidates realised that the percentage uncertainty in the volume was three times the percentage uncertainty in the diameter. Candidates who did well, clearly showed their working. Some candidates tried to use a maximum/minimum method. This was a more complex method and more difficult for candidates to gain the correct answer. In this case, the maximum mass needed to be divided by the minimum volume or the minimum mass needed to be divided by the maximum volume  AfL How to use percentage uncertainties. Exemplar 5 (v) Determine the percentage uncertainty in ρ.  The candidate's answer is logically structured showing the percentage uncertainty in the mass and volume and then adding them together so gaining both marks. An answer of 14% would have been acceptable.
b		Extension = 0.096 – 0.078 or 0.018 m	C1	

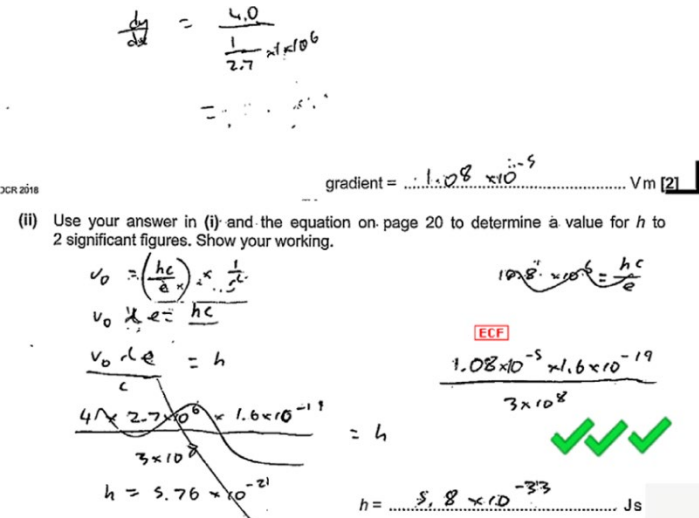
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			Weight = 0.023×9.81 or 0.22563 $13 \text{ (N m}^{-1}\text{)}$	C1 A1	Allow ECF for incorrect mass conversion from (iv) Allow $12.6 \text{ (N m}^{-1}\text{)}$ or $12.5 \text{ (N m}^{-1}\text{)}$ <u>Examiner's Comments</u> The majority of the candidates clearly showed their working and calculated the force constant correctly. Some incorrectly used the energy stored equation.
	c	i	Apparent weight = 0.01×13 (= 0.13 N) (Upthrust = $0.226 - 0.13$) = 0.10 (N)	C1 A1	Allow ECF from (b) Allow 0.008×12.5 Allow 0.1 (N) (1sf) <u>Examiner's Comments</u> In this question, many candidates calculated the apparent weight and then incorrectly assumed that this was the upthrust. Other errors included using the incorrect values for length to determine the extension. Some candidates correctly determined the upthrust by determining the change in extension.
		ii	$\rho = \frac{0.10}{9.81 \times 8.4 \times 10^{-6}}$ $1200 \text{ (kg m}^{-3}\text{)}$	C1 A1	Allow ECF from (i) <u>Examiner's Comments</u> Candidates generally found this last question challenging. Some candidates who did less well, attempted to use the equation for liquid pressure. Candidates who did well again clearly showed their reasoning.
			Total	15	
5 5		i	$Vq = \frac{1}{2}mv^2$ and $\lambda = \frac{h}{mv}$ Clear algebra leading to $\lambda^2 = \frac{h^2}{2mq} \times \frac{1}{V}$	M1 A1	Allow p for mv Allow e for q in (b)(i) – this is to be treated as a 'slip'
		ii	(% uncertainty in λ^2 =) 10% 1 (% uncertainty in λ =) 5% Straight line of best fit passes through all error bars 2 gradient = 1.0×10^{-22} $\frac{h^2}{2mq} =$ gradient 3 $\frac{(6.63 \times 10^{-34})^2}{2 \times m \times 3.2 \times 10^{-19}} =$ gradient	C1 A1 B1 C1 C1	Note 10 (%) on answer line will score the C1 mark Ignore POT for this mark; Allow $\pm 0.20 \times 10^{-22}$

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			$m = 6.9 \times 10^{-27}$ (kg) (hence about 10^{-26} kg)	C1 A1	Possible ECF for incorrect value of gradient Note check for AE (condone rounding error here) and answer must be about 10^{-26} (kg) for any incorrect gradient value for this A1 mark Special case: 1.37×10^{-26} kg scores 3 marks for $q = 1.6 \times 10^{-19}$ C because answer is about 10^{-26} kg
			Total	9	
5 6		i	A straight line with non-zero V_0 intercept gradient = 1.3×10^{-6}	B1 B1	Ignore spread of data points on either side of the line Allow Intercept > 0 and < 1.0 V Allow $(1.10 \text{ to } 1.60) \times 10^{-6}$; no need to check calculation <u>Examiner's Comments</u> Most candidates scored either 1 or 2 marks. The straight lines of best fit were generally well drawn. A significant number of the candidates forced their lines to go through the origin. The tolerance for the value of the gradient was deliberately made large. The ultimate penalty was the power of ten. Very few made two errors here – straight line through the origin and missing 10^{-6} factor.
		ii	gradient = $\frac{hc}{e}$ (Any subject) $h = \frac{1.3 \times 10^{-6} \times 1.60 \times 10^{-19}}{3.00 \times 10^8}$ (Any subject) $h = 6.9 \times 10^{-34}$ (J s)	C1 C1 A1	Possible ECF from (i) Note the answer must be given 2 SF only <u>Examiner's Comments</u> This was not an easy question, but a good number of candidates did exceptionally well on this practical-style question. The first mark was for correctly identifying 'gradient = hc/e', and subsequent marks were for correct substitution and writing the final to 2 significant figures (SF). A significant number of candidates quoted their correct h value to more than the required SF. Many candidates were scoring full marks through the error carried forward rule. Exemplar 9

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				 gradient = 1.08×10^{-5} Vm [2] (ii) Use your answer in (i) and the equation on page 20 to determine a value for h to 2 significant figures. Show your working. $E_0 = \frac{hc}{\lambda}$ $h = \frac{E_0 \lambda}{c}$ $h = \frac{4.7 \times 10^{-19} \times 1.6 \times 10^{-11}}{3 \times 10^8}$ $h = 5.76 \times 10^{-21} \text{ Js}$ ECF
		difference = $\frac{6.9 \times 10^{-34} - 6.6(3) \times 10^{-34}}{6.6(3) \times 10^{-34}} \times 100 \%$ difference = 4.1 %	Possible ECF from (ii) Ignore sign Not division by value from (ii) Allow 1 SF answer	B1
	i v	Random (error) / data points are spread about line Systematic (error) / line does not pass through origin Take (many) repeat readings (of V_0) and average Conduct the experiment in a darkroom / use (black) tube over the LED to view when it is lit / use a (digital) voltmeter with no zero error	B1 B1 B1 B1 Allow other sensible suggestion Not faulty voltmeter Examiner's Comments The two errors in this experiment were <i>systematic</i> and <i>random</i> errors (see learning outcome 2.2.1a in the H556 specification). Many candidates did not name these two errors, instead focussing	B1

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					on nebulous terms such as <i>human error</i>, <i>equipment error</i>, etc. Appropriate descriptions of these two errors were allowed. Only a small number of candidates appreciated that taking multiple readings of V_0 and averaging will lead to reduction in the random error. A pleasing number of candidates realised that the main reason for the non-zero intercept (systematic error) was the ambient light and switching off the lights would improve matters. Sorting out the zero-error on the voltmeter was an acceptable alternative. Descriptions about using 'precise instruments' for measuring potential difference or light intensity often led to no credit.
			Total	10	
5 7	a	i	Missing data point and error bar plotted correctly.	B1	Allow $\frac{1}{2}$ square tolerance.
		ii	Force measured by pulling back plate with a newton-meter.	B1	
		ii	Extension measured with a ruler (placed close to the transparent plastic tube).	B1	
		ii i	Best fit line drawn correctly and gradient determined correctly.	B1	Ignore POT for this mark; gradient = 50 ± 4 (N m ⁻¹)
		ii i	Worst fit line drawn correctly and its gradient determined correctly.	B1	Note: The line must have a greater/smaller gradient than the best fit line and must pass through all the error bars. Ignore POT for this mark.
		ii i	$2k = 50$ (N m ⁻¹), therefore $k = 25$ (N m ⁻¹)	B1	Possible ECF.
		ii i	Absolute uncertainty determined correctly.	B1	Possible ECF within calculation.
		i v	$F \propto x$ / straight line passing through the origin.	B1	
		v	energy stored = $\frac{1}{2} \times 50 \times 0.12^2$	C1	Possible ECF from (iii)
		v	$\frac{1}{2} \times 50 \times 0.12^2 = \frac{1}{2} \times 0.39 \times v^2$	C1	Allow 1 mark for $v = 0.96$ m s ⁻¹ ; used k for single spring
		v	$v = 1.4$ (m s ⁻¹)	A1	
	b		force constant of spring arrangement) = $\frac{2k}{3}$	M1	
			$\frac{2k}{3}x = ma$	M1	
			$a = \frac{2}{3 \times 0.39}kx$	A0	
			$a = 1.7$ kx		
			Total	13	
5 8		i	Beta radiation would not penetrate/ would be absorbed by the lead	B1	Not gamma radiation would be stopped

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				Ignore reference to alpha radiation <u>Examiner's Comments</u> Most candidates were obviously very familiar with this and gave a clear response. Credit was given for either Gradient of best fit line: - a clear comparison of $\ln N = -\mu d + \ln N_0$ with $y = mx + c$ - using log rules to give $\ln(N_0 e^{-\mu d}) = -\mu d + \ln N_0$
		ii	$\ln N = -\mu d + \ln N_0$ compared to $y = mx + c$ (so $m = -\mu$ and $c = \ln N_0$)	B1 or $\ln N = \ln(N_0 e^{-\mu d}) = \ln N_0 - \mu d$ <u>Examiner's Comments</u> Candidates who gained the uncertainty mark mostly used the standard method of finding half the range i.e. $(\ln 340 - \ln 260)/2$. However, a very common response was to calculate the fractional uncertainty in N (i.e. $40/300$) rather than the absolute uncertainty in $\ln N$. This was not given without mathematical justification e.g. $\Delta(\ln N) \approx (\Delta N)/N$.
		ii i	5.70 ± 0.14	Both answers must be to 2d.p. Allow ± 0.13 not second B1 mark without correct working shown e.g. $\ln 300 - \ln 260$ or $(5.83 - 5.56)/2$ Allow $\Delta N/N$ ($= 40/300$) but only if $\Delta(\ln N) \approx \Delta N/N$ is quoted B1 B1 <u>Examiner's Comments</u> The majority of candidates had no difficulty in plotting the point (50, 5.70) correctly. Both best and worst fit lines were usually drawn well enough, although some had very thick pencil lines and a surprising number had not been extended to the $\ln N$ axis. Almost all candidates gained the mark for using a sufficiently large triangle ($\Delta d > 25\text{mm}$) for calculating the gradient of their best fit line.
		i v	Point plotted correctly to within $\frac{1}{2}$ small square Best fit and worst fit line(s) drawn	Ignore accuracy of length of error bar ECF (ii)2 for incorrect value(s) in table ECF (ii)2 for incorrect value(s) in table B1 B1 Best fit line should have an equal scatter of points about the line Worst fit line should be steepest/shallowest possible line that passes through <u>all</u> the error bars (allow $\pm \frac{1}{2}$ small square tolerance vertically)

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					<u>Examiner's Comments</u> Most mathematically able candidates quickly obtained the result $\mu d_{1/2} = \ln 2$ and then used it with their value of μ. Other candidates used a variety of (usually correct) graphical methods with Fig. 2.2.
		v	gradient of best fit line = $(-) \mu = (-) 54 \text{ (m}^{-1}\text{)}$ large triangle used to determine gradient of best fit line calculation of absolute uncertainty using <u>their</u> values in the formula ($\text{wfl gradient} - \text{bfl gradient}$) uncertainty and value of μ to same number of dp	B1 B1 B1 B1	Allow 51 to 56 Allow value of μ up to 4 SF ECF(ii)3 for wrongly plotted point $\Delta d > 25\text{mm}$ (seen from graph or working) ECF (ii)3 for worst fit line Ignore any POT error in gradients Allow value of absolute uncertainty up to 3 SF only e.g. 53.4 ± 5.6 or 54 ± 6
		v i	$\mu d_{1/2} = \ln 2$ (or 0.693) $d_{1/2} = 0.013 \text{ (m)}$	C1 A1	ECF (ii)4 for $\frac{1}{2}$ <u>Alternative method:</u> $\ln(N_0 / 2) = 7.67 \text{ (C1)}$ then use of graph to give $d_{1/2} = 0.013 \pm 0.001 \text{ (m)}$ (A1)
			Total	12	