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 *uncertainty*. 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**	

9			A	1	
			Total	**1**	
10			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 '*Systematic errors do not affect the experiment*' or '*Speed does not change when x changes*' demonstrated a poor understanding of the question and of systematic errors.
			Total	**1**	
11			D	1	
			Total	**1**	
12			**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**	
13			**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**	
14			D	1	
			Total	**1**	

15			D	1	**Examiner's Comments** 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 diameter^2. This gives the correct answer D.
			Total	**1**	
16			D	1	
			Total	**1**	
17			C	1	
			Total	**1**	
18			D	1	
			Total	**1**	
19			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 *measured value*; actual/real/allowed/correct for *true* **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 **Examiner's Comments** 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 *The Language of Measurement* (ASE 2010).
			Total	**2**	
20			$v \rightarrow$ m s^{-1} **or** $v^2 \rightarrow$ m^2 s^{-2} Clear algebra leading to base unit = kg m^{-1}	M1 A1	

			Total	2	
21	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.

		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 Δ*y* / Δ*x*.
	d		ρ = 5700 × 1.9 × 10^{-5}	C1	**Note**: ECF from **(ii)** **Allow** any subject for equation **Not** use of data points from table
			ρ = 0.108 <u>given to 2 or 3 sf</u>	A1	
			Ω m	B1	**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**	
22			$\frac{0.12}{1.20}(\times 100)$ or $\frac{0.24}{4.00}(\times 100)$ or (*k* =) 2.78 (kg m^{-1}) [2 × 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**	
23			*T* = 60/1600 or *T* = 3.75 × 10^{-2} (s) (*v* = π × 0.50/3.75 × 10^{-2}) speed = 42 (m s^{-1})	**C1** **A1**	**Allow:** f = 26.7 or $\frac{1600}{60}$ (Hz) or ω = 168 (s^{-1}) **Note:** *v* must be to 2 or more SF

			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})** **Examiner's Comments** 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**	
24	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' **Examiner's Comments** 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 **Examiner's Comments** 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 **Examiner's Comments** 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

					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.
		ii	**Level 3 (5–6 marks)** Clear explanation, description **and** determination *There is a well-developed line of reasoning which is clear and logically structured.* *The information presented is relevant and substantiated.* **Level 2 (3–4 marks)** Some explanation, description **and** determination Or Some explanation and clear determination *There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.* **Level 1 (1–2 marks)** Limited explanation or description or determination *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.* **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 <u>°C</u> • 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 <u>°C</u> to −240 <u>°C</u> 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-

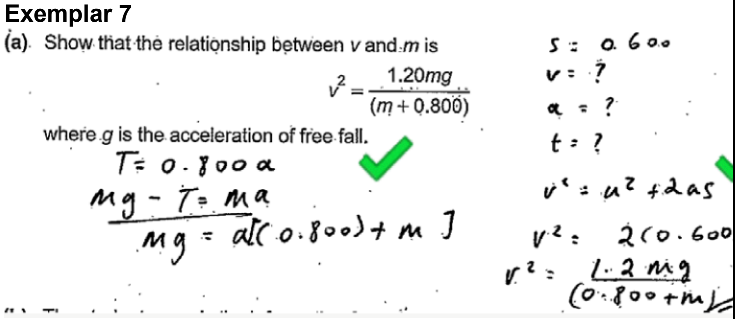
					plotting the graph was not required and merely wasted time for little reward.
	d		Draw the worst fit line (through all the error bars) (AW). Determine the new value for absolute zero and find the difference between the value in **(c)(ii)** and this new intercept. (AW)	**B1** **B1**	**Examiner's Comments** 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 / <u>wait</u> 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			$\frac{0.002}{0.1000}(\times 100)$ or $\frac{0.1}{1.4}(\times 100)$ or $g = \frac{1.4^2}{2 \times 0.100}$ (2 × 0.071 ...+ 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%

			absolute uncertainty = 1.6 (m s^{-2}) **OR** $g_{max} = \frac{1.5^2}{2 \times 0.098}$ (= 11.48) or $g_{min} = \frac{1.3^2}{2 \times 0.102}$ (= 8.28) range = 3.2 (m s^{-2}) absolute uncertainty = 1.6 (m s^{-2})	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**	
26			(mean) = 1.87(2) (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**	
27	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 (m s^{-1})	B1 B1 B1	$\Delta x > 0.6 \times 10^{-3}$s Expect between 80 and 82 (m s^{-1}) **Allow** 320 ± 20; **allow ECF** from an incorrect gradient
	b	i	Value of 1/*F* determined correctly from graph *F* = 350 (Hz)	C1 A1	**Allow values between** 2.83×10^{-3}s and 2.84×10^{-3}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**	
28		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 π (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	λ = 0.80 (m) $v = f\lambda$, $v = 75 \times 0.80$	C1	**Allow** 80 (cm) for this C1 mark

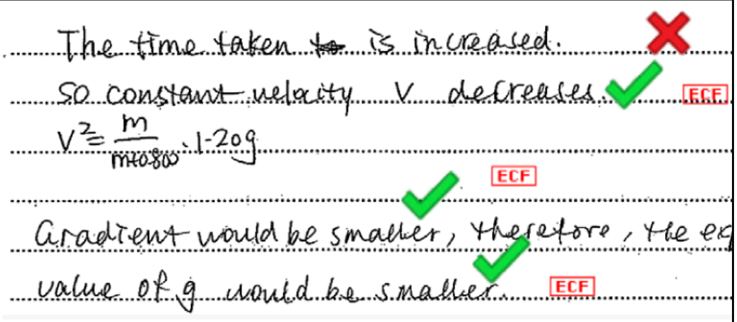
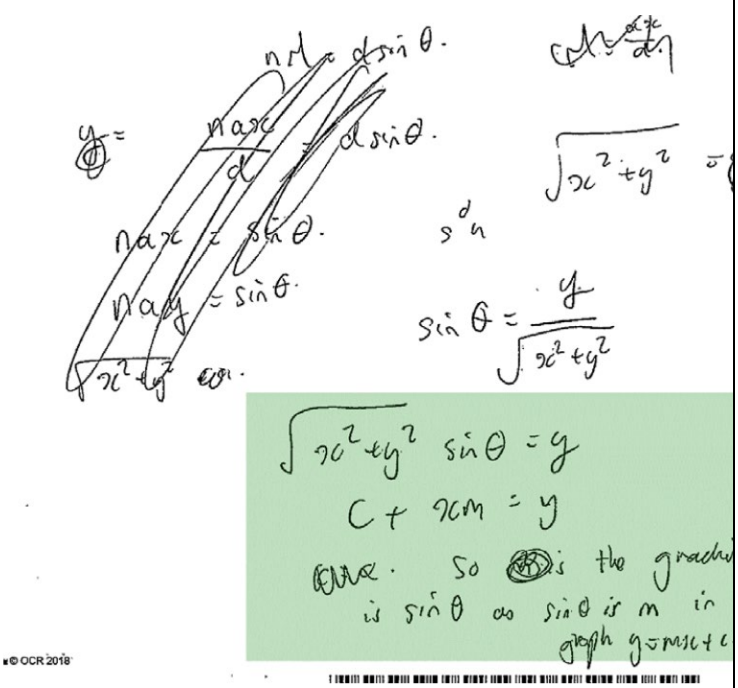
		ii	$v = 60$ (m s^{-1}) absolute uncertainty = $\frac{2.0}{40} \times 60$	A1	**Allow** 1 mark for 30 (m s^{-1}) from the C1A1 marks; λ = 0.40 m used
		ii	absolute uncertainty = 3.0 (m s^{-1})	A1	**Note** 60 ± 3 (m s^{-1}) scores full marks **Allow** 2 marks for 6000 ± 300 (m s^{-1}); λ in cm (POT error) **Allow** 2 marks for 30 ± 1.5 (m s^{-1}); λ = 0.40 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 ± 1.5) m s^{-1}. Examiners awarded two marks for such an answer.
			Total	**4**	
29	a	i	points on the line read to the nearest half square size of triangle is greater than half the length of the drawn line and $\Delta y / \Delta x$	B1 B1	**Allow** Δy for $y_2 - y_1$ and Δx for $x_2 - x_1$ $\Delta x \geq 0.1625$
		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)
		iii	Δgradient (0.13 - 0.12 or 0.12 - 0.10) $\frac{\Delta\text{gradient}}{\text{gradient}} \times 100 = 8.3\%$ or 17% OR Δk (82 – 75 or 98-82) $\frac{\Delta k}{k} \times 100 = 8.5\%$ or 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	

	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 = gradient = 1.60	B1	**allow** 1.56 to 1.64; **allow** 1.6
		i	y = 0.86 (± 0.01); × = 1.98 so *y*-intercept = 0.86 − 1.6 × 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) ± 0.1 or 0.2 where plausible working is shown
		ii	b = gradient of steepest line = 1.75 giving uncertainty ± 0.15	B1	
			Total	**10**	
3 1		i	$g = \frac{2s}{t^2}$ / $g = \frac{2\times 1.200}{0.50^2}$	C1	
		i	*g* = 9.6 (m s^{-2})	A1	
		ii	(% uncertainty in *s*) = 0.08 % or		
		ii	(% uncertainty in *t*) = 4.00 % % uncertainty in *g* = ((2 × 4.00) + 0.08)	C1	
		ii	% uncertainty in *g* = 8.08 (%)	A1	**Allow** 8.1% or 8 %
			Total	**4**	
3 2			(force =) 2.2 × 10^{-3} × 9.81 2.2 × 10^{-3} × 9.81 = *B* × 5.0 × 0.060 (= 0.072 T) (absolute uncertainty =) $\frac{0.2}{6.0}+\frac{0.1}{5.0}$(×0.072 = 0.0038 T) *B* = 0.072 ± 0.004	C1 C1 C1 A1	**Allow** calculation of percentage uncertainty = 5.3% **Allow** calculation of max B (=0.0759 T) and min B (=0.0683 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. **Examiner's Comments** 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*sinθ 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,

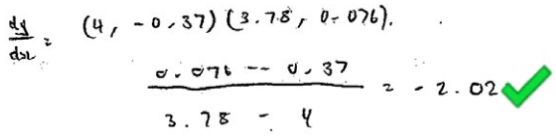
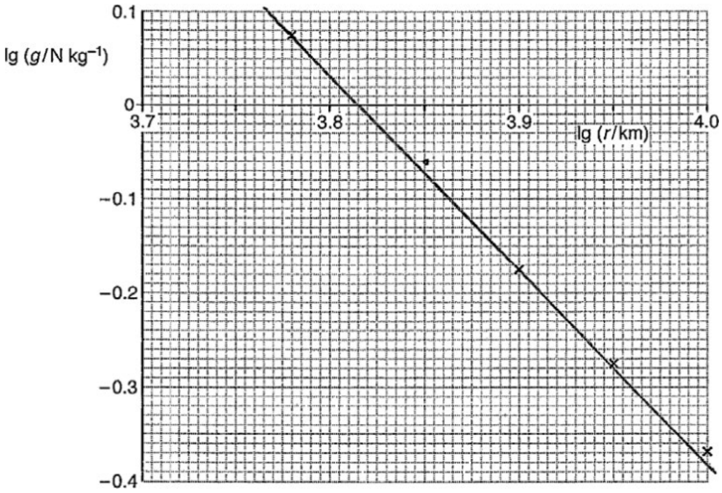
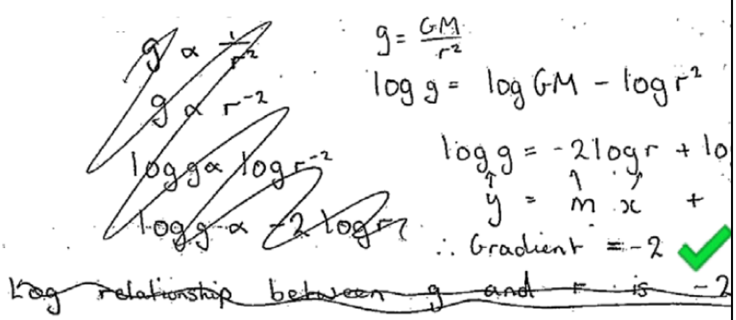
					leaving their final answer in different significant figures. It was noted that several candidates underlined this instruction and in general they tended to follow it. It is good practice to do this.
			Total	**4**	
33			Line of best fit drawn through the data points Gradient = 38 (*Ck*ln2 = gradient) $1.2 \times 10^{-3} \times k \times \ln 2 = 38$ $k = 4.6 \times 10^4$ (Ω 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**	
34		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*) *ρ* = gradient of line × *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**	
35	a		weight × *y* = *Fx* (*ALρg*) × *y* = *Fx* $y = \left(\frac{F}{AL\rho g}\right)x$	M1 M1 A0	**Allow** W or mg *Wy* = *Fx* or *mgy* = *Fx*

	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	$\left(\frac{F}{AL\rho g}\right)$ = 1.5 $\frac{6.8}{6.4\times10^{-5}\times0.90\times\rho\times9.81}$ = 1.5 ρ = 8.0 × 10^3 (kg m^{-3})	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 ½(m + 0.8)v^2 = 0.6 mg (and hence equation as shown on	M1 A1	**allow** mgh = ½Mv^2 as long as it is clear that m and M are different, i.e. NOT mgh = ½mv^2 **allow** linear motion equation $v^2 = u^2 + 2as$ and $F = Ma$ $(W =)\ mg = (m + 0.8)a$; u = 0 and s = 0.6 **Examiner's Comments** The challenge to candidates in answering this *show that* 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 $mgh = \pm½mv^2$ 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 = ? v² = u² + 2as v² = 2(0.600 v² = 1.2mg / (0.800 + m)
	b	i	(v^2 =) 4.93 (±) 0.22	B1 B1	**allow** 4.9 (±) 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 ±½ 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

					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 = $v^2/[m/(m + 0.8)] = 1.2$ g **or expect** $y = v^2$ <u>and</u> $x = m/(m + 0.800)$ so gradient = 1.20*g* **<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 B1 B1 B1	roughly between extremes of top and bottom error bars or by eye; consequential **ecfs** for rest of **(ii)** Δx > 0.13; **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 **<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 α g /AW **so** calculated *g* is greater	B1 B1 B1 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>** 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. **Exemplar 8**

Question			Answer	Marks	Guidance
					 The time taken ~~to~~ is increased. so constant velocity V decreases $V^2 = \frac{m}{m+0.800} \cdot 1.20g$ Gradient would be smaller, therefore, the ex value of g would be smaller.
			Total	**15**	
37	a		y = sin (θ) $\sqrt{x^2+y^2}$ compared with “y=mx+c”	**B1**	**Allow:** gradient = $\frac{\Delta y}{\Delta(\sqrt{x^2+y^2})}$ with sin (*θ*) = O/H **Not:** gradient = $\frac{y}{(\sqrt{x^2+y^2})}$ **unless** “c=0” seen. **<u>Examiner’s Comments</u>** 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**  The exemplar shows a clear way of demonstrating how to show that the gradient of the line of the graph should be sin(*θ*).
	b	i	(Straight line of best fit showing) <u>gradient</u> = 0.73 (*d*sin *θ* = *nλ*) $\frac{1.0 \times 10^{-3}}{600} \times 0.73 = 2 \times \lambda$ *λ* = 6.1 × 10^{-7} (m)	**C1** **C1**	**Allow:** gradient in range 0.70–0.76. **Allow:** evaluation of *θ* = 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) ×

				A1	10^{-7} m **Examiner's Comments** 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(*θ*) 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) **absolute uncertainty is too small** to be shown (reasonably on this graph's scale) (AW)	B1	**Ignore: error** too small **Examiner's Comments** 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.
		iii	(The values for λ or *θ* will be) less precise (as independent measurements less likely to agree) (AW)	B1	**Examiner's Comments** 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. *Precision* The term 'precision' is defined of page 40 the Practical Skills Handbook, along with other useful terms that attempt to describe the quality of data
			Total	**6**	
38		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. **Examiner's Comments** 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 ± 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 **Examiner's Comments** Providing the candidate had entered values in the tables, the data point was almost always plotted correctly. The best fit line caused

					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**   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 i	(Triangle used to determine gradient and) gradient calculation is shown to be within range −1.90 to −2.20	**B1**	**<u>Examiner's Comments</u>** Most candidates correctly found the gradient of their best fit straight line.
		i v	lg(g) = lg(GM) − 2lg(r) or lg(g) = − 2lg(r) + lg(GM) seen **Compared** with $y = mx + c$, and hence gradient = − 2	**M1** **A1**	**Allow:** incorrect handling of negative g. **<u>Examiner's Comments</u>** **Exemplar 4**  The exemplar shows both an unsuccessful and a successful

					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 ↑ or (sin) θ *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3 – 4 marks)** Description of procedure or correct determination of ↑, but no estimation of uncertainty **or** Clear estimation of uncertainty in wavelength but limited description of procedure and/or determination of ↑ or (sin) θ **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*) *There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.* **Level 1 (1 – 2 marks)** A limited selection from the scientific points worthy of credit. *There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.* **0 marks** *No response or no response worthy of credit.* Frontal	1 (AO 3)	Use level of response annotations in RM Assessor, e.g. L2 for 4 marks, L2^ for 3 marks, etc. L1 maximum for any answers which use formula ↑ = *ax*/D **Indicative scientific points may include:** **Procedure** • use formula *n*↑ = *d*sinθ • *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 x 10^{-6} m • use *x* = 0.10 m and distance to grating = 0.50 m to calculate tan θ (= 0.2) • θ = 11.3° • sin θ = 0.196 • alternatively, calculate hypotenuse of triangle (using Pythagoras's theorem) = 0.51 m, giving sinθ (= 0.10/2600½) = 0.196 • allow use of small angle rule (sinθ 冱 tanθ 冱 θ = 0.2) • calculate ↑ (= 0.196 x 10-3/300) = 650 nm **Estimation of uncertainty** • negligible uncertainty in *d* (and *n*) • uncertainty in sin θ 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 θ / θ / sin θ = 3% • so % uncertainty in ↑ = % uncertainty in sin θ = 3% **Examiner's Comments** 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 λ=ax/D. This may be because the formula nλ = dsinθ is in the astrophysics section of the formula sheet.

Candidates who chose to use the correct formula nλ = dsinθ 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 θ.

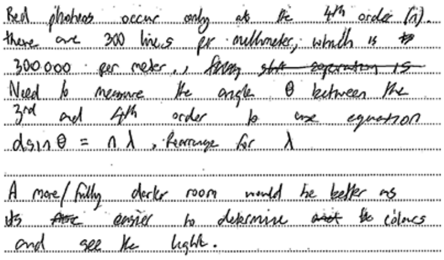
AfL

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 *nλ = dsinθ*.

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 (a).
there are 300 lines per millimeter, which is
300 000 per meter, , ~~slit separation is~~
Need to measure the angle θ between the
3rd and 4th order to use equation
dsinθ = nλ, Rearrange for λ

A more/fully darker room would be better as
its ~~Ace~~ easier to determine ~~and~~ the colours
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**	

4 0		i	$hf = \phi + KE_{(max)}$ 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 $hf_0 = \phi + KE_{max}$.
		ii	Data point (to with ½ 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** $h = (6.4 \text{ to } 7.4) \times 10^{-34}$ (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 from **biii** - h from worst line) × 100 ÷ h from **biii** **or** Calculate the average h using f_0 and ϕ (values) % uncertainty = (½ range ÷ average h) × 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

					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 *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3–4 marks)** Some procedure, some measurements and some analysis. *There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.* **Level 1 (1–2 marks)** Limited procedure and limited measurements **or** limited analysis *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.* **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 = 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**

					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.
		iii	$1000 \times 1.15 \times 10^{-5} \times 9.81 = 0.11$ N OR $0.0075 \times 9.81 = 0.074$ N $F = 0.11 - 0.074 = 0.037$ (N) OR 9.81 (1000 − 650) or $1.15 \times 10^{-5} \times (1000 - 650)$ $F = 1.15 \times 10^{-5} \times 9.81\ (1000 - 650) = 0.039$ (N)	C1 A1 C1 A1	**Allow** use of 7.47×10^{-3} 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**	
42	a	i	vertical component =30.0 sin(70°) or 30.0 cos(20°) vertical component = 28.2 (m s^{-1})	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 $(30 \sin(70))^2/(2 \times 9.81)$ **No ECF from (a)(i) for the second mark**

			h = 40.5 (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° or 10.2…. (m s^{-1}) or 30.0 sin 20°. $E_k = {}^1/_2 \times 0.057 \times 10.26^2$ E_k = 3.0(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 *show* 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.
			
			There is a well–developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.
			
			Level 2 (3–4 marks)
			Some description and some analysis.
			
			There is a line of reasoning presented with some structure. The information presented is in the most–part relevant and supported by some evidence.
			
			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

			or limited analysis *There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.* **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**

Use your knowledge of projectile motion to suggest the relationship between v a
how an experiment can be safely conducted to test this relationship and how t
analysed.

make sure no one in w

As it a projectile the horizontal of velocity is constant given a is negligible then a equation of x could become $x = vt$ where x is traveled v is velocity of ball and time of flight therefor for a const of flight it can be said x ∝ v

~~To test this it is very hard to time of flight constant as this is to its time of freefall~~

To test this a ball would be of a table at varying speed calculate this speed a light can be used passing through center of the metal ball. As d travelled is equal to the diameter o ball, measured by a ruler, spe be calculated using distance/time f light gate. For safety the ball land in sand as not to shat land on someones foot. This also m measuring x much easier as x equal to the horizontal distance fro edge of the table to the center Sand measured using a ruler. If taken to fall is kept constant by using a slope which and e by raising or lowering the point when v is plotted a x on a graph it can be to be linear and pass throu 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 $v \propto \chi$ 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

					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**	
43			***Level 3 (5–6 marks)** Clear explanation and discussion *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3–4 marks)** Some explanation and some discussion *There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.* **Level 1 (1–2 marks)** Limited explanation **or** limited discussion *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.* **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**	
44	a		**Level 3 (5-6 marks)** Clear evaluation of Fig. 22.1 **and** clear analysis *There is a well-developed line of reasoning which is clear and logically structured. The information presented is*	**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

			relevant and substantiated. **Level 2 (3-4 marks)** Some evaluation of Fig. 22.1 **and** some analysis *There is a line of reasoning presented with some structure.* *The information presented is in the most part relevant and supported by some evidence.* **Level 1 (1-2 marks)** Limited evaluation of Fig. 22.1 **or** limited analysis *There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.* **0 marks** *No response or no response worthy of credit.*		• 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) ∝ <u>*rate*</u> of change of (magnetic) flux <u>linkage</u>	**M1** **A1** **B1**	**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' **Allow** 'equal to / =' **Ignore** 'cutting of flux' **Not** just $E = (-)\Delta(N\phi)/\Delta t$ **Examiner's Comment** The topic electromagnetic induction always challenges candidates. Successful responses often showed correct use of technical terms such as *magnetic flux* or *flux linkage.* 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 **electro**magnetic field in their descriptions rather than magnetic field.

		ii	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 × 20 or 240 (V) (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 *'there was a changing magnetic flux as the current increased from zero to a steady value'.* 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**	
45		i	<u>**_A_ =**</u> 470/8.8 × 10^{-13} = 5.3 × 10^{14} (Bq) λ = ln 2/(88 × 3.16 × 10^{7}) (= 2.5 x 10^{-10} s^{-1}) ($A = \lambda N$); N (= 5.3 x10^{14} / 2.5 x 10^{-10}) = 2.1 x 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	$P = P_o \exp(-\lambda t)$ P = 470 exp (− ln 2 x 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**	
46	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** nλ or λ **Not** phase difference **Allow** $(n + \frac{1}{2})\lambda$

			At point Q: path difference between slits and screen is an odd number of half wavelengths (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 nλ. 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	**1** x = 4.22 mm $\lambda = \frac{4.22 \times 10^{-3} \times 0.56 \times 10^{-3}}{4.50}$ 5.25 × 10^{-7} m $\frac{0.02}{4.5}$ or $\frac{0.02}{0.56}$ or $\frac{0.2}{42.2}$ $\left(\frac{0.02}{4.5} + \frac{0.02}{0.56} + \frac{0.2}{42.2}\right) \times 100 = 4.48\ \%$ Alternative max / min method: **2** $\lambda_{max} = \frac{4.24 \times 10^{-3} \times 0.58 \times 10^{-3}}{4.48} = 5.49 \times$ and/or $\lambda_{min} = \frac{4.20 \times 10^{-3} \times 0.54 \times 10^{-3}}{4.52} = 5.02 \times$ $\frac{\Delta\lambda}{\lambda} \times 100 = 4.4\%\ or\ 4.6\%$	C1 C1 A1 C1 A1 B1 B1	**Note x** = 42.2 mm or 4.2 × 10^{-2} m scores zero **Note x** = 3.84, 4.77 × 10^{-7} 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	$\frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{5.25 \text{ x } 10^{-7}} = \frac{1.989 \times 10^{-25}}{\mathbf{5\ b\ ii\ 1}} = 3.7$ $n = \frac{50 \times 10^{-3}}{3.79 \times 10^{-19}} = 2.5 \times 10^{23} \times \mathbf{5\ b\ ii\ 1} = 1.3 \times$	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 × 1.6 × 10^{-19}= 4.16 × 10^{-19} J ORA	M1	**Allow** photon has 2.37 eV of energy

			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**	
47	a		3.6 ± 0.4 ($m^2\ s^{-2}$)	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. *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **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. *There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.* **Level 1 (1–2 marks)** Line of best fit drawn and gradient attempted. Mention of energy and / or where uncertainties may occur. *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.* **0 marks** No response or no response worthy of credit.	B1 × 6	**Explanation** 1. Principle of conservation of energy used to derive relationship. 2. $mgh = ½ mv^2$ or $v^2 = 2gh$ 3. A graph of v^2 against h will be a straight line (through the origin). 4. Gradient of line = 2*g*. **Determination** 1. Line of best fit drawn through all data points. 2. Gradient in the range 17 to 21 ($m^2\ s^{-2}$). 3. *g* determined correctly from the gradient. **Uncertainty** 1. Worst line of fit drawn. 2. Correct attempt to determine the uncertainty.
			Total	**8**	
48	a	i	0.22 and 0.26	B1	

		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	
		iii	sensible reason for t being too large or s too small	B1	e.g. electromagnet does not release instantaneously,trapdoor is stiff, faulty contacts,etc e.g. scale on ruler does not start at the end / AW
			Total	**12**	
49		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 = fλ 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

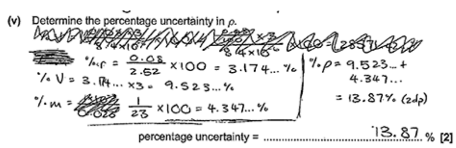
					distance there and back. Only the most able of the candidates scored full marks.
		iii	$v = 2 \times 170$ $v = 340$ (m s^{-1})	B1	Possible ECF from **(b)(i)** **<u>Examiner's Comments</u>** Almost all candidates picked up 1 mark for multiplying their answer from **(b)(i)** by 2. This included those who 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.
		iv	Decrease frequency / *f* (ORA) *L* / *λ* increases (so, smaller % uncertainty) (ORA) **or** 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) **<u>Examiner's Comments</u>** 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**	
50		i	($F = ma$ =) $190 \times 10^3 = 2.1 \times 10^5$ a $a = 0.90$ (m s^{-2})	M1 A0	a = 0.905 to 3 SF
		ii	($v^2 = u^2 + 2as$ gives) $36 = 2 \times 0.90 \times s$ s = 20 (m)	C1 A1	**Allow** any valid suvat approach; **allow ECF** from (i) **Note** using a = 1 gives s = 18(m)
		iii	**1** $P = Fv$ One correct calculation e.g. $F = 100 \times 10^3$ and v = 42 gives $P = 4.2 \times 10^6$ (W) Fv = constant **2** (P = VI = 4.2MW so) $4.2 \times 10^6 = 25 \times 10^3 \times I$ I = 170 (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* = 4MW or **ECF from (iii)1** Expect answers between 160 - 170 (A)

			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. *'current in ampere'.* Some answers were just wrong; these include *force, charge, energy* and *kelvin.*
	b	i	$R = \frac{\rho L}{A}$ **and** $A = \pi\left(\frac{d}{2}\right)^2$ $R_X = \frac{4\rho L}{\pi d^2}$ and $R_Y = \frac{8\rho L}{\pi d^2}$ Clear steps leading to $R = \frac{12\rho L}{\pi d^2}$	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) (Ω) $\frac{0.1}{9.5}$ or $2\times\frac{0.003}{0.270}$ **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 × 2.34 = 0.077 R = 2.3 ± 0.1 (Ω) **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 ± 0.1 (Ω) **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 ± 0.08 (Ω) **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 ± 0.1 Ω or 2.34 ± 0.08 Ω. Some candidates successfully calculated the maximum and the

					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 '*larger because d was smaller or* $R \propto 1/d^2$'. On most scripts, it was difficult to follow if the resistance was the **actual** one or the **calculated** one.
			Total	**9**	
5 2		i	**1** A straight line of best-fit drawn passing through all error bars.	B1	
		i	**2** $V = V_0e^{-t/CR}$, 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 (−) 7.7×10^{-4} (s Ω^{-1})	C1	**Allow** gradient in the range 7.5 to 8.0×10^{-4}
		i	*C* = gradient/ln(0.5) = (−) $7.7 \times 10^{-4}/\ln(0.5)$ $C = 1.1 \times 10^{-3}$ (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**: $\frac{\text{difference between worst and best - fit gradients}}{\text{value of best gradient from } \textbf{(i)3}} \times 100$
			Total	**8**	
5 3		i	Line of best fit drawn gradient = 2.8	B1 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 **<u>Examiner's Comments</u>** 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.

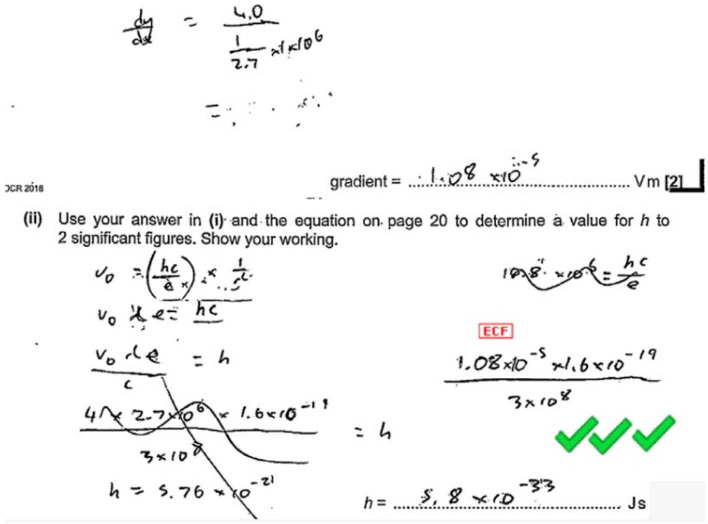
		ii	$E = I(r + R)$ **and** $R = \rho L/A$ $\frac{1}{I} = \frac{r}{E} + \frac{\rho}{AE}L$ (and comparison with $y = mx$ + c leads to gradient $\frac{\rho}{AE}$)	C1 A1	**Allow** $E = V + IR$ **and** $R = \rho L/A$ **<u>Examiner's Comments</u>** Most candidates struggled with **(c)(ii)**. Less than 1 in 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 $y = mx + c$.
		iii	(ρ = gradient × AE) $\rho = 2.8 \times \pi \times (0.19 \times 10^{-3})^2 \times 1.5$ $\rho = 4.8 \times 10^{-7}$ (Ω 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 **<u>Examiner's Comments</u>** 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.
		iv	The graph / points just shift horizontally (AW) 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' **<u>Examiner's Comments</u>** 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 1.9×10^{-6} Ω m or forgot to convert the millimetres into metres to get a value of 0.48 Ω 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

					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) **Examiner's Comments** 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 **Examiner's Comments** 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 = ½ x range = ½ x (maximum value – minimum value)
		ii i	Volume = $\frac{4}{3}$ × π × (1.26 × 10^{-2})^3 = 8.379 × 10^{-6} 8.4×10^{-6} m^2	M1 A0	$\frac{1}{6} \times \pi \times (2.52 \times 10^{-2})^3$ or $\frac{4}{3} \times \pi \times \left(\frac{2.52\times10^{-2}}{2}\right)^3$ **Examiner's Comments** 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	$\frac{0.023}{8.4\times10^{-6}}$ or 2738 2700 (kg m^{-3}) or 2.7 x 103 (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 x 106 (kg m^{-3})

					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 Δ*d* = 0.09 **Allow** maximum/minimum methods **Note** 13% for Δ*d* = 0.07 or 15% for Δ*d* = 0.09 [ECF 5.5% for Δ*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**  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	

			Weight = 0.023 x 9.81 or 0.22563 13 (N m^{-1})	C1 A1	**Allow ECF** for incorrect mass conversion from **(iv)** **Allow** 12.6 (N m^{-1}) or 12.5 (N m^{-1}) **Examiner's Comments** 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 x 13 (= 0.13 N) (Upthrust = 0.226 - 0.13) = 0.10 (N)	C1 A1	**Allow ECF** from **(b)** **Allow** 0.008 x 12.5 **Allow** 0.1 (N) (1sf) **Examiner's Comments** 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 (kg m^{-3})	C1 A1	**Allow ECF** from **(i)** **Examiner's Comments** 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	**1** (% uncertainty in λ^2 =) 10% (% uncertainty in λ =) 5% **2** Straight line of best fit passes through all error bars gradient = 1.0 (× 10^{-22}) **3** $\frac{h^2}{2mq} =$ gradient $\frac{(6.63 \times 10^{-34})^2}{2 \times m \times 3.2 \times 10^{-19}} =$ gradient	C1 A1 B1 C1 C1	**Note** 10 (%) on answer line will score the C1 mark **Ignore** POT for this mark; **Allow** ± 0.20 (× 10^{-22})

			$m = 6.9 \times 10^{-27}$ (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**	
56		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 to 1.60) × 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**

					 This exemplar illustrates how full marks can always be scored from error carried forward (ECF) rule. The gradient of 1.08×10^{-5} was well outside the range allowed. This had already been penalised in the earlier part **20(b)(i)**. This erroneous value has been used correctly in this section. The answer is nowhere close to the Planck constant, but this is irrelevant – the physics has been applied correctly here, the answer is correctly written with 2 SF, so well deserved 3 marks for this E-grade candidate.
		iii	difference = $\frac{6.9 \times 10^{-34} - 6.6(3) \times 10^{-34}}{6.6(3) \times 10^{-34}} \times 100$ % difference = 4.1 %	B1	Possible ECF from **(ii)** **Ignore** sign **Not** division by value from **(ii)** **Allow** 1 SF answer
		iv	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 **<u>Examiner's Comments</u>** The two errors in this experiment were *systematic* and *random* errors (see learning outcome 2.2.1a in the H556 specification). Many candidates did not name these two errors, instead focussing

					on nebulous terms such as *human error*, *equipment error*, 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**	
57	a	i	Missing data point and error bar plotted correctly.	B1	**Allow** ½ 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	
		iii	Best fit line drawn correctly and gradient determined correctly.	B1	**Ignore** POT for this mark; gradient = 50 ± 4 (N m^{-1})
		iii	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.
		iii	$2k$ = 50 (N m^{-1}), therefore k = 25 (N m^{-1})	B1	Possible ECF.
		iii	Absolute uncertainty determined correctly.	B1	Possible ECF within calculation.
		iv	$F \propto x$ / straight line passing through the origin.	B1	
		v	energy stored = ½ × 50 × 0.12^2	C1	Possible ECF from **(iii)**
		v	½ × 50 × 0.12^2 = ½ × 0.39 × 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) = $\frac{2k}{3}$ $\frac{2k}{3}x = ma$	M1	
			$a = \frac{2}{3 \times 0.39}kx$	M1	
			a = 1.7 kx	A0	
			Total	**13**	
58		i	Beta radiation would not penetrate/ would be absorbed by the lead	B1	**Not** gamma radiation would be stopped

					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. (ln340– ln260)/2. However, a very common response was to calculate the fractional uncertainty in N (i.e. 40/300) rather than the absolute uncertainty in lnN. This was not given without mathematical justification e.g. $\Delta(\ln N) \approx (\Delta N)/N$.
		iii	5.70 ± 0.14	B1 B1	Both answers must be to 2d.p. **Allow** ± 0.13 not second B1 mark without correct working shown e.g. ln300 – ln260 or (5.83-5.56)/2 **Allow** $\Delta N/N$ (= 40/300) but only if $\Delta(\ln N) \approx \Delta N/N$ is quoted **<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 lnN axis. Almost all candidates gained the mark for using a sufficiently large triangle (Δd > 25mm) for calculating the gradient of their best fit line.
		iv	Point plotted correctly to within ½ small square Best fit and worst fit line(s) drawn	B1 B1	**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 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 ±½ small square tolerance vertically)

					Examiner's Comments Most mathematically able candidates quickly obtained the result *μ*d1/2 = ln2 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 = (-) *μ* = (-) 54 (m^{-1}) large triangle used to determine gradient of best fit line calculation of absolute uncertainty using <u>their</u> values in the formula (|wfl gradient – 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 Δd > 25mm (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
		vi	$\mu d_{½}$ = ln2 (or 0.693) $d_{½}$ = 0.013 (m)	C1 A1	**ECF (ii)4** for ½ <u>Alternative method</u>: ln(N_0 /2) =7.67 (C1) then use of graph to give $d_{½}$ = 0.013±0.001 (m) (A1)
			Total	**12**	