Mark scheme

Question	Answer/Indicative content	Marks	Guidance
1	**Level 3 (5–6 marks)** Clear description **and** clear uncertainties *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)** Clear description (eg correct circuit, valid method for varying temperature, r found from graph) **or** clear uncertainties (eg adds error bars to graph and uses a wfl to find uncertainties) **or** Some description **and** limited uncertainties *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 (eg thermistor symbol correct, range of temperatures used, *V* and *I* measured) **or** Limited uncertainties (eg uncertainties not related to graph, uncertainty in *r* found from Δintercepts rather than Δgradients) *There is an attempt at a logical structure with a line of reasoning. The information is*	B1 × 6	Use level of response annotations in RM Assessor **Indicative scientific points may include:** **Description** • correct circuit symbols and diagram • vary resistance of thermistor, record *V* and *I* • method to vary resistance of thermistor, e.g. water bath and thermometer, start from 0°C • Plot V (y-axis) against *I* (x-axis) • e.m.f. = y-intercept; r = - gradient • alternatively, $P = IV$, $R = V/I$ • plot *P* (y-axis) against *R* (x-axis) • maximum power occurs when $r = R$ • e.m.f. found from $\varepsilon = V + Ir$ **Uncertainties** • Gather repeat readings of *V* and *I* at each temperature if possible and estimate uncertainty in *V* and *I* from half the range of the repeated values • If no repeats, use accuracy (or (half) resolution) of ammeter and voltmeter for uncertainty in *V* and *I* • Add error bars to graph and draw a wfl • Find gradient and y-intercept of wfl • Uncertainty in r / e.m.f. is difference between gradients / y-intercepts of best and worst line • For alternative method, estimate width of peak to find uncertainty in *r* and find uncertainty in e.m.f. using $\varepsilon = V + Ir$ **<u>Examiner's Comments</u>** Although it was clear that many candidates had performed an experiment to determine *r* and ε for a cell, they were sometimes thrown by the need to use a thermistor rather than a variable resistor. Many candidates drew the symbol for a variable resistor anyway instead of a thermistor, and others put the variable resistor into the circuit alongside the thermistor. Some suggestions for varying the temperature of the thermistor were impractical. Although it would be practically difficult to take several values of V and I at exactly the same temperature, candidates were allowed to use error bars found from half the range of repeated values, rather than by using the resolution of the ammeter and voltmeter. Often candidates

<table>
<tr><td></td><td></td><td></td><td>in the most part relevant.

0 mark
No response or no response worthy of credit.</td><td></td><td>were rather vague when trying to describe how to determine the uncertainties; ‘Use the worst fit line’ was often all the instruction that was given.</td></tr>
<tr><td></td><td></td><td></td><td>Total</td><td>6</td><td></td></tr>
<tr><td>2</td><td>a</td><td></td><td>a measurement is precise if repeat readings are closely clustered (or reverse argument)

quantitative data used to support their conclusion</td><td>B1
B1</td><td>Allow if there is a small spread (of results about the mean value) / small range / small uncertainties (or small error bars on graph)
Ignore comments about number of sig figs

Either range, absolute or % error calculated correctly for at least one stated value of N

<table>
<tr><td>N</td><td>Range /s</td><td>abs unc/s)</td><td>%unc</td></tr>
<tr><td>1</td><td>0.6</td><td>+/- 0.3</td><td>2.1 or 4.2</td></tr>
<tr><td>2</td><td>0.7</td><td>+/- 0.4</td><td>0.8 1.6</td></tr>
<tr><td>3</td><td>1.4</td><td>+/- 0.7</td><td>0.6 1.2</td></tr>
<tr><td>4</td><td>1.6</td><td>+/- 0.8</td><td>0.4 0.8</td></tr>
<tr><td>5</td><td>10.5</td><td>+/- 5.3</td><td>1.5 3.0</td></tr>
<tr><td>6</td><td>13.2</td><td>+/- 6.6</td><td>1.3 2.6</td></tr>
</table>

<u>Examiner’s Comments</u>

There is still a common misconception that data given to 3s.f. is more precise than data given to 2s.f. However, most candidates were able to describe a precise data set in terms of a narrow spread, or a small percentage uncertainty. Unfortunately, these candidates were often vague in their evaluation of the given data, giving statements that were too general such as ‘the data is fairly close together’ or ‘it gets less precise as N increases’. Some candidates made statements such as ‘For N = 1, the range is 0.6s’, and they were given credit, but a better answer would go on to compare this to the mean value of 14.4s saying, for example, that this gives a percentage uncertainty of 4.2%</td></tr>
<tr><td></td><td>b</td><td></td><td>14.4 <u>and</u> 50.0</td><td>B1</td><td>Both values given to 1dp
Mark entries in first table (on page 4) only if second table (on page 6) is left blank

<u>Examiner’s Comments</u>

It is good practice to give all values in a column of a table to the same number of decimal places.</td></tr>
<tr><td></td><td>c</td><td>i</td><td>y-axis labelled “T / s”

y-axis scale completed</td><td>B1
B1</td><td>Allow suitable equivalent e.g. T (s), Time in secs

Scales markings of 100, 200, 300, 400 and 500 every 2 cm</td></tr>
</table>

			correctly all six x-co-ordinates correctly plotted all six data points plotted accurately	M1 A1	Check at 1, 4, 9, 16, 25 and 36; ±½ small square tolerance. Check visually by fit to bfl; ±½ small square tolerance. **ECF** candidate's values for *N* =1 and 2 **Examiner's Comments** It was easy to put a scale onto this graph, and very few candidates used a non-linear scale or one with a poor choice of intervals. Some candidates, however, forgot to add units to their time axis. Most plotted the points easily, although the first point often proved tricky.
		ii	suitable best fit line	B1	There must be an even scatter of points above and below the line **Examiner's Comments** Almost all candidates were able to draw a best fit line with an even scatter of points above and below the line
		iii	evidence of use of at least half of the width of the drawn line Gradient =14 (s)	B1 B1	Evidenced by triangle drawn on graph or by Δx in working for gradient Correct line should have $\Delta x \geq 17.5$ **Allow** any answer between 13 and 15(s) **ECF** candidate's own best fit line **Examiner's Comments** Again, this was well done, with most candidates choosing a large triangle to calculate their gradient and drawing it onto the graph. Note that it is important to use points on the line of best fit to calculate a gradient (which are not necessarily points from the table).
		iv	$R = \frac{gradient}{C \ln 2}$ Value of *R* is in the range 19 – 22 (kΩ) uncertainty is 5% of *R* with value given to same number of dp as *R*	B1 B1	For reference, *R* in $k\Omega = \frac{\text{gradient value in d(iii)}}{0.69}$ **ECF** candidate's gradient value in **d(iii)** **Allow** answer given in Ohms if unit clearly stated **Allow** answer given to 1sf i.e. 20 (kΩ) **Expect** 1 (kΩ) **Allow** to more than 1 s.f. but uncertainty <u>must</u> be given to same number of d.p. as candidate's value for *R* If answer given in Ohms, **allow** uncertainty also given in Ohms to same number of d.p. as *R* **Examiner's Comments**

					Common problems in 2(d)(iv) • giving the value of *R* in Ω rather than kΩ. • giving the value and its absolute uncertainty to a different number of decimal places.
	d	i	systematic	B1	**Examiner's Comments** This was a systematic error, since it would affect all the results for *N* = 6 (and for larger values of *N*, if taken) in the same way
		ii	(smaller T value for N = 6 so) smaller gradient and therefore smaller R value	B1	**Ignore** references to smaller or bigger *C* **Examiner's Comments** The students calculated their value for *R* by using the formula *R* (in kΩ) = ln (2) / gradient. If their sixth capacitance was too small then their gradient would also have been too small (because their point for *N* = 6 (N^2 = 36) would have been slightly lower). This means that their calculated value for *R* would have been too small.
			Total	**14**	
3			**B or D**	1	**Examiner's Comments** Many candidates used their knowledge of circular motion to select either option B or option D, both of which were acceptable, being mathematically equivalent.
			Total	**1**	
4	a		Calculates gradient using at least half the graph *eV=hf* **Or** *h=gradient* × 1.6 × 10^{-19} *h* = *3.5* × 10^{-34} J s	B1 C1 A1	Minimum range of x value 3.5x10^{14} Range 3.4 to 3.5 × 10^{-34} J s 2sf **Examiner's Comments** There was some variability in performance with this question, but many responses achieved 3 marks for a correct calculation and value for the Planck constant using data from the graph. The most common reason for responses being given 0 marks were for an error in their gradient calculations for either taking readings from less than half the graph, or for not including the correct power for frequency 10^{14}. Some candidates did correctly calculate the gradient from the graph, but then did not select and apply eV=hf to calculate a value of the Planck constant.
	b		$\frac{6.63 \times 10^{-34} - 3.5 \times 10^{-34}}{6.63 \times 10^{-34}}$ 47%	C1 A1	**ECF** from (b) **Allow** range 47% to 49%

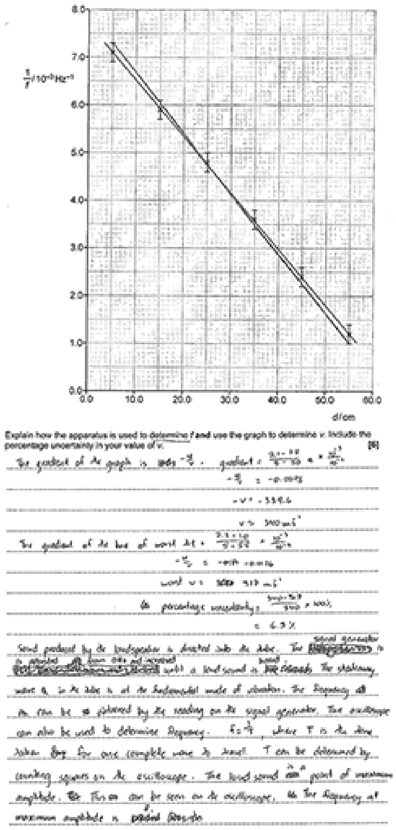
					Not 50% from 52.8% if calculated from $3.5\times10^{-34}/6.63\times10^{-34}$ **Examiner's Comments** Candidates did not perform well on this question as many candidates were given 0 marks. The most common reason for candidates not achieving marks was for not calculating a difference between the calculated and accepted value for the Planck constant with many candidates carrying out the calculation calculated value/accepted value x 100%. **Assessment for learning** Please refer to page 36 of the Practical Skills Handbook for information on correct methodology on calculating percentage difference between calculated and accepted values.
			Total	**5**	
5			**C**	1	**Examiner's Comments** Candidates performed well on this question to correctly calculate the percentage uncertainty in the calculated value of W as answer C, by calculating the sum of each individual percentage uncertainty in each measurement.
			Total	**1**	
6			B	1	**Examiner's Comments** Around two thirds of candidates were able to correctly apply the zero error in their calculation. **D** was a common distractor where the zero error was added onto the micrometre reading.
			Total	**1**	
7			**Level 3 (5-6 marks)** Clear description of method to measure *h* and *t* **and** graph analysed to determine *g* and the percentage uncertainty in *g* *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.*	B1 x 6	Use level of response annotations in RM Assessor **Indicative scientific points may include:** **Description of method to** measure *h* and *t* • Use of metre rule(r) / tape measure (not ruler) • Place rule in retort stand • Use of set square / fiducial marker • Timer (or datalogger / computer with detail) connected to electromagnet / trapdoor • Switch off electromagnet to start timer and drop ball • When ball hits trapdoor timer is stopped.

			Level 2 (3-4 marks) Some description of method to measure *h* and *t* **and** analysis of graph attempted to determine *g* and percentage uncertainty in *g* **or** Clear description of method to measure *h* and *t* **and** limited analysis of graph to determine *g* **or** Limited description of method to measure *h* or *t* **and** graph analysed to determine *g* and the percentage uncertainty in *g* *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 of the method to measure *h* or *t* **or** Limited analysis to determine *g* *There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.* **0 mark** *No response or no response worthy of credit.*		• Allow for diameter of ball in height measurement • Resolution of instruments millimetre /millisecond **Ignore** light gates, video **Analysis of data** • Gradient = $\sqrt{\frac{2}{g}}$ or $g = \frac{2}{\text{gradient}^2}$ • Evidence of method of determining gradient • Gradient in the range 0.44 to 0.47 • Determines *g* (≈9.5 m s^{-2}) • Correct power of ten and unit • Draws worst acceptable line • Determines gradient of worst acceptable line • Calculates absolute uncertainty in gradient • Determines *g* from worst acceptable line • Determines percentage uncertainty in gradient • Percentage uncertainty in *g* either 2 × percentage uncertainty in gradient or from *g* values **<u>Examiner's Comments</u>** This question was designed to test candidates' understanding of practical techniques both designing an experiment and analysing results. High scoring candidates described measuring *h* using a metre rule or tape measure and allowed for the diameter of the ball. Many candidates were unable to explain the use of the electromagnet to release the ball. Some low scoring candidates suggested using a stopwatch. Since the time measurements were recorded to the nearest millisecond it was expected that candidates would describe how the electromagnet and light gate would connect to an electronic timer or datalogger. For the analysis, candidates were expected to link the given equation to the equation of a straight line and thus identify how *g* was related to the gradient. The next logical step would then be to calculate the gradient. For this, it was expected that candidates would demonstrate substituting values from the line on the graph (not data points from the table) to determine the gradient and thus calculate a value of *g* with an appropriate unit. To determine percentage uncertainty, candidate needed to draw the worst acceptable line. This should be either the steepest or shallowest line that passes within all the error bars. Candidates then needed to calculate the worst acceptable gradient. Candidates gained credit for either calculating the percentage uncertainty in *g* from twice the

					percentage uncertainty in the gradient or from calculating worst value of g and then determining the percentage uncertainty. **Assessment for learning** Candidates should have the opportunity to practise determining values for constants using the gradient and y-intercept of straight-line graphs. Candidates should have the opportunity to practise drawing worst acceptable straight lines through error bars and understand the techniques to determine uncertainties in calculated constants using the worst acceptable gradient and/or y-intercept.
			Total	**6**	
8		i	$\varepsilon = I\,(R + r)$ $R = \rho L/A$ **and** $A = \pi d^{2}/4$ clear steps leading to given equation	M1 M1 A1	**Allow** $\varepsilon = V + Ir$ **and** $V = IR$ **Allow** $A = \pi r^2$ **and** $r = d/2$ **Allow** area formula by inference, if clear **<u>Examiner's Comments</u>** Almost all candidates showed excellent ability in substituting and rearranging equations. The starting point was $\varepsilon = I\,(R + r)$ where $R = \rho L/A$. Some candidates rearranged $\varepsilon = I\,(R + r)$ before writing it down, starting with $R = \varepsilon / I - r$ or similar. Centres should encourage starting a proof with the standard form of the equations. The main difficulty was in substituting $A = \pi r^2 = \pi(d/2)^2$ into the formula for R. Poor presentation occasionally made responses difficult to mark.
		ii	(gradient = Δy/Δx where Δx ≥ 0.35) gradient = **5.0 ($A^{-1}\ m^{-1}$)** $\rho = \frac{\pi \times (0.455 \times 10^{-3})^2 \times 1.45 \times gradient}{4}$ ρ = **1.2×10^{-6} (Ω m)**	C1 A1	**Allow** answer to 1sf Mark is **either** for the correct gradient **or** for working which would lead to 5.00 ± 0.10, seen anywhere in the question Correct to at least 2sf **Allow** the correct answer with no working shown for if the gradient (or working for the gradient) is correct **Allow ECF** for gradient ($\rho = 2.358 \times 10^{-7}$ × gradient) **<u>Examiner's Comments</u>** A gradient of 5 was chosen here deliberately to make the question as accessible as possible. Most candidates were

					able to see from the equation that the gradient would be equal to 4 $\rho/\pi\varepsilon d^2$. However, a significant number did not remember that d was measured in mm and so they had a power of ten error in their value for ρ. The question asks, 'Calculate the gradient ... and use this to determine ... the resistivity ρ'. It was helpful when candidates wrote down 'gradient = ...' to make their working clear.
		iii	r = y-intercept × ε = 0.40 × 1.45 r = **0.58(Ω)** y-intercept$_{MAX}$ = 0.73 (A^{-1}) **EITHER** Fractional uncertainty in r = 0.05/1.45 + 0.33/0.40 = 0.034 + 0.825 = 0.86 0.86 x 0.58 = 0.5(Ω) to 1sf so **r = 0.6 ± 0.5** (Ω) **OR** r_{MAX} = y-intercept$_{MAX}$ × ε_{MAX} = 0.73 x 1.5 = 1.1(Ω) 1.1 − 0.58 = 0.5(Ω) to 1sf so **r = 0.6 ± 0.5** (Ω)	B1 M1 A1 A1 (A1) (A1)	Mark is for working leading to the correct value of r. r = 0.58(Ω) seen either in working or on answer line implies B1 **Allow** answers in the range 0.70 to 0.75 **Ignore** any attempt to calculate uncertainty in gradient Expect answers in the range 0.78 − 0.91 (or 78% to 91%) **Ignore** units if given Expect answers for absolute uncertainty in the range 0.45 − 0.53 Value and uncertainty <u>must</u> be given to same number of dp Expect answers in the range 1.05 − 1.13 Expect answers for absolute uncertainty in the range 0.45 − 0.55 Value and uncertainty <u>must</u> be given to same number of dp Special case: **allow** abs unc of 0.55 giving r = 0.6 ± 0.6 (Ω) **<u>Examiner's Comments</u>** From the equation, y-intercept = r/ε and so r = y-intercept × ε. This was a relatively simple calculation. From the question stem, ε = 1.45 ± 0.05 V and, from the graph, y-intercept = 0.40 ± 0.33. Since r is found by multiplying y-intercept and ε, we can apply the rule: % uncertainty in r = % uncertainty in y-intercept + % uncertainty in ε. An alternative approach is to find the upper bound for r, which is the greatest value of y-intercept (0.73 from graph) × greatest value of ε (1.45 + 0.05 = 1.5V). Candidates should be reminded to quote the uncertainty to the same number of decimal places as their value for the

					internal resistance. Once again, poor presentation often made responses difficult to mark. For example, it is much easier to award a mark for the statement ‘intercept of worst line = 0.7’ or ‘intercept = 0.4 ± 0.3’ than to try and spot it mid-calculation.
			Total	**9**	
9			**Level 3 (5–6 marks)** Clear description of method to determine *f* **and** graph analysed to determine *v* and the percentage uncertainty in *v* *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 of method to determine *f* **and** some analysis of data to determine *v* or the percentage uncertainty in *v* **or** Limited description of method to determine *f* **and** graph analysed to determine *v* and an attempt to determine the percentage uncertainty in *v* **or** Clear description of method to determine *f* **and** limited analysis of graph *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 of the method to determine *f* **or** Limited analysis to determine *v*	B1 × 6	Use level of response annotations in RM Assessor **Indicative scientific points may include:** **Description of method** • Adjust frequency until maximum amplitude observed / heard • Start from a low frequency • Since fundamental frequency is the lowest resonance • Measure period of wave on oscilloscope • Period = timebase x horizontal distance • $f = 1/T$ • read frequency from signal generator. **Analysis of data** • Gradient = $-\frac{4}{v}$ • Determines gradient of line (-0.012 $Hz^{-1}\ m^{-1}$) • Determines v (330 to 344 $m\ s^{-1}$) • Correct power of ten and unit • Draws worst acceptable line • Determines gradient of worst acceptable line • Calculates absolute uncertainty in gradient • Determines percentage uncertainty in gradient • Percentage uncertainty in gradient = percentage uncertainty in *v* <u>**Examiner’s Comments**</u> The second level of response question gave candidates the opportunity of drawing conclusions from an experiment as well as explaining how the fundamental frequency *f* may be determined experimentally. For good answers to these type of questions, candidates need to structure their answers logically so that all parts of the question are answered. An explanation to determine *f* should include the adjustment of the frequency and how to determine the fundamental frequency with the idea of the loudest sound. More successful candidates discussed the peak on the

			There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant. **0 mark** *No response or no response worthy of credit.*		oscilloscope and starting from a low frequency. It was also expected that candidates could describe how to determine the frequency from an oscilloscope. Ideally reference would be made to the time-base. To determine the value of *v* with the percentage uncertainty, candidates needed to show their working clearly, taking into account the powers of ten and units from the graph. Exemplar 3  This candidate's response is structured and detailed. Firstly, this candidate has added the steepest worst acceptable line to the graph which passes through all the error bars. The candidate then identifies how the gradient is related to the frequency of the wave before calculating the gradient. The calculation of the gradient is demonstrated and the candidate has also clearly taken into account the powers of ten on each axis of the graph before determining *v* with a correct unit. This process is repeated for the worst acceptable line with each of the steps shown before percentage uncertainty is calculated. Throughout this section, it is easy to follow the candidate's method. It is clear that the candidate has used a large triangle to calculate the gradient.

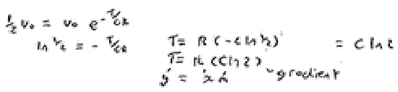
					The candidate then explains how *f* is determined by adjusting the signal generator until a loud sound is heard and then explaining how the frequency is determined by the oscilloscope.
			Total	**6**	
10		i	callipers	B1	**<u>Examiner's Comments</u>** Many candidates stated a ruler or metre rule without realising that these measuring instruments had a resolution of 1 mm not 0.1 mm. Other candidates incorrectly stated micrometer – a micrometer is not usually used for distances greater than two or three centimetres and normally a micrometer has a resolution of 0.01 mm or better. **Assessment for learning** Candidates should experience a wide range of measuring instruments in a science laboratory.
		ii	32.7 ± 0.2 (mm)	B1	**<u>Examiner's Comments</u>** Most candidates correctly determined *x* but a significant minority of candidates did not realise that the uncertainty in the measurements needed to be added. **Assessment for learning** Candidates should understand that when quantities are added or subtracted the absolute uncertainties are added. **OCR support** In the Practical Skills Handbook there is a section on uncertainties.
		iii	18 ×0.0327 $(\frac{18 \times 0.0327}{9.81} =)$ 0.060 (2sf)	C1 A1	**ALLOW ECF** from **(a)(ii)** **ALLOW** 36 ×0.01635 (alternative method; 1 spring) **Note** Answer must be 2 sf **ALLOW** one mark for 0.06 (1sf) **ALLOW** one mark for 60 (power of ten error)

					Examiner's Comments The common error was to use 36 N m^{-1} as the force constant and 0.0327 m as the extension. Other errors included either rounding the answer to one significant figure (0.06) or not changing the millimetre to metre. Clear working was needed to allow error carried forward marks into the next section. **Misconception** A number of candidates did not understand significant figures. Candidates should understand the implication of trailing zeros both before and after the decimal place. For example, 0.06 is one significant figure, 0.060 is two significant figures, etc.
		iv	$W = \frac{1}{2} \times 18 \times 0.0327^2$ 9.6 $\times 10^{-3}$ (J)	C1 A1	**ALLOW ECF** from **(a)(ii)** and **(iii)** for POT and/or *k* E.g. For x = 32.7: 9.6 $\times 10^{3}$ (J) For k = 36 Nm^{-1}: 19.2 $\times 10^{-3}$ (J) For x = 32.7 and k = 36 N m^{-1}: 19.2 $\times 10^{3}$(J) **Examiner's Comments** Most candidates gained credit in this question. Many correctly used $W = 0.5kx^2$. Other candidates correctly used $W = 0.5Fx$ using their value for F from the previous part. Some lower scoring candidates incorrectly determined the change in gravitational potential energy.
			Total	**6**	
11		i	=1 × 0.00097 =1000 parsecs	A1	1030 to 3sf
		ii	=0.00097÷7.5 x 10^{-3} (x100%) =13%	C1 A1	NOT half of the precision here (reference specification) Accept 1 sig fig value 10% Unrounded answer is 12.93... % **Examiner's Comments** The maximum stellar distance is given by the smallest parallax Hipparcos can measure, i.e. 9.7 × 10^{-4} arcsec. The distance corresponding to this parallax is 1/9.7 × 10^{-4} = 1030 pc. To find the percentage uncertainty in the distance, candidates needed to divide the smallest detectable

					change in the parallax by the parallax itself. This is equivalent to the percentage uncertainty in the distance because of the reciprocal relationship of distance with parallax. Many candidates correctly determined both quantities. A minority of candidates confused the two similar sounding quantities.
			Total	3	
12			C	1	**<u>Examiner's Comments</u>** This question was answered correctly by the vast majority of candidates and it was encouraging to see detailed working at the side of the question.
			Total	1	
13		i	$f = 1/T$ working shown to give T^2 = $T^2 = \left(\frac{8\pi^2}{3g}\right)L$	B1 B1	**Allow** T = $T = 2\pi\left(\frac{2L}{3g}\right)^{\frac{1}{2}}$ **or** $f^2 = 1/T^2$ Subject must be T^2 **Allow** $T^2/L = 8\pi^2/3g$ **<u>Examiner's Comments</u>** The expected response here was to start from the given relationship $f = \frac{1}{2\pi}\sqrt{\frac{3g}{2L}}$ and then use $T = 1/f$ to manipulate the expression into the form $y = mx + c$. Candidates who recognised this generally had sufficient skill in algebra to arrive at the correct answer.
		ii	$g = \left(\frac{8\pi^2}{3 \times 2.64}\right)$ $g = 9.97$ (ms^{-2})	C1 A1	Answer must be given to at least 3sf **<u>Examiner's Comments</u>** Candidates needed to substitute gradient = 2.64 into the formula $g = \frac{8\pi^2}{3 \times \text{gradient}}$ This was arguably the easiest question on the paper. Although almost all candidates scored both marks, a few lost a mark through thinking that 9.97 = 10.0 to 3sf.
		iii	line of worst fit drawn	B1	Steepest or shallowest possible line that passes through all the error bars (allow ±½ small square tolerance vertically) If two lines are drawn then they must both be correct **<u>Examiner's Comments</u>**

					A line joining the top of the furthest right hand error bar to the bottom of the furthest left hand error bar (or vice versa) passed through all the error bars. Either was accepted. A tolerance of ±½ small square was allowed at either end. The most common misconception was that the worst fit line joined the top of the right hand error bar to the top of the left hand error bar (or vice versa).
		iv	gradient of worst line calculated with large triangle working to find percentage uncertainty in *g* answer consistent with candidate's worst line	B1 M1 A1	$\Delta L \geq 0.06$m Shallowest gradient ≈ 2.1($s^2\ m^{-1}$) and steepest ≈ 2.9 ($s^2\ m^{-1}$) $\frac{\text{worst value of g} - 9.97}{9.97}$ (x 100%) **Allow** % uncertainty in gradient = $\frac{\text{gradient of wfl} - 2.64}{2.64}$ (x 100%) Expect answer ≈ 10% (steepest wfl) and ≈ 27% (shallowest wfl) **Allow** a negative answer **<u>Examiner's Comments</u>** It is important to show all working in this type of question. Firstly, in checking the gradient of the worst fit line, the examiner needs to determine whether a large triangle has been used in the calculation. Therefore it is helpful if candidates draw the triangle they intend to use and write down all their read-offs. Secondly, the working to find the percentage uncertainty in *g* has to be shown in full because the correct answer is $\frac{\text{worst value of } g - 9.97}{9.97}$ and not $\frac{\text{worst value of } g - 9.97}{\text{worst value of } g}$ Although the percentage uncertainty in the gradient was not exactly the same as the percentage uncertainty in *g*, both methods were accepted.
		v	percentage difference = $\frac{9.97 - 9.81}{9.81}$ × 100% = 1.6% **or** absolute difference = 9.97 − 9.81 = 0.16 **or** absolute uncertainty = (9.97 − value of *g* from wfl) conclusion consistent with candidate's answer to **(b)(iv)**	M1 A1	Possible **ECF** from **(b)(ii)** Value for *g* is accurate if % uncertainty >% difference **or** if absolute uncertainty > absolute difference **or** if 9.81 lies within the uncertainty range for *g* **<u>Examiner's Comments</u>** Most candidates were able to calculate either the absolute or the percentage difference between the experimental result (9.97) and the true value of *g* (9.81). Many candidates wrongly called this the percentage uncertainty or the percentage error in the result, but their calculation was accepted anyway.

					A common misconception was that the relatively small percentage difference (1.6%) between the experimental result and the true values meant that the experiment was accurate. However, this is not necessarily the case. A result is only accurate if it is close to the true value and, unless we know the *uncertainty* in our result, we cannot judge whether or not this is the case. For example, suppose that the uncertainty in our result was 1% i.e. we found that g = 9.97±0.10. Then our result for g would *not* be accurate. Our result must be somewhere between 10.07 and 9.87, and the true value of g (9.81) lies outside this range.
			Total	**10**	
14		i	Oscilloscope / CRO	B1	**Allow** <u>a.c.</u> voltmeter **Ignore** datalogger / multimeter **<u>Examiner's Comments</u>** Most candidates appreciated that a voltage was to be measured, however it was evident that only a small proportion realised that it would be alternating and so a simple "voltmeter" would not be sufficient. Candidates putting the correct response of "oscilloscope" may well be those who have carried out practical work using search coils.
		ii	**1** f **2** θ or sin θ	B1 B1	**Not** any other symbol. **Only** mark quantity letters – ignore any words, but allow frequency. **Allow** θ or sinθ with any or all of K, I_0, A, N. **Only** mark quantity letters – ignore any words. **<u>Examiner's Comments</u>** Part 1 was answered better than part 2 in general. For part 1, the majority of candidates appreciated that the "rate" will have included the frequency although many included other irrelevant (and therefore incorrect) terms too. In part 2, the concept of what causes the magnetic flux linkage to "change" did not appear to be well understood; A and/or N were often an incorrect response, presumably as the candidate was aware that these terms are included in a calculation for flux linkage.
		iii	$f = \frac{0.62}{5000 \times 4.0 \times 10^{-2} \times 8.0 \times 7.8 \times 10^{-5}}$ / f = 49.67…. (Hz) $\frac{0.2}{8.0}$ / $\frac{0.1}{7.8}$ / $\frac{0.03}{0.62}$ abs uncertainty = $(\frac{0.2}{8.0} + \frac{0.1}{7.8} + \frac{0.03}{0.62})$	C1 C1	Any individual raw uncertainty Max value = 54.11 (Hz) **and** min value = 45.54 (Hz) for f **Allow 8.6%** as evidence of this calculation

			×49.67… / 4.28… (Hz) f = 50 ± 4 (Hz)	C1 A1	For min / max method: difference / 2 = 4.29 (Hz) **Allow** ecf on abs uncertainty from incorrect f Any ecf on f must be given to 2sf and uncertainty sf consistent. **Not** the paper SF penalty **<u>Examiner's Comments</u>** A good fraction of candidates were able to score full marks on this question. It is clear that many had been well prepared in treatment of errors, and 8.6% was seen often in the working. A common mistake among more successful responses was giving the error as 4.3, rather than 4. Less successful often simply added the raw uncertainties, giving 0.33, which was often then placed on the answer line. Some candidates missed out the factor of 10^{-5} in their calculation of f. Other approaches to obtain errors, such as calculating maximum and minimum values for f were seen and these can also lead to full marks.
			Total	**7**	
15		i	Evidence of use of $V = V_0 e^{-t/CR}$ leading to ln (½) = $-T/CR$ or ln2 = T/CR $T = C\ln 2 \times R$ compared with $y = mx$ with gradient = $C\ln 2$	M1 A1	**Must** see exponential decay as starting point (allow Q for V) **Allow** t for T **Allow** x for V and x_0 for V_0 **Not** T/R = gradient **<u>Examiner's Comments</u>** The treatment of natural logs was generally well done across the ability range and those who started from a correct exponential equation were generally able to score the first mark. There was some confusion among the less successful responses about the role of the negative sign, without them appreciating that ln(2) = − ln (½) and it was evident that some simply ignored it. Although many candidates were able to get to the correct equation, few linked it appropriately to the equation of a straight line and did not show that the gradient was Cln2, as required. Exemplar 3 shows a candidate producing elegant solution.  A response that works through the logs clearly and then relates it well to the form of y = mx + c.
		ii	**1** Best-fit line drawn correctly gradient = 5.4 (× 10^{-9})	B1 B! B1	**Note** line must pass through all (vertical part of) error-bars. If more than one line drawn, all lines must pass through all error-bars (1/2 square tolerance). **Allow** ± 0.2 (× 10^{-9})

			2 C = (gradient / ln2) = 7.8×10^{-9} (F) $7.8 \times 10^{-9} = \frac{\varepsilon \times 3.1 \times 10^{-2}}{8.0 \times 10^{-5}}$ $\varepsilon = 2.0 \times 10^{-11}$ (Fm^{-1})	C1 A1	**Ignore** POT **Ecf** from incorrect gradient, but penalise POT error here Possible ECF from **(b)(ii)1** **Allow** 1 mark if final answer is relative permittivity correctly calculated (ε divided by 8.85 x× 10^{-12}) **<u>Examiner's Comments</u>** In part 1, nearly all the candidates were able to draw a correct straight best-fit line which passed through all the error bars. It was actually rather difficult not to do this, although several candidates did multiple lines (assuming they were unable to remove an original) and if any fell outside of the error bars, then it could not be given marks. In calculating the gradient, misreads from the graph were common either from the vertical scale or often assuming that the horizontal scale started from zero. A common mistake among the range of abilities was to miss out the 10^6 in the denominator of the gradient. Several candidates may have interpreted the question as meaning that the gradient was C, as they calculated the gradient but took it no further. Part 2 was generally well done by many candidates. Some of the less successful responses were unable to rearrange the capacitance equation correctly, often swapping over the d and A values. A small proportion calculated the relative permittivity and as long as this was done correctly, it could score the first mark. A common error was to attempt to use $C = 4\pi\varepsilon r$ which proved to be unproductive. **Assessment for learning** Good practice for straight best-fit lines includes: • A single straight line – not a line drawn in two or more parts. • Use of a sharp pencil – once a line is drawn in pen, it is almost impossible to correct. • Aiming to have an equal number of data points above and below the line – not always possible due to potential variations in data, but this should be a general aim. • Looking for anomalous points – should not form part of the best-fit.

					• Being aware of a false origin – if present then the line should not necessarily be expected to go through this point. • Drawing a line through the origin – would (0,0) be expected to be a data point, and consideration of a potential systematic error in the data. • Use of error bars – if present (generally in the dependent data), then the line must pass through the vertical error bars on every point.
			Total	**7**	
16			**B**	1	**<u>Examiner's Comments</u>** The candidates who got this correct spotted that the uncertainty should be calculated by finding half of the range.
			Total	**1**	
17		i	Line of best fit drawn	B1	**Not** drawn through 0.5/5.0 **<u>Examiner's Comments</u>** Most candidates performed well with this question as they correctly drew a line of best fit through the data points but a few candidates drew a line of best fit through the points (0.5, 5.0).
		ii	gradient <u>calculated</u> **and** gradient = 6.2×10^{-34} (J s) Correct use equation of straight line, **and** <u>gradient</u> to determine the *y*-intercept / φ $\varphi = 2.7 \times 10^{-19}$ (J)	C1 M1 A1	**Allow** value in the range 5.8 to 6.6×10^{-34} (J s) **ECF** from incorrect value of *h* **Allow** value in the range 2.4 to 3.0×10^{-19} (J) **<u>Examiner's Comments</u>** This question was assessing candidates' skill to calculate a gradient value from the graph and use this value in an expression for the equation of a straight line to determine a value for the work function of the material which was the y-intercept, therefore few candidates correctly calculated a value within a stated range. Candidates were not given marks for using the stated value of $h = 6.63 \times 10^{-34}$ J s as this did not assess the skill required by the question. Some candidates attempted to calculate a gradient value, so marks were given if they applied it in a correct expression of an equation for the straight line.
			Total	**4**	

18		i	**Any acceptable methods e.g.** Note matched to a note produced by a speaker connected to a variable (calibrated) signal generator/ Reduce background sound level **OR** Count the number of oscillations and divide by time taken (from a stopwatch/oscilloscope/slow motion camera) Take many oscillations e.g. 5 or 10/ longer time **OR** Microphone connected to oscilloscope to measure *T* / period <u>and</u> *f* = 1/*T*/period Reduce background sound level **OR** Use a (calibrated) strobe to determine the frequency Dim down the lights (AW) to get the best results	B1 B1	**Allow** vibration generator connected to a variable (calibrated) signal generator **Allow** Adjust signal generator to the fundamental frequency (when a stationary wave is achieved) **<u>Examiner's Comments</u>** The advance information listed that practical skills would be assessed within topic 4.4 waves, but only some candidates were able to describe a simple method to determine the fundamental frequency of the oscillating wire. Marks were still given for a suitable method for determining the fundamental frequency of any oscillating wire, e.g. using a vibration generator and variable signal generator but few candidates developed their method to describe how they would obtain accurate measurements, e.g. measuring the time for 10 oscillations and then dividing by 10 to find the time period *T*, etc. Candidates may not have had the opportunity to carry out this practical skill independently but they should be familiar with the procedure and how measurements are taken to accurately find the fundamental frequency of a stationary wave. Exemplar 2 The wavelength at the fundamental frequency is 2L, so they could have used speed = wavelength × frequency to find fundamental frequency, as when the wavelength is at 2L the fundamental frequency will appear be shown. They had [2] to do $\frac{speed}{2L}$ to find the fundamental frequency of the wire. It will be the point where there are nodes only at the supports. Exemplar 2 shows a typical middle range response. This response demonstrates a lack of knowledge and understanding of the practical skills required to measure the fundamental frequency as there is no description of a method to measure the time period of a stationary wave.
18		ii	**1** 1.24 (m) ($v = f\lambda$) **2** $v = 58 \times 1.24$ $v = 72$ (m s^{-1}) % uncertainty = [2 × 2.5] + 1.0 + 0.5 (= 6.5) **3** $0.065 \times [4 \times 58^2 \times 9.7 \times 10^{-4} \times 0.62]$ absolute uncertainty = 0.53 (N)	B1 C1 A1 C1 A1	**Allow** 1.2(m) **<u>Examiner's Comments</u>** Most candidates performed well on this question as they correctly applied that at the fundamental frequency $\lambda = 2L$. Candidates at the lower end did not recall the wavelength of the stationary wave in terms of the length of wire. **ECF** from (b)(ii)1 **<u>Examiner's Comments</u>** Nearly 80% of candidates correctly selected and applied the formula $v = f\lambda$. Where candidates had incorrectly determined the wavelength at the fundamental frequency,

					they were given marks for carrying out a correct calculation using their value. Answer to **2sf** only **Allow ECF** 1 mark for %uncertainty of 4% and absolute uncertainty 0.32N **2sf** **Examiner's Comments** About a third of candidates used the information given in the question to determine the percentage uncertainty of 6.5% and used this to find the absolute uncertainty. Some candidates used the maximum and minimum values of the tension to find the absolute uncertainty. Some candidates correctly calculated a value for the absolute uncertainty but did not give their answer to 2 significant figures as the question requested.
			Total	**7**	
19	a		$A = \frac{48 \times 10^{-8} \times 11.8}{31}$ or 1.827×10^{-7} $d^2 = \frac{4 \times 1.827 \times 10^{-7}}{\pi}$ or 2.326×10^{-7} 4.8×10^{-4} (m)	C1 C1 A1	**Allow** 5.82×10^{-8} (determines r^2) for 1 mark **Allow** 2.4×10^{-4} (determines r) for 2 marks **Examiner's Comments** Many candidates scored all three marks on this question. High scoring candidates often determined the cross-sectional area of the wire before determining the diameter. Some candidates omitted to take a square root or determined the radius of the wire.
	b	i	Correct symbols circuit for components including four cells Circuit diagram: ammeter connected in series with battery and ring A and voltmeter in parallel with ring A / battery.	B1 B1	**Ignore** other circuit components (e.g. rheostat) **Note** if variable resistor added to circuit then voltmeter must be in parallel with ring A. **Examiner's Comments** It was expected that the correct circuit symbols would be used. A small number of candidates were unable to position the ammeter and voltmeter correctly.
		ii	$R\left(=\frac{6.2}{0.34}\right) = 18\ (\Omega)$	A1	**Allow** 18.2 (Ω) **Examiner's Comments** The majority of the candidates answered this question correctly. Although it is a simple question, candidates should be advised to show their working.
		iii	$\frac{0.02}{0.34}(\times 100)$ or $\frac{0.2}{6.2}(\times 100)$ Percentage uncertainty (= 5.9 + 3.2) = 9.1 %	C1 A1	**Allow** max/min methods, e.g. $\frac{6.4}{0.32}$ or $\frac{6.0}{0.36}$ **Allow** 9 (%) **Do not allow** bald 10(%) **Examiner's Comments**

					This question was answered well by the large majority of candidates. Many correctly worked out the percentage uncertainty in the current and added it to the percentage uncertainty in the potential difference. This was the simplest method. A few candidates used maximum/minimum methods. In this case it needed to be maximum potential difference divided by minimum current or minimum potential difference divided by maximum current.
		iv	When using the battery pack, current is lower than when connected to the mains ORA When using the battery pack the temperature of the wire / heating effect is lower ORA	B1 B1	**<u>Examiner's Comments</u>** Candidates found this question challenging. Few candidates realised that the current was smaller so the heating effect would be less.
		v	Any **two** from: Repeat experiment with a different number of cells / use a variable resistor Use more sensitive meter(s) or reading to greater precision Plot a graph of *V* against *I*	1 B1 × 2	**Allow** variable power supply **Do not allow** power supply greater than 12 V **Do not allow** more accurate meters / digital meters **<u>Examiner's Comments</u>** There were many vague answers to this question. Ideally there should be more measurements taken. Some candidates discussed using a variable resistor or potentiometer in the circuit and other suggested then plotting a graph. Some candidates discussed increasing the power supply. Some candidates also suggested using more sensitive meters or meters reading to a greater precision. Marks were not given for using more accurate meters or digital meters.
			Total	**12**	