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 in the most part relevant.* **0 mark** *No response or no response worthy of credit.*	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 $\varepsilon = V + Ir$ **Examiner's Comments** 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 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.
			Total	**6**	
2			Circuit diagram Battery as power source **and** Voltmeter in parallel with thermistor **and** Ammeter in series with thermistor Record temperature (with a thermometer) and corresponding current and pd readings (as the temperature falls) Take at least 5 readings **or** take readings at regular intervals Calculates resistance using R=V/I	B1 B1 B1 B1	All circuit symbols correct **Ignore** other components drawn in the circuit diagram e.g. variable resistor **Allow** stated temperature intervals for recording temperature **Allow** voltage for potential difference Correct rearrangement required **Examiner's Comments** Overall, candidates performed well on this question with most achieving at least 1 mark and some achieving over 2 marks. Most candidates were given marks for a correctly drawn circuit diagram (including current circuit symbols for the components required

					for the investigation) and for a correct rearrangement of V=IR to be able calculate the resistance. Some candidates would describe that measurements would need to be read from the ammeter and voltmeter, which was insufficient as the measurements of current and potential difference needed to be specified to achieve the mark.
			Total	**4**	
3			**C**	1	**Examiner's Comments** Overall, candidates performed well. They correctly determined that because the copper wire, **Q**, has an equal cross-sectional area to copper wire, **P**, that *n* (the number density of charge carriers) is the same for both wires. Most candidates determined that the resistance of **Q** would double in size due to the length of wire **Q** being twice as long, hence why the most common distractor was D.
			Total	**1**	
4	a	i	use (vernier / digital / dial) calliper(s) **or** micrometer (taking readings) at different positions / orientations (along the wire)	B1 B1	**Ignore** take multiple readings **Examiner's Comments** There are five measurements listed, so we were expecting candidates to comment on sampling the diameter at various locations/orientations as well as naming the measuring instrument used.
		ii	exclude the 0.495 (mm) anomaly add the remaining 4 values and divide by 4 / calculate mean of the remaining values calculate half the range of the remaining values	M1 A1 A1	May be inferred from calculations **Allow** the correct calculation which leads to 0.455 **Ignore** references to median or mode or average **Allow** the correct calculation which leads to 0.005 **Ignore** difference between mean and highest (or lowest) value **Ignore** references to resolution of the measuring instrument **Examiner's Comments**

					If you add all 5 results together and divide by 5, the answer does not come to 0.455 mm. So clearly the student in the question has discarded the anomalous result in the table before performing their calculation. The general rule for giving a single result from a set of data is to calculate the *mean* average (not the mode or the median). The uncertainty is found from half the range. Giving the uncertainty as ± half of the smallest scale division is the general rule to use when we have only one single reading, which is not the case here. **How to quote a single result from a set of data** • Use the *mean* average • Uncertainty = half the range
•	b	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 (ρ = 2.358 × 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)	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

			1.1 − 0.58 = 0.5(Ω) to 1sf so **r = 0.6 ± 0.5** (Ω)		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	**14**	
5			D	1	**<u>Examiner's Comments</u>** This question was generally answered well with most candidates correctly determining that as the temperature of the filament lamp increased so did the

					resistance of the filament lamp. By applying *V* = *IR* they then determined that the potential difference would also increase due to increased resistance. The most common distractor was C.
			Total	**1**	
6			C	1	**Examiner's Comments** This question was answered well with most candidates giving the correct answer C by applying the equation $R = \rho L/A$ for a conductor.
			Total	**1**	
7			C	1	**Examiner's Comments** This question was answered well as candidates were able to determine the correct expression for the gradient by applying the equation $R = \rho L/A$.
			Total	**1**	
8			A	1	**Examiner's Comments** This question will have looked familiar to many candidates, as it involves changing dimensions of wire to calculate a value. Here, however, the question is asking about the resistivity of the wire which (given that they are both copper) remains the same. Only a little over one quarter of the candidates appreciated this; by far the majority calculated the ratio of resistances and gave the response **B**. This highlights the importance of reading the question carefully and not assuming that it is the same as one they have previously seen.
			Total	**1**	
9	a		e.m.f → (chemical) to electrical and p.d. → from electrical (to thermal / heat)	B1	**Allow** e.m.f. is work done on charges and pd is work by charges **Allow** battery for e.m.f and resistor for

			or e.m.f → charges/electrons gain energy and p.d. → charges/electrons lose energy		p.d. **Allow** less p.d. (than e.m.f.) due to energy transferred in <u>internal</u> resistance (must be clear that it is internal or cell resistance and not any other circuit resistance). **AW** **<u>Examiner's Comments</u>** The important word in this question is energy and so any response needs to be framed with this in mind. This is directly from the specification point 4.2.2 (e). Many candidates stated differences between the magnitudes of the e.m.f. and p.d. without referring to energy and so could not be given a mark. There were many good responses, and the simplest was to state how the electrical energy is transferred in each case.
	b		length (of wire)	B1	**<u>Examiner's Comments</u>** This was correctly answered by the majority of candidates; it was clear that some had not read the question and answered along the lines of changing the number of turns/coils, presumably thinking about a rheostat. Another common incorrect answer was temperature.
	c	i	$E = V + Ir$ / $E = IR + Ir$ / $E = I(R + r)$ Clear manipulation leading to $\frac{1}{I} = \frac{R}{E} + \frac{r}{E}$	M1 A1	**Allow** ε for E throughout **Expect** at least one line of intermediate correct algebra leading to correct expression, explicitly shown. **<u>Examiner's Comments</u>** Many candidates were able to do this relatively simple manipulation. The circuit diagram should alert the candidates that this question is based on internal resistance and allow them to select one of the appropriate starting points. Some less successful responses chose other routes, such as $I = I_1 + I_2$, but then quickly found

					themselves unable to go further, unless by using incorrect algebra.
		ii	**1** I^{-1} = 0.8 (A^{-1}) / I = 1.25 (A) P (= 1.25^2 × 3.0) = 4.7 (W) **2** (Intercept =) 0.20 (A^{-1}) r = (0.20 × 5.0) = 1.0 (Ω)	C1 A1 M1 A1	**Allow** I = 1.3 (A). **Expect** at least 2sf. **No ecf** from graph misread. **Allow** 5.1 (W) from use of 1.3 (A) Value of 0.2 anywhere in calculation implies correct reading of intercept. **Allow** ± 0.02. **Allow** current = 5 (A) implies intercept correctly read **Do not allow** substitutions into $E = IR + Ir$ other than using the intercept. **Allow** 1 SF answer **Alternative** r = (E / I = 5 / 5) = 1.0 (Ω) **<u>Examiner's Comments</u>** The vast majority of candidates were able to complete 1 correctly – there were few misreads from the graph, although some candidates took the reading of 0.8 as the current rather than the inverse of the current. There were also a few arithmetic slips with some candidates correctly setting out their calculation, such as $P = 1.25^2$ × 3.0, but then not squaring the current. 2 was answered slightly less successfully and although the reading of the intercept was taken, some candidates could go no further.
			Total	**8**	
10			**B**	1	**<u>Examiner's Comments</u>** This proved to be a challenging question with only around a quarter of the candidates able to obtain the correct response. It was likely that written working was helpful here and many candidates set out some form of a potential divider calculation. Some did this in ratios and others made up a value for the two resistances (e.g. 10 Ω) which they then decreased to 8.0 Ω for the thermistor. The incorrect responses were spread fairly evenly

					across the distractors, which is maybe surprising as it would be expected that candidates should have appreciated that the p.d. across the thermistor would now be less than the initial 4.5 V.
			Total	1	
11	a	i	Graph from 1.5 V at **0/A** to 0 V at **L/B** Curve of decreasing gradient	M1 A1	**Allow** curve of increasing gradient/straight line **Examiner's Comments** Many candidates were given no marks for this question and there was a significant number of candidates who omitted the question. Typical incorrect responses were to draw a line showing a directly proportional relationship between *V* and *L*. Very few candidates were given 2 marks for correctly showing a decreasing gradient.
		ii	At **A** / *x* = 0, *V* = 1.5 V and at **B** / x = *L*, *V* = 0.75 V/p.d is shared/halved Total resistance increases so current decreases (as length of wire **L** and resistor of **R** are in series)	B1 B1	**Allow** *V* (across **R**) decreases as *x* increases (as **S** moves from **A** to **B**) **Allow** Explanation of potential divider e.g. At **B** resistance of length of wire = resistance of **R** **Examiner's Comments** Over half of candidates were given no marks for this question as they would often confuse the potential difference *V* across the fixed resistor with the potential difference across the resistance wire and because they had not determined that when the connecting wire BC was removed the resistance wire and fixed resistor were in series. If candidates were given 1 mark it was for correctly describing the relationship between *V* and *x* but with little or confused understanding of a potential divider.
	b	i	p.d across wire = 14.4 − 12.0 = (2.4 V) resistance of wire $\frac{2.4}{3.0}$ (= 0.80Ω) $0.80 = \frac{\rho \times 25.0}{0.54 \times 10^{-6}}$ ρ = 1.7 xd7; 10^{-8} (Ω m)	C1 C1	**ECF** R = 2.8Ω (V = 8.4 V) to give *ρ* = 6.0 × 10^{-8} (Ω m) for 3 marks **Examiner's Comments** Candidates did not perform well on

				C1 A1	this question as they did not understand what the question was asking candidates to calculate. The skill and understanding with this question were to first determine that the p.d. was shared across the two lamps and the metal wire which most candidates did not do and apply it to calculate a value of resistance of the metal wire. Candidates were able to select and carry out a correct calculation using $R = \rho L/A$ which demonstrated that they understood a value for resistance was required for the calculation but many used an incorrect value of *R*. Many candidates would calculate the resistance of the metal wire as R = 6.0 V / 3.0 A = 2 Ω (the resistance of one of the lamps) and would also not correctly convert the cross-sectional area into m^2. **Misconception** Candidates did not fully read the question that the resistivity of the metal wire **only** was to be calculated and that to calculate the resistivity correctly they had to determine the p.d. across the metal wire (p.d. across the wire = 14.4 V – (2 × 6.0 V)). Conversion error as candidates did not convert mm^2 to m^2 for the cross-sectional area.
		ii	($I = Anev$) $3.0 = 0.54 \times 10^{-6} \times 1.60 \times 10^{-19} \times 8.5 \times 10^{28} \times v$ $v = 4.1 \times 10^{-4}$ (m s^{-1})	C1 A1	Do not penalise the same **POT** error in 0.54 mm^2 from **(c)(i)** again **<u>Examiner's Comments</u>** Most candidates were given at least 1 mark with half the candidates correctly calculating the drift velocity using the formula $I = Anev$. Less successful responses did not select the correct formula and some candidates had an incorrect or absent conversion of the cross-sectional area to m^2.

			Total	**10**	
12			A	1	**Examiner's Comments** Generally, candidates performed well on this question as they used and applied their knowledge that resistance decreased non-linearly with temperature. The most common distractor was answer B.
			Total	**1**	
13	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 <u>four</u> 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(%) **<u>Examiner's Comments</u>** 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**	