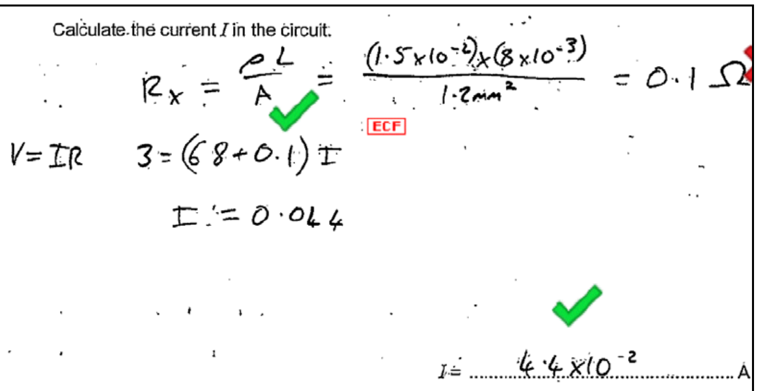
Mark scheme - Resistivity

Question			Answer/Indicative content	Marks	Guidance
1			**A**	1	
			Total	**1**	
2			D	1	
			Total	**1**	
3			**C**	1	
			Total	**1**	
4			**D**	1	**<u>Examiner's Comments</u>** This question was about the resistance equation $R = \frac{\rho L}{A}$ which appears in the Data, Formulae and Relationship Booklet. This was a good discriminator for the top-end candidates. The majority of the candidates opted for the answer C, which was simply 1.50 times the original resistance of the wire. The crucial statement that the 'volume of the wire remains the same' was omitted by most candidates. The volume of the wire remains constant. The cross-sectional area of the wire will decrease by a factor of 1.50 as its length increases by this same factor. Since resistance $R \propto \frac{L}{A}$, this implies that the resistance of the stretched wire will increase by a factor of 1.50^2. This makes the resistance of the extended wire equal to $1.50^2 \times 3.00 = 6.75\ \Omega$. The analysis above shows how it is easy to follow incorrect logic when a single pivotal statement in the question is skimmed over.
			Total	**1**	
5			C	1	
			Total	**1**	
6			B	1	**<u>Examiner's Comments</u>** This was a question on combining together three important expression in the topic of electricity; $V = IR$, $R = \rho L/A$ and $I = Anev$. On top of this, there was the additional information that **P** and **Q** were in parallel and hence the potential difference across each wire was the same. The mean drift velocity *v* of the electrons is given by the expression $v = \frac{V}{ne\rho L} \propto \frac{1}{L}$. The cross-sectional area *A*, and hence the diameter *d* of the wire has no effect on *v*. The relationship above implies that for

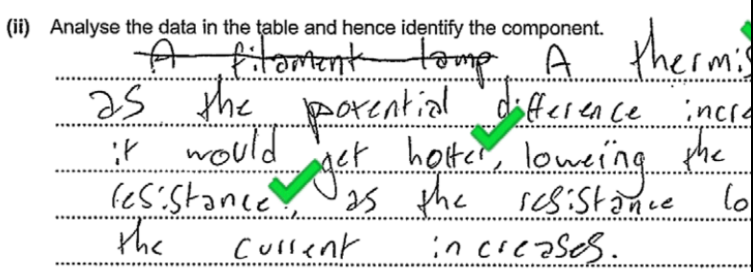
					wire **Q**, $v = \frac{1}{3} \times 0.60 = 0.20$ mm s^{-1}. The correct answer is **B**. All the distractors were equally popular. About a third of the candidates, mostly from the very top end of the ability range, were successful in this very demanding question.
			Total	**1**	
7			**C**	1	
			Total	**1**	
8			A	1	
			Total	**1**	
9			**B**	**1**	
			Total	**1**	
10			$R = \frac{\rho L}{A} = \frac{1.5 \times 10^{-2} \times 8.0 \times 10^{-3}}{1.2 \times 10^{-6}}$ **or** 100(Ω) (total resistance =) 168 (Ω) (current = 3.0/168) I = 0.018 A	**C1** **C1** **A1**	Possible POT error here **Note** using $A = (1.2 \times 10^{-6})^2$ is wrong physics, hence this C1 mark is lost Possible ECF from incorrect value of R for this C1 mark and the next A1 mark **Allow** 2 marks 0.044 (A); A taken as 1.2×10^{-3}, which gives R = **0.1** and I = 3.0/**68.1** = 0.044 (A) **Not** I = 3.0/**68** = 0.044 (A) because this is wrong physics **Examiner's Comments** There were several challenges in this question. Success was dependent on knowledge of resistivity and series circuit. There was also the added complication of converting the 12 mm^2 to 12×10^{-6} m^2. The most common error was with powers of ten, with the resistance calculated as 0.1 Ω instead of 100 Ω − where 1 mm^2 was being taken as 10^{-3} m^2 rather than 10^{-6} m^2. **Exemplar 11**

					 Calculate the current I in the circuit. $R_x = \frac{\rho L}{A} = \frac{(1.5\times10^{-6})\times(8\times10^{-3})}{1.2 mm^2} = 0.1\ \Omega$ ECF $V=IR$ $3=(68+0.1)I$ $I = 0.044$ $I = 4.4\times10^{-2}$ A This exemplar illustrates how even top−end candidates can lose a mark. The error in the powers of ten has been penalised by the examiner. This incorrect value has then been allowed through subsequent calculations. Two marks have been gained even though the final answer is incorrect. It is worth remembering the knowing your physics will always pay dividends.
			Total	**2**	
1 1			Silicon will have a smaller number density, ORA Silicon will have a larger resistivity, ORA	B1 B1	**Allow** semiconductor for silicon; metal for nichrome **Examiner's Comments** High achieving candidates found this question straightforward. Some candidates on (a)(iii) used *N* instead of *n*. Part (b) caused the most difficulty with candidates either using 150 W rather than 0.150 kW or changing the time to seconds. **Misconception** The worst acceptable line is either the steepest line that passes within all the error bars or the shallowest error line that passes within all the error bars.
			Total	**2**	
1 2			L → [m] and A → [m^2] **or** L/A → [m^{-1}] kg m^3 s^{-3} A^{-2}	C1 A1	**Allow** $\frac{\text{kg m}^3}{\text{s}^3\ \text{A}^2}$ **or** kg m^3/s^3 A^2 **Examiner's Comments** The majority of the candidates effortlessly showed the base units for resistivity to be kg m^3 s^{-3} A^{-2}. The structure from most was immaculate. It was good to see shortcuts being used too. Some candidates went straight to the units for resistivity (Ω m), and then multiplied the units given for resistance multiplied by m. **Misconception**

					The most common misconception, mainly at the lower end, was that the A in the resistance equation was the unit for current, the ampere A. This led to the incorrect answer kg ms^{-3} A^{-1}
			Total	**2**	
13	a	i	Manipulate R = V/I and R = ρ t / L^2	M1	
		i	Rearrangement	M1	
		ii	0.13 × (25 × $10^{-3})^2$ / 32 × 10^{-3} × 0.60 × 10^{-3}	C1	Watch for attention to units
		iii	= 4.2 Ω m	A1	
	b		Relate current to energy transfer / temperature increase	B1	AW
			More free electrons	B1	
			Total	**6**	
14	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	$\left(\%\text{ uncertainty} = \frac{2\times0.001}{0.049}\times 100 =\right)$ 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		$\rho = 5700 \times 1.9 \times 10^{-5}$	C1	**Note**: ECF from **(ii)** **Allow** any subject for equation **Not** use of data points from table
			$\rho = 0.108$ <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**	

15		i	$(\frac{1200}{300})$ 4.0	B1	**Allow** 1 SF
		ii	$180 = \frac{\rho \times 25}{6.7 \times 10^{-8}}$ $\rho = 4.8 \times 10^{-7}$ (Ω m)	C1 A1	**Note** answer is 4.82×10^{-7} to 3 SF
			Total	**3**	
16			Any **three** from: • Total resistance of the lamps increases by a factor of 1.5. • Resistance of each lamp increases with current. • Resistance increases because of increased temperature. • Lamps are non-ohmic components.	B1×3	
			Total	**3**	
17	a		Best fit straight line drawn through the last 4 data points.	B1	
			Gradient of the line determined.	B1	
			p= gradient **x** *A*, hence resistivity = (1.1± 0.1) **x** 10^{-6} (Ω m)	B1	**Allow** a maximum of 2 marks if the line of best fit is drawn through all 5 data points.
	b		The actual resistance values will be smaller.	B1	
			The gradient of the graph will be lower.	B1	
			Hence resistivity of the metal will be smaller than the value in **(b)**.	B1	
			Total	**6**	
18		i	R = 3000 + 1500 V = 12 × 1500/4500 = 4(.0) (V)	C1 A1	R = 4500 (Ω) **or** *I* = *V/R* = 12 /4500 = 2.67 mA V_{1500} = 2.67 mA x 1.5 kΩ = 4.0 (V)
		ii	V (= 12 × 1500/1600) = 11.25 (V) ΔV = 11.25 – 4.0 = 7.25 (V)	C1 A0	
			Total	**3**	
19		i	(*P* = *VI* = 10.0 × 0.030) power = 0.30 (W)	**B1**	

					Allow 0.3 (W) without any SF penalty **Allow** 300 <u>**m**</u>(W)
		ii	The component is (an NTC) thermistor. (As *V* or *I* increases the) resistance of the component decreases Any <u>one</u> from: Component cannot be a diode / LED because of current in one direction only (AW) (As *V* or *I* increases the) component gets warmer / increase in number density (of free charge carriers)	**B1** **B1** **B1**	**Allow** calculations at 5 V and 10 V to support this, **ignore** POT errors <u>**Examiner's Comments**</u> The question was effective in two parts. Use the data to determine the resistance of the component at different potential difference, and then use this data to make judgement in identifying the component. Most candidates gained two or more marks. Some descriptions went astray with mention of Ohm's law or *I*-*V* characteristics. A significant number of candidates gave good reasoning but spoilt their answers by opting for a diode, an LDR or a filament lamp. **Exemplar 10**  (ii) Analyse the data in the table and hence identify the component. ~~A filament lamp~~ A thermis as the potential difference incre it would get hotter, lowering the resistance, as the resistance lo the current increases. This exemplar illustrates how a brief answer can score maximum marks. This answer is from a grade C candidate. Answers from top'end candidates were verbose and supported by values of resistances.
			Total	**4**	
20		i	resistance = 1.80 / 0.026 (= 69.2 Ω)	C1	
		i	resistivity $= \frac{69.2 \times 1.3 \times 10^{-7}}{0.75}$ = 1.2×10^{-5} (Ω	A1	
		ii	Contact resistance due to croc clips hence the resistance in the circuit must be greater.	B1	**Allow**: Correct zero error on meters (e.g voltmeter reading is 'higher' or ammeter reading is 'lower') hence the (determined) resistance is greater.
		ii	**or** Heating of wire hence the resistance of the wire increases. **or** (Finite) resistance of ammeter hence the total resistance of circuit increases. **or** Actual length between croc-clips is shorter or < 0.75 m; hence resistance of wire is greater.	B1	

			Total	**4**	
21		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 determine *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**	
22			The resistance of the thermistor increases.	B1	
			The current in the circuit decreases.	B1	
			The p.d. across the resistor decreases because of $V = IR$ or $V \propto R$.	B1	
			The p.d. becomes constant. (AW)	B1	
			Total	**4**	
23		i	R (= ρ*L*/A) = 1.8 × 10^{-8} × 1500/1.1 × 10^{-4} R = 0.25 (Ω)	C1 A1	
		ii	$E = \sigma/\varepsilon = T/A\varepsilon$ (so $T = EA\mathcal{E}$) T = 1.2 x 10^{10} x 1.1 x 10^{-4} x 0.013 T = 1.7 x 104 (N) or 17 (kN)	C1 C1 A1	**or** calculation of σ =1.56 x 10^8 (Nm^{-2}) **or** T = 1.56 x 10^8 x 1.1 x 10^{-4}
			Total	**5**	
24		i	(Current causes) increase in temperature of thermistor Resistance of thermistor decreases (and hence *V* decreases) **or** Current in the circuit increases, p.d. across resistor increases (and hence *V*decreases)	B1 B1	**Allow** warms up / heat ups **Ignore** increase temperature of the circuit

		ii	V = 2.4 (V) or V_R = 3.6 (V) I = 0.30 (A) resistance = 8.0 (Ω) **OR** V = 2.4 (V) and a potential divider equation / idea $2.4 = \frac{R}{R+12} \times 6.0$ or $\frac{R}{2.4} = \frac{12}{3.6}$ resistance = 8.0 (Ω)	C1 C1 A1 C1 C1 A1	**Not** V = 2.2 (V); misreading **Allow** ECF if V = 2.2 (V) is used **Allow** 8 (1 SF answer) **Not** V = 2.2 (V); misreading **Allow** ECF if V = 2.2 (V) is used **Allow** 8 (1 SF answer)
			Total	**5**	
25		i	current = 0.030 (A) ($I = Anev$); $0.030 = 3.8 \times 10^{-6} \times 5.0 \times 10^{25} \times 1.6 \times 10^{-19} \times v$ $v = 9.9 \times 10^{-4}$ (m s^{-1})	**C1** **A1**	**Examiner's Comments** Almost all candidates were familiar with the equation $I = Anev$. The modal score here was two marks. Most scripts had well-structured answers. The final answer was often quoted to the correct number of significant figures and written in standard form. A very small number of candidates incorrectly calculated the current using 'current = VR = 3.0 × 100 = 300 A'; this scored zero because of incorrect physics.
		ii	The resistance (of the thermistor or circuit) decreases Current / I / ammeter reading increases **because** $I \propto 1/R$ or number density (of charge carriers) increases Voltmeter reading does not change (because there is no internal resistance)	**B1** **B1** **B1**	**Allow** $V = IR$ (any subject) and V = constant **Allow** 'more electrons / more charge carriers' **Allow** voltmeter reading stays 3.0 (V) **Examiner's Comments** This question on the heating of a thermistor favoured the top-end candidates. Most candidates recognised that the resistance of the NTC thermistor decreased as its temperature was increased. The explanation of why the current increased lacked robustness. Some correctly gave the explanation as *'increased number density of free electrons'* or successfully showed that current was inversely proportional to the resistance. The fate of the voltmeter reading baffled many candidates. The answer was simple, the voltmeter reading remained unchanged because the battery had no internal resistance. For many, the voltmeter reading increased because *'p.d. was proportional to the current'*.
			Total	**5**	

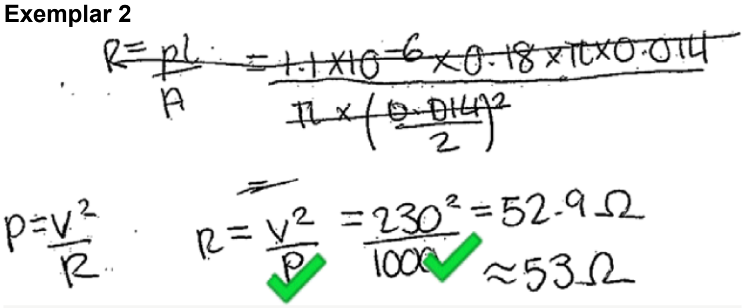
2 6			**Level 3 (5–6 marks)** Clear description **and** clear analysis of data *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3–4 marks)** Some description **and** some analysis of data **OR** Clear description **OR** Clear analysis of data *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** Some description **OR** Some analysis of data *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	B1×6	**Indicative scientific points may include:** **Description** • Circuit showing supply, ammeter, voltmeter and resistance wire / coil • Measure I (in coil) with ammeter • Measure V (across coil) with voltmeter • Power (for coil) calculated: $P = VI$ • Resistance of thermistor either calculated using $R = V/I$ **or** measured with ohmmeter • Change P / change V / use variable power supply / use variable resistor (to change I) • Keep the number of turns of coil constant throughout / no draughts / wait until the resistance stabilises **Analysis** • $\lg P = \lg k + n \lg R$ (or natural logs ln) • Plot a graph of $\lg P$ against $\lg R$ • If expression is correct, then a straight line with non-zero intercept • gradient = n • intercept = $\lg k$ • $k = 10^{\text{intercept}}$ (or $k = e^{\text{intercept}}$ for natural logs)
			Total	**6**	
2 7			**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.*	**B1 × 6**	**Indicative scientific points may include:** **Description** Determine R_0 using ice water mixture or* Record V and I for various temperatures If wire is not insulated some conduction through water/use insulated wire Use small current to minimise heating effect or connect to supply for short time for readings Stir the water Wait for temperature to stabilise/bath to come to equilibrium Avoid parallax errors when reading instruments Comment about large scale increments on instruments/digital meters for precision of measurements/AW

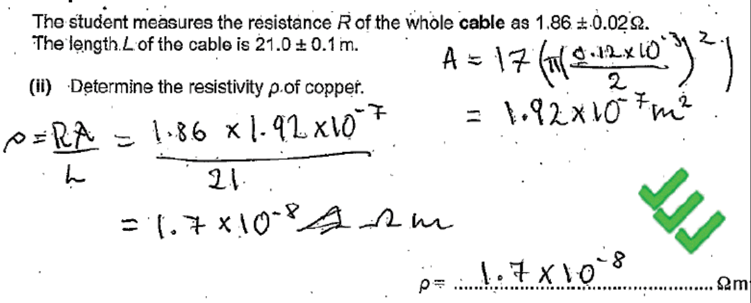
			Level 1 (1–2 marks) Limited description or analysis *There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.* **0 marks** No response or no response worthy of credit.		**Analysis** • Determine resistance from $R = V/I$ • Graph of R against θ is a straight line / Graph of R/R_0 against θ is a straight line • Correct interpretation of gradient m to find k; i.e. $k = m/R_0$ or $k = m$ • *R_0 by extrapolation from linear graph *descriptors D1 and A4 are alternatives **<u>Examiner's Comments</u>** This question proved to be a suitable starter as almost all wrote a full page answer or even completed it on one of the spare pages at the back of the examination booklet. The majority of candidates described the basic procedure to perform the experiment. There was a small group who did not appreciate that R_0 referred to 0°C but took it to be their initial room temperature. Some of these contradicted themselves once they reached the analysis of data section of their answer. Some started with ice water whilst others just found R_0 by extrapolation from the graph. A few good candidates compared both methods as a check on the reliability of their experiment. The example (exemplar 1) of an L3 answer shown here implies this check without stating it clearly. **Exemplar 1**

					At a variety of temperatures from 0-100° in 10°C intervals record the current & voltage of the wire. Do this when you do keep the temperature constant and the wire is also at this temperature. ie hold it at the temperature for 2 mins before taking results. Also stir the water to ensure it is all the same temperature. Once you have results for all temperatures. Repeat twice more and take averages. Work out the resistance for each temperature using $\frac{V}{I} = R$. Plot a graph of $\frac{R}{R_0}$ against θ where R_0 is the value you got for 0°C or as close to this temperature you could get. Plot a line of best fit & work out the gradient. If it is a straight line then the relationship is true. The gradient should be k and the y intercept 1. This graph k gives the value for k. To improve accuracy you should repeat the experiment a multiple times and take an average gradient to give a more accurate result. You should also get your water & then cool to 0°C, or a close possible, to give a more precise value for R_0. About half of the candidates remembered to stir the heating water. Only a minority allowed time for thermal equilibrium to be reached with the heating removed before taking measurements. Many did not state how they heated the water which was important because a group described using the given nichrome wire and supply for this purpose. Many wanted to take the unnecessary precaution of lagging the beaker or using a lid to avoid heat loss. One sensible improvement suggested was to use a digital thermometer in place of the one in the diagram. The advantages of this change were not always explained. The candidates were able to explain how to process the data to obtain a value for *k*. Only a very few did not draw a graph. As in question 5b many are not clear about the difference between a linear and a proportional relationship. A good exposition describing a suitable graph with a *y*-intercept of R_0 could be ruined by the statement that the graph showed that *R* was proportional to *θ*.
			Total	**6**	
28		i	*R* = 2.0 + 8.0 = 10 (Ω) (*I* = 1.2/10); *I* = 0.12 (A) (1.5 = 1.2 + 0.12r); *r* = 2.5 (Ω)	**C1** **C1** **A1**	**Allow** other correct methods **Allow** 2 marks for 4.5 (Ω); *R* = 18 Ω with *I* = 0.067 (A) **Examiner's Comments**

					This question required careful examination of a series circuit. The answer was very much dependent on knowing that 1.2 V was the p.d. across the 2.0 Ω **and** half of the resistance wire. Using total resistance other than 10.0 Ω led to incorrect value for the internal resistance. Less than about a third of the candidates secured full marks. Some of the most frequent difficulties were: • Assuming the p.d. across the 2.0 Ω resistor was 1.2 V. • Using 1.5 V as the terminal p.d. rather than 1.2 V. • Experiencing problems rearranging the equation *E* = *V* +*Ir.*
		ii	As *d* increases the (total) resistance (of the circuit) increases (ORA) and therefore the current / *I* decreases (ORA) Any one from: • Explanation of *V* increasing in terms of *V* + *Ir* = *E* or *V* + V_r = 1.5 or *V* = *E* - lost volts • Explanation of *V* increasing in terms of potential divider • Analysis showing *V* ≈ 0.7 V when *d* = 0 or *V* ≈ 1.3 V when *d* = 1.0 m or any other value of *V* for a given *d*	M1 A1 B1	**Allow** 'As length (of wire) increases resistance increases' (ORA) **Allow** 'lost volts / p.d across *r* / *Ir* decreases, so *V* increases' **Examiner's Comments** The question required an explanation in terms of the current in the circuit as the distance *d* increased. Many candidates realised that the increase in the length of the resistance wire meant an increase in the total resistance of the circuit and hence, a smaller current in the circuit. Some went one step further and correctly concluded that *V* increases as the p.d. across the internal resistance decreases. A significant number of candidates either described the variation *V* with *d* without any explanation or guessed the physics. No credit could be given for answers such as 'the *graph gets less steep'* and *'the current changes because the electrons have to travel a longer length'.*
			Total	**6**	
29	a	i	$R = \frac{230^2}{3500} = 15.11$ 15 (Ω)	M1 A0	**Allow** calculation of current (15.2) and *R* = *V* / *I* **Not** 3500 / 230 = 15.2 **Examiner's Comments** This question asked candidates to show that the resistance of one of the heaters was 15 Ohms. Some candidates divided 3500 W by 230 V which gave an answer of 15.2 A which was the current. If these candidates then divided 230 V by 15.2 A they still gained the mark.
		ii	$A = \pi \times 0.00055^2 (= 9.5 \times 10^{-7}\ \text{m}^2)$ $L = \frac{15 \times 9.5 \times 10^{-7}}{1.6 \times 10^{-6}}$ 8.9 (m)	C1 C1 A1	**Note** 8.9 × 10^n scores two marks **Allow** 15.1 gives 9.0 m **Examiner's Comments**

					It was pleasing to see many good answers to the determination of the length of the wire. Candidates showed clearly how they determined the area and then substituted correctly into the rearranged equation for resistivity. Some candidates round their answer to one significant figure.
		iii	(Ohm's law states that) *V* proportional to *I* (provided the physical conditions / temperature remain constant) Since the <u>temperature is not constant</u>, Ohm's law will not apply	B1 B1	**Allow** one mark for Ohm's law will not apply because as temperature changes the resistance changes **Examiner's Comments** Candidates often scored a mark for stating Ohm's law; candidates should define any symbols used. Candidates often did not refer to any temperature change in the heater. Vague answers referring to "heating" did not score.
	b		3.5 × 7 or 3.5 × 7 × 7 or 10.5 × 7 or 10.5 × 7 × 7 or 514.5 514.5 × 7.6p = £39.10 or £39.11	C1 A1	**Note** for use of 17 hours £94.96 scores one mark **Allow** 3910p or 3911 p or £39.1 or £39.102 **Examiner's Comments** A surprising number of candidates did not correctly determine the cost of electricity. Many candidates did not use three heaters or seven days. For the award of the intermediate mark, clear working needed to be shown.
			Total	**8**	
30		i	$R = V^2/P$ or $P = V^2/R$ $R = 230^2/1000 = 52.9$ or 53(Ω)	C1 A1	**or** $P = VI$ and $R = V/I$ with $I = 4.34$ (A) This is a 'show that' question so the A1 mark is for giving both the full substitution of values and the final answer. The final answer may be to 2 or more SF.
		ii	number of turns, n = 180/1.5 (= 120) length ($l = \pi dn$)= 3.14 (or π) × 0.014 × 120 = 5.28 (m)	C1 A1	This is a 'show that' question so the A1 mark is for giving both the full substitution of values and the final answer. The final answer may be to 2 or more SF.
		iii	$A = (\rho l/R) = 1.1 \times 10^{-6} \times 5.28/52.9$ $A = 0.11 \times 10^{-6}$ (m^2) so swg = 28	M1 A1 A1	**allow** 53 **allow** solution which calculates diameter of wire using $\pi d^2/4$ rather than finding *A* **give max** 1/3 for using data from the table, i.e. finding *R* = 53 Ω using correct value of *A* **or** *d* = 0.37 (mm) the A marks cannot be-awarded unless the M mark is awarded. **<u>Examiner's Comments</u>** The purpose of this question was to challenge the candidates to use their knowledge to solve a laboratory based practical problem. The

					majority approached part (i) correctly by considering the power data for the fire element. A significant minority were drawn to the formula relating resistance and resistivity. Many of these realised that this approach was incorrect and changed to the correct approach. Here is a typical example (exemplar 2) of a script where the candidate continued to complete the whole question correctly. The rest remained at a loss and did not gain any marks for parts (ii) and (iii). **Exemplar 2**  In part (ii) a minority again tried the resistivity formula rather than an approach using geometry. Finally in part (iii) the resistivity formula was applied with success. The question overall proved to be a good discriminator of ability and understanding.
			Total	**7**	
3 1		i	$12\,000 = \frac{Q}{4\pi\varepsilon_0 r}$ $12\,000 = \frac{Q}{4\pi\varepsilon_0 \times 0.19}$ $Q = 2.5(4) \times 10^{-7}$ (C)	C1 C1 A0	**Allow** $E = (V / d =)\ 6.316 \times 10^4$ **C1** and $E = 6.316 \times 10^4 = \frac{Q}{4\pi\varepsilon_0 \times 0.19^2}$ **C1**
		ii	**1** $t = 78 \times 3600$ $(I =) \frac{2.5 \times 10^{-7}}{78 \times 3600}$ $I = 8.9 \times 10^{-13}$ (A) **2** $(R =) \frac{6000}{9.0 \times 10^{-13}}$ **or** 6.7×10^{15} (Ω) **or** $V = IR$ and $R = \frac{\rho L}{A}$ $\frac{6000}{9.0 \times 10^{-13}} = \frac{\rho \times 0.38}{1.1 \times 10^{-4}}$ $\rho = 1.9 \times 10^{12}$ (Ω m)	C1 C1 A0 C1 C1 A1	There is no ECF from **(b)(i)** **Note** 2.54×10^{-7} gives an answer 9.0×10^{-13} A There is no ECF from **(b)(ii)1** **Take** 12000 V as **TE** for this C1 mark, then ECF **Note** 8.9×10^{-13} (A) gives an answer 2.0×10^{12} (Ω m)
			Total	**7**	
3 2		i	Micrometer Repeat readings <u>in different directions/along wire/different wires</u> <u>and</u> average	**B1** **B1**	**Allow** calliper **Not** vernier scale <u>**Examiner's Comments**</u> Most candidates were able to identify a suitable measuring

					instrument such as a micrometer. To score the second mark candidates were expected to explain the purpose of repeating readings that the reading would be repeated in different directions or along the wire and the mean or average diameter would be determined. to assure that the outcome is precise.
		ii	$A = \frac{\pi \times (0.12 \times 10^{-3})^2}{4} = 1.13 \times 10^{-8}$ $\rho = \frac{1.86 \times A}{21}$ OR $\rho = \frac{17 \times 1.86 \times 1.1 \times 10^{-8}}{21}$ ρ = 1.7 × 10^{-8} (Ω m)	C1 C1 A1	**Note** ρ must be the subject **Allow** 2 marks for 1.0 × 10^{-9} (factor of 17 omitted) **Allow** 2 marks for 6.8 × 10^{-8} (diameter used instead of radius) **Allow** 2 marks for 0.017 (POT omitted) **<u>Examiner's Comments</u>** A very large number candidates did not take into account that the resistance of the cable was the resistance of 17 wires in parallel. Many candidates did not clearly show their working. Good candidates calculated the cross-sectional area of one wire and then correctly rearranged the resistivity equation from the data booklet. Some lower ability candidates had difficulty in calculating the cross-sectional area of the wire and there were often power of ten errors. **Exemplar 6**  This candidate has correctly approached the question by determining the total area of the copper in the cable and then correctly used the equation. Again, the equations used are clearly demonstrated.
		iii	$\frac{0.1}{21}$ or $\frac{0.02}{1.86}$ or $\frac{0.01}{0.12}$	C1	**Allow** max/min methods ρ_{max} = 2.03 × 10^{-8} and ρ_{min} = 1.41 × 10^{-8} (B1) $\frac{\Delta\rho}{\rho}$ x100 (B1) x100 (B1)

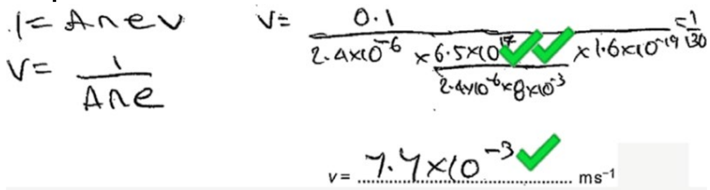
			$\left(\frac{0.1}{21}+\frac{0.02}{1.86}+2\times\frac{0.01}{0.12}\right)\times 100 = 18\ (.2)\%$	**A1**	**Allow** 17.8% Do not penalise significant figures **Allow** 1 mark for 9.88% **Allow** 20% with evidence of working **Examiner's Comments** Many candidates clearly determined the percentage uncertainties on *L*, *R* and *d* which gained the first mark. A common final answer (which scored one mark) was 9.88% because candidates did not multiply the percentage uncertainty in *d* by two to allow for d^2. Some candidates attempted a maximum or minimum method − this was a long method and it was easy to make an error. When working out the maximum value, the maximum value of *R* and *d* needed to be used with the minimum value of *L*.
			Total	**7**	
3 3		i	Arrow in anticlockwise direction	B1	**Allow** this mark for correct direction shown on diagram either on or off connecting wires **Examiner's Comments** This question required the candidates to appreciate that the sum of the emfs will lead to an anticlockwise conventional current. This question was answered well by the majority of candidates, however a number put two directions on, one from each cell. **Misconception** The unusual setting out of the circuit meant that some candidates were unsure whether parts of the circuit were in series or parallel. This could have been overcome by following the circuit or even by redrawing it.
		ii	(*E* =) 4.5 – 2.4 **or** (R_T =) 0.80 + 0.50 + 1.2 4.5 – 2.4 = *I* × (0.80 + 0.50 + 1.2) *I* = 0.84 (A)	C1 C1 A1	*E* = 2.1 (V); R_T = 2.5 (Ω) Treat missing 1.2 resistance as TE **Allow** 2 marks for 2.8 (A); E = 6.9 V used **Examiner's Comments** This calculation required the candidate to set out the whole circuit in one. Around one third did not score any marks on this question as they attempted to treat each cell individually and then produce some form of average. Other common misunderstandings included treating the 0.5 ohm and 0.8 ohm resistors as if they were in parallel, and adding the emfs.

		iii	($I = Anev$) $0.84 = \pi \times (2.3 \times 10^{-4})^2 \times 4.2 \times 10^{28} \times 1.60 \times 10^{-19} \times v$ $v = 7.5 \times 10^{-4}$ (m s^{-1})	C1 A1	Possible ECF from **(ii)** Note answer is 2.5×10^{-3} (m s^{-1}) for $I = 2.76$ (A) **Allow** 1 mark for 1.9×10^{-4}; diameter used as radius **Examiner's Comments** This question was well done by a large number of candidates, many of whom scored full marks by correctly following through with their value of current from the previous part. Few candidates used the diameter instead of the radius when determining the cross sectional area, and for the most part the setting out of the calculation meant that credit could be given even if arithmetic errors occurred later.
		iv	Sensible suggestion, e.g. use a water bath / fan / only switch on when taking readings Need to lower the temperature / reduce resistance of **R**	M1 A1	**Allow** keep the surroundings cold **Allow** to keep the temperature / resistance constant **OR allow** increase in temperature increases resistance **Examiner's Comments** Candidates were expected to provide any method of cooling the circuit, or preventing it heating in the first place. A wide variety of solutions were given and as long it is viable, it was credited. ? **Misconception** Some candidates gave perfectly viable solutions, but these involved changes to the circuit, which was not allowed in the question. It is very important to make sure than any response does fit what is being asked.
			Total	**8**	
34	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) **2** R = 2.3(4) (Ω) $\frac{0.1}{9.5}$ or $2\times\frac{0.003}{0.270}$ $\frac{0.1}{9.5}+2\times\frac{0.003}{0.270}$ or 0.0327 or 3.2 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 ± 0.077 Ω. Some candidates realised that the actual value of R would be *'larger because d was smaller or R ∝ 1/d²'*. On most scripts, it was difficult to follow if the resistance was the **actual** one or the **calculated** one.
			Total	**9**	
35		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	$E = I\,(r + \text{R})$ **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**	
36		i	(R =) $\frac{6.0}{0.150}$ R = 40 Ω	**M1** **A0**	**Allow** any correct value of V (± 0.1 V) divided by the correct value of I (± 10 mA) from the straight line for **R** **<u>Examiner's Comments</u>** The majority of the candidates scored 1 mark here for clearly using the graph to show the resistance of **R** to be 40 Ω. Most used a data point from the straight line. A significant number also used the idea that the gradient of the straight line is equal to the inverse of the resistance. However, candidates are reminded that resistance is equal potential difference divided by current, but in this context of a straight line through the origin, determining resistance from the gradient was allowed. Of course, determining the gradient of a curve is simply incorrect physics for determining resistance.
		ii	(V_L =) 1.4 (V) **or** (V_R =) 4.0 (V) **or** (R_T =) 6.0/0.1 (Ω) ($V_{terminal}$ =) 5.4 (V) **or** (V_r =) 0.6 (V) **or** (r =) 60 − 54 (Ω) r = 6.0 (Ω)	**C1** **C1** **A1**	**Allow** full credit for other correct methods Possible ECF from **(i)** **Allow** ± 0.1 V for the value of p.d. from the graph **Note** getting to this stage will also secure the first C1 mark **Allow** 1 SF answer here without any SF penalt **<u>Examiner's Comments</u>** This was a discriminating question with many of the top-end candidates effortless getting the correct answer of 6.0 Ω for the internal resistance r. The most common error was omitting the resistance of the filament lamp in the calculation. This gave an incorrect value of 20 Ω for the internal resistance. Candidates doing this still managed to pick up 1 mark for the total resistance of 60 Ω.
		iii	$\rho = \frac{40 \times 2.4 \times 10^{-6}}{8.0 \times 10^{-3}}$ (Any subject) ρ = 0.012 (Ω m)	**C1** **A1**	**Allow** ECF **Allow** 1 mark for either 0.018 for using 60 Ω, 0.016(2) for using 54 Ω or for 0.0018 for 6.0 Ω **<u>Examiner's Comments</u>** The success in this question depended on understanding the term n in the equation $I = Anev$ given in the Data, Formulae and

						Relationship booklet. A significant number of candidates took *n* to be the total number of charge carriers within the volume of **R**, instead of the number of charge carriers per unit volume (number density). Those who appreciated this had no problems coping with prefixes and powers of ten. The correct answer was 7.7×10^{-3} m s^{-1}. Using 6.5×10^{17} for the number density, gave an answer of 4.0×10^{5} m s^{-1}; examiners credited 1 mark for this incorrect answer, mainly for the manipulating and using the equation $I = Anev$. **Exemplar 6**  This exemplar illustrates a perfect answer from a C-grade candidate. The equation has been rearranged correctly and the substitution is all correct and easy to follow. The number density *n* has not been calculated separately – it forms an integral part of the whole calculation. The one big benefit of this is that you do not end up with rounding errors. A decent technique demonstrated here. All correct for 3 marks.
		iv	$n = \frac{6.5 \times 10^{17}}{2.4 \times 10^{-6} \times 0.008}$ **or** $n = 3.385 \times 10^{25}$ (m^{-3}) $v = \frac{0.100}{2.4 \times 10^{-6} \times 3.385 \times 10^{25} \times 1.60 \times 10^{-19}}$ (Any subject) $v = 7.7 \times 10^{-3}$ (m s^{-3})	C1 C1 A1	**Note** do not penalise again for the same POT error **Allow** 1 mark for $4(.0) \times 10^{5}$ (m s^{-1}); $n = 6.5 \times 10^{17}$ used
			Total	**9**	