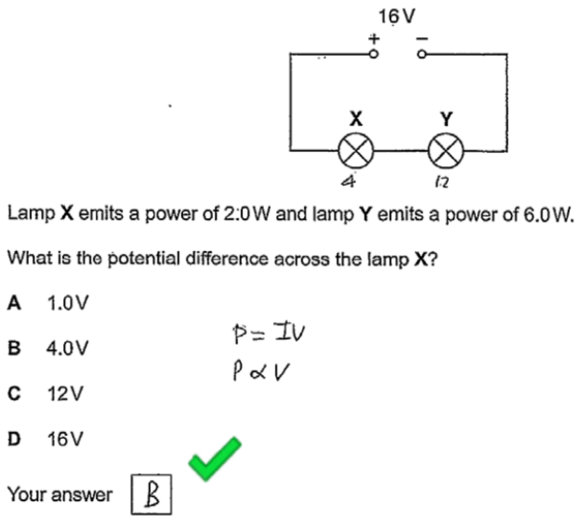
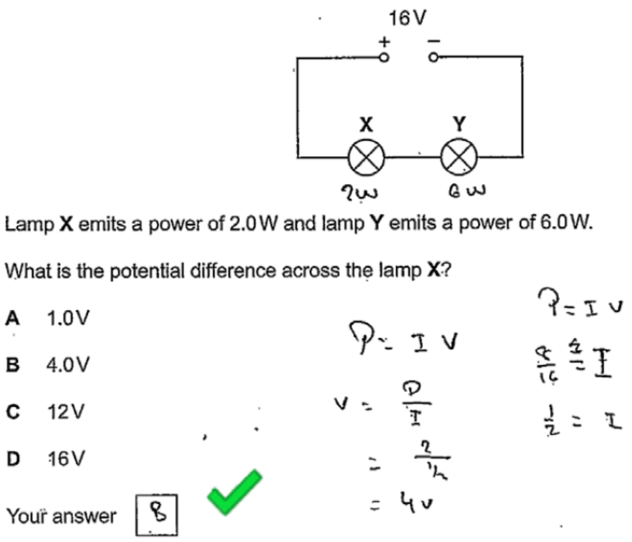
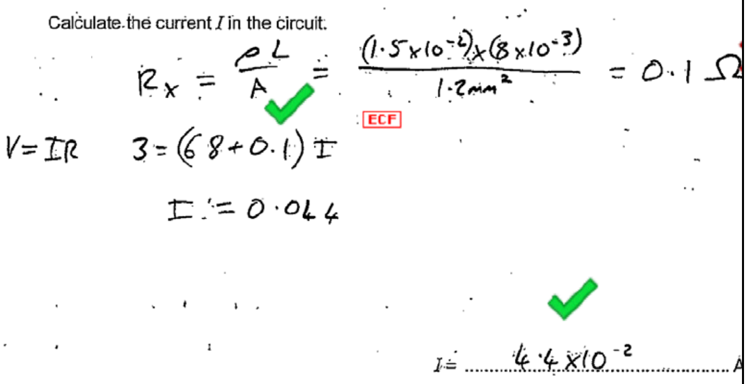
Mark scheme - Resistance

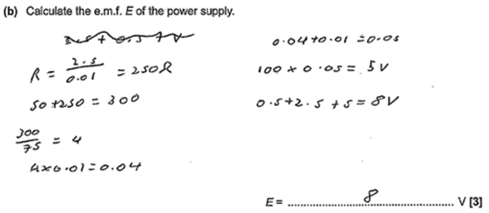
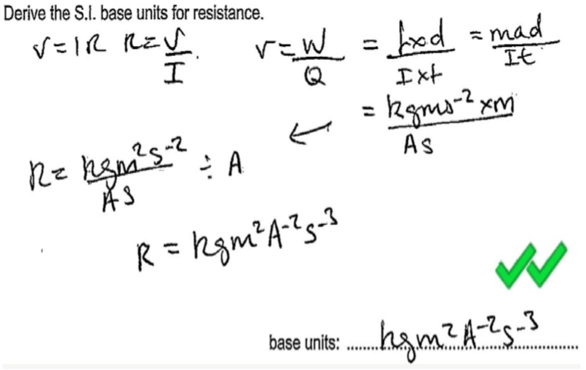
Question			Answer/Indicative content	Marks	Guidance
1			**A**	**1**	
			Total	**1**	
2			C	1	**Examiner's Comments** All of the questions showed a positive discrimination, and the less able candidates could access the easier questions. The questions in Section A do require careful reading and scrutiny. Candidates are advised to reflect carefully before recording their response in the box. Candidates must endeavour to use a variety of quick techniques when answering multiple choice questions. The candidates to demonstrate their knowledge and understanding of physics. Tested knowledge of how uncertainties compound when determining resistance of a filament lamp.
			Total	**1**	
3			**B**	1	**<u>Examiner's Comments</u>** Candidates answered this question well. A range of techniques could be used to get to the correct answer **B**. This is illustrated by the two exemplars below. **Exemplar 2**  Lamp **X** emits a power of 2.0W and lamp **Y** emits a power of 6.0W. What is the potential difference across the lamp **X**? **A** 1.0V **B** 4.0V **C** 12V **D** 16V Your answer B This shows the thought processes of a top-end candidate. The current in the series circuit is constant, hence the potential difference must be proportional to the power dissipation. These two lines is all it took for this candidate to identify the correct answer **B**.

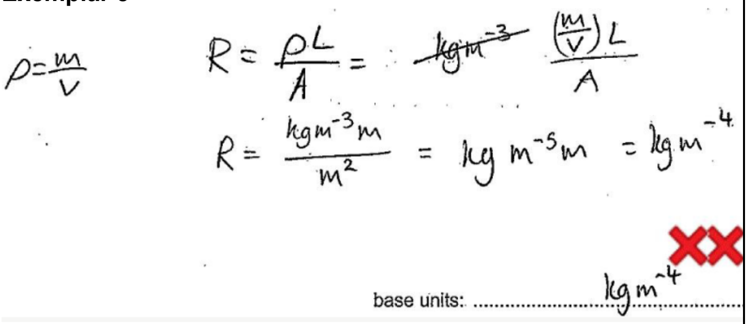
					Exemplar 3  Lamp **X** emits a power of 2.0W and lamp **Y** emits a power of 6.0W. What is the potential difference across the lamp **X**? **A** 1.0V **B** 4.0V **C** 12V **D** 16V Your answer B $P = IV$ $V = \frac{P}{I}$ $= \frac{2}{\frac{1}{2}}$ $= 4V$ $P = IV$ $\frac{8}{16} = I$ $\frac{1}{2} = I$ Here's another equally valid technique, which may have been a bit time–consuming for this grade D candidate. The total power dissipated has been used to determine the current in the circuit. The correct value of 4.0 V across lamp **X** has been calculated using this current and the equation $P = VI$. It is worth noting the sensible approach of annotating the figure. This would have helped to steer away from the popular distractor C.
			Total	**1**	
4			B	1	
			Total	**1**	
5			D	1	**<u>Examiner's Comments</u>** The correct response is **D**. This question also proved to be challenging as not many candidates will have come across this style of circuit before. Therefore in most cases, it will have to have been worked out from application of conventional current flow. It would likely be evident that LED **Q** is lit, probably accounting for the very few candidates selecting response **B**. Many candidates incorrectly selected response **A**, presumably as its polarity is the same as **Q**.
			Total	**1**	
6			D	1	
			Total	**1**	
7			**X** (filament) lamp **Y** (fixed)(ohmic) resistor	**B1**	**Allow** <u>ptc</u> thermistor / heater element **Not** metallic conductor **<u>Examiner's Comments</u>** Many candidates did not appear to recognise the I-V characteristics for a filament lamp or an ohmic resistor. Incorrect answers that were

					often seen included diodes and LDRs. X could have been a thermistor with a positive temperature coefficient (ptc) although the specification only makes reference to thermistors with negative temperature coefficients
			Total	**1**	
8			the current (induced in the aerial) is alternating (5 × 10^8 times per second) (so the meter would register zero) / AW **or** the diode (half-)rectifies the current / changes the current (from a.c.) to d.c. / AW	B1	**Allow** 'a diode only lets current pass through in one direction' AW **<u>Examiner's Comments</u>** Allowing a mark for the diode only letting current pass in one direction enabled many candidates to score this mark. There was little mention of alternating current among the responses.
			Total	**1**	
9			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* =*ρL/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**, $V = \frac{1}{3}$×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**	
10			5.56 (V) and data point plotted correctly to ± ½ small square.	B1	
			Total	**1**	
11			**D**	1	
			Total	**1**	
12			Current less Cell has internal resistance **or** greater (total) resistance **or** p.d. across internal resistor **or** p.d. across resistor/10.0 (Ω)	B1 B1	**Allow** 'lost volts' / power lost in cell **Ignore** wires have resistance
			Total	**2**	

1 3			(V_R =) 2.7 (V) **or** (current =) 0.018 (A) (ratio = $\frac{0.018\times1.8}{0.018\times2.7}$) ratio = 0.67	C1 A1	**Note** the mark can be scored on circuit diagram **Note** values of powers are: 0.0324 W and 0.0486 W **Allow** 2/3; **Not** 0.66 (rounding error)
			Total	**2**	
1 4			$R=\frac{\rho L}{A}=\frac{1.5\times10^{-2}\times8.0\times10^{-3}}{1.2\times10^{-6}}$ **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 × 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 **<u>Examiner's Comments</u>** 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. $R_x = \frac{\rho L}{A} = \frac{(1.5\times10^{-2})\times(8\times10^{-3})}{1.2mm^2} = 0.1\,\Omega$ ECF $V=IR$ $3=(68+0.1)I$ $I = 0.044$ I = 4.4×10^{-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**	
15	a		current = 0.01 (A) p.d. = 0.01 × 50 (= 0.50 V)	M1 A1	**Examiner's Comments** This was an accessible question on determining the p.d. across the LED using the data from **Fig. 19.2**. The universal approach was short and precise: V = 0.01 × 50 = 0.50 V. However, a significant number of candidates used a longer route involving the potential divider rule and the 250 Ω resistance of the LED.
	b		(V_{75} =) **0.5 + 2.5** (V) **or** (R_{LED}) = **250** (Ω) **or** (R_p =) **60** (Ω) (I_{100} =) **0.05** (A) (E = 3.0 + 0.05 × 100) E = 8.0 (V)	C1 C1 A1	**Allow** other correct methods **Note** there is no ECF from (**a**) **Allow** 1 SF for the p.d. of 3 (V) There is no ECF here from wrong physics (XP) from the parallel network **Allow** 1 SF answer of 8 **Examiner's Comments** The analysis of the circuit proved to be problematic with most of the candidates getting as far as calculating either the resistance of the LED as 250 Ω or the p.d. across the LED-50 Ω resistor combination as 3.0 V. The stages thereafter demonstrated all the usual misconceptions; these are summarised later. About a quarter of the candidates produced flawless solutions using a range of techniques from Kirchhoff's two laws to potential dividers. The simplest solution had the correct current of 0.050 A in the 100 Ω resistor, followed by the correct value of the e.m.f. of 8.0 V. This type of solution is shown in exemplar 7. **Misconception** These were the most common errors made in calculating the e.m.f. of the power supply. • Calculating the total resistance of the parallel network by omitting the resistance of the LED. • The current in the 100 Ω resistor was the same as the current of 0.010 A in the LED. • The current in the 100 Ω resistor was the same as the current of 0.040 A in the 75 Ω resistor.

					• Using the potential divider equation by completely omitting the LED-50 Ω resistor series network. **Exemplar 7**  (b) Calculate the e.m.f. E of the power supply. $R = \frac{2.5}{0.01} = 250\Omega$ $50 + 250 = 300$ $\frac{300}{75} = 4$ $4 \times 0.01 = 0.04$ $0.04 + 0.01 = 0.05$ $100 \times 0.05 = 5V$ $0.5 + 2.5 + 5 = 8V$ E = 8 V [3] This exemplar shows a perfect response from a middle-grade candidate. The response should have been written to 2 SF. However, because the answer was 8.0 V, a 1 SF response was allowed without incurring any penalty.
			Total	**5**	
16			$(R = \frac{V}{I} = \frac{W}{QI};\ Q = It$ charge → A s **or** energy → kg m s^{-2} × m **or** kg m^2 s^{-2} (base units) kg m^2 A^{-2} s^{-3}	**C1** **A1**	**Allow** other correct methods **Allow** Q or C **or** coulomb for ‘charge’; E **or** W **or** joule **or** J **or** work done for ‘energy’ **Allow** 1 mark for J s^{-1} A^{-2} **Allow** $\frac{\text{kg m}^2}{\text{A}^2\,\text{s}^3}$ **or** kg m^2 /(A^2 s^3) **Not** kg m^2 / A^2 / s^3 **or** kg m^2 / s^3 / A^2 **<u>Examiner’s Comments</u>** This was a challenging question, which provided the ideal opportunity for top-end candidates to use a variety of methods to get the correct S.I. base units of kg m^2 A^{-2} s^{-3} for resistance. A significant number of candidates secured 1 mark for a partial answer with either charge → A s, or energy → kg m^2 s^{-2}. The rules for exponents were a bit perplexing for the low-scoring candidates. Many also misunderstood S.I. units. **Exemplar 4**  Derive the S.I. base units for resistance. $V = IR \quad R = \frac{V}{I}. \quad V = \frac{W}{Q} = \frac{F \times d}{I \times t} = \frac{mad}{It}$ $= \frac{kgms^{-2} \times m}{As}$ $R = \frac{kgm^2s^{-2}}{As} \div A$ $R = kgm^2A^{-2}s^{-3}$ base units: $kgm^2A^{-2}s^{-3}$

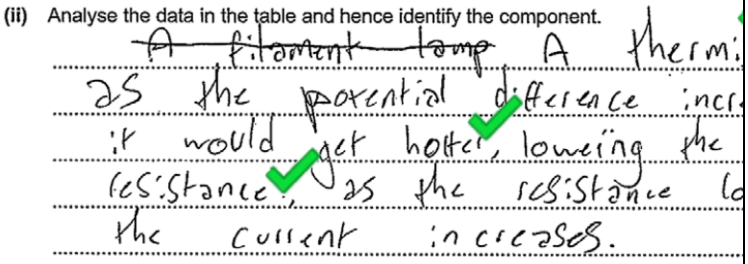
					This exemplar illustrates a flawless answer from a top-end candidate. The equations are clear to see and follow. The units of each physical quantities are clearly identified and the appropriate S.I. units for the quantities have been successfully manipulated to give the correct answer. Compare this with the exemplar below which illustrates a common misconception. **Exemplar 5**  $\rho = \frac{m}{V}$ $R = \frac{\rho L}{A} = \cancel{kgm^{-3}}\ \frac{\left(\frac{m}{V}\right)L}{A}$ $R = \frac{kgm^{-3}m}{m^2} = kg\,m^{-5}m = kg\,m^{-4}$ base units: $kg\,m^{-4}$ This exemplar illustrates a common error made by some candidates across the ability spectrum. ? The resistivity ρ in the equation for resistance has been mistaken for density (which unfortunately has the same label). There can be no credit for wrong physics. It is vital to know your equations. **Key:** ? **Misconception**
			Total	**2**	
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	p.d. across 1.2 kΩ = 0.9 V	C1	
		i	$\frac{R_{LDR}}{1200} = \frac{5.1}{0.9}$determines current and R = 5.1 / I	C1	
		i	R LDR = 6800 (Ω)	A0	**Allow**: 6.8 k(Ω)
		i	Or $5.1 = \frac{R}{R+1.2} \times 6.0$	C1	
		i	0.9*R* = 6.12 or 0.15*R* = 1020	C1	**Allow** $\frac{6.8}{6.8+1.2} \times 6.0 = 5.1$for two marks
		i	R LDR = 6.8 (kΩ)	A0	**Allow**: 6800 (Ω) **Examiner's Comments** There were a number of correct methods using various arrangements of the potential divider equation. Candidates were able to arrange a complicated equation in a number of cases. Other candidates correctly determined the potential difference across the fixed resistor and then the current.
		ii	$(I = \frac{5.1}{6800} = \frac{6}{8000} = \frac{0.9}{1200})$		
		ii	current = 7.5×10^{-4} (A)	B1	**Examiner's Comments** Most candidates were able to calculate the current delivered by the battery. Candidates who did not score this mark often incorrectly assumed that the potential difference across the fixed resistor was 6 V.
			Total	**3**	
19	a		current = $\frac{0.060}{2.4}$ or current = 0.025 (A)	C1	
			$R = \frac{6.0 - 2.4}{0.025}$	C1	
			R = 140 (Ω)	A1	**Note** answer to 3 sf is 144 Ω
	b		$I = Anev$ and $A = 2.0 \times 10^{-6}$ (m^2)	C1	
			$0.025 = 2.0 \times 10^{-6} \times 1.4 \times 10^{25} \times 1.60 \times 10^{-19} \times v$	C1	**Allow** any subject Possible ecf
			$v = 5.6 \times 10^{-3}$ (m s^{-1})	A1	
	c		The current is constant, therefore $v \propto n^{-1}$.	M1	
			The mean drift velocity is therefore smaller.	A1	
			Total	**8**	
20			Fig. 4.1: total resistance = 3*R*	C1	
			Fig. 4.2: total resistance = 2*R* / 3	C1	
			ratio = $\frac{V}{3R} \div \frac{V}{2R/3} \frac{V}{2R/3} \frac{V}{2R/3}$ = 0.22	A1	**Allow**: 2/9

			Total	**3**	
21			(V_A =) 6.0 (V) **or** (R_A =) 30 (Ω) For parallel lamps, any one from: ($V_{\|\|}$ =) 2.0 (V) **or** (I =) 0.10 (A) **or** (R_L =) 20 (Ω) **or** ($R_{\|\|}$ =) 10 (Ω) resistance = 40 (Ω)	C1 C1 A1	**Not** $R_{\|\|}$ = 15 (Ω); this is XP
			Total	**3**	
22			$I = I_1 + I_2$	M1	
			V is the same (for each resistor)	M1	
			$\frac{V}{R} = \frac{V}{R_1} + \frac{V}{R_2}$ leading to correct expression	A1	
			Total	**3**	
23			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**	
24		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**	
25		i	In darkness LDR has more resistance / p.d. across LDR is large **or** In light LDR has less resistance / p.d. across LDR is small Clear idea that when the LED is on, this will force the p.d. across LED / LDR to decrease, forcing the LED to	B1 B1	

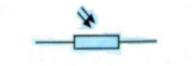
			switch off (ORA) (The cycle of LED switching on and off is repeated)		Note the explanation must be in terms of p.d. / potential divider. **Ignore** current
		ii	A sensible suggestion, e.g. Point the LED away from the LDR / increase distance (between LED and LDR) / insert a card between (LED and LDR)	B1	
			Total	**3**	
26			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**	
27			−1.0 V to 2.6 V: $I = 0$ / negligible and $R = \infty$ / (very) large (AW)	B1	
			2.6 V to 3.0 V: R decreases	B1	**Allow** 'rapid decrease in R'
			3.0 V to 3.4 V: R decreases	B1	**Allow** 'slow decrease in R' **Not** R is constant (because it is a straight line)
			Justification of a B1 point in terms of $R = V/I$. For example to show: • R is infinite: $R = 2.0/0 = \infty$ • R decreases: R calculated once and has $R = \infty$, or R calculated twice	B1	**Not** R = gradient^{-1} **Ignore** powers of 10 and units **Note**: V and I values within ±1 small square **Examiner's Comments** Most candidates scored two or more marks, but examiners felt that there were many missed opportunities here. The most common error was to quote the resistance of the LED as zero when it was not conducting. Sadly, this was often supported by the calculation $R = V/0 = 0$. A number of candidates attributed the decrease in the resistance beyond 2.6 V to the '*increase in the temperature of the LED*'. The straight line section of the graph for the last voltage range led many candidates to quote Ohm's law and the statement that 'the resistance of the *LED is* constant'. A very small number of candidates opted to write about a bulb or a lamp. Top-end candidates effortlessly used $R = V/I$ to calculate the resistance at various p.ds and draw sensible conclusions from their calculations.
			Total	**4**	
28		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**	
29		i	With the variable resistor set at zero / close to zero, the p.d. across the resistor is zero / small, so p.d. across lamp is 2.4 V / large.	B1	
		i	With the variable resistor set at its maximum value, there is a p.d. across the variable resistor, so p.d. across the lamp is not small.	B1	
		ii	The lamp is connected to the slider contact of a potentiometer arrangement.	B1	
		ii	Ammeter and voltmeter connected correctly.	B1	
			Total	**4**	
30			Any <u>three</u> from: • Fig. 23.3 - p.d. split equally / (p.d. across each =) **3.0** (V) • Fig. 23.3 - current = **0.36** (A) (from the graph) • Fig. 23.4 - p.d. = **6.0** (V) (across each or combination) • Fig. 23.4 - current (= 2 × 0.50) = **1.0**(0) (A)	M1×3	**Note** that each of the M1 mark can be implied in a calculation **Note** 8.3.. (Ω) will score the **3.0** V and the **0.36** A marks **Note** 12 (Ω) will score the **6.0** V mark
			0.36 × 3 (= 1.08) is about 1.0 (A)	A1	**Note** this mark is for showing that I_P is about 3 times I_S **<u>Examiner's Comments</u>** This question produced a range of marks, with most candidates securing 2 or more marks. For the lamps in series, it was important to recognise that the potential difference across each lamp is 3.0 V. From the I-V graph, this meant a current I_S of about 0.36 A. For the lamps in parallel, the current in each lamp was 0.50 A because the potential difference across each lamp was 6.0 V. This meant that the current I_P was twice the current in each lamp; 1.00 A. The current I_P

					is about 2.8 times greater than current I_S. This final step of the analysis was often omitted by most of the candidates. A significant number of candidates scored no marks here and about 10% of the candidates omitted this question altogether. **Misconception** The most common mistake made by candidates, across the ability spectrum, was to assume that each lamp had a constant resistance of 12 Ω in the series combination. A lamp is a non-ohmic component. At a potential difference of 3.0 V, the resistance of each lamp is about 8.3 Ω.
			Total	**4**	
31		i	($P = VI$ = 10.0 × 0.030) power = 0.30 (W)	**B1**	**Allow** 0.3 (W) without any SF penalty **Allow** 300 **m**(W)
		ii	The component is (an NTC) thermistor. (As V or I increases the) resistance of the component decreases Any one 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 **Examiner's Comments** 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 therm as the potential difference incr it would get hotter, loweing 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**	
32			Resistance of LDR decreases / (total) resistance (of circuit) decreases (AW)	M1	
			Current / ammeter reading increases (AW)	A1	
			With increase in current the p.d. across (fixed) resistor / 1.2 kΩ resistor increases (AW)	B1	**Allow** p.d. across resistor increases / p.d. across LDR decreases / resistor has greater share of p.d. / LDR has smaller share of p.d.
			(For fixed e.m.f.) voltmeter reading decreases (AW)	B1	**Examiner's Comments** This part expected candidates to explain how the ammeter and voltmeter readings would change. Answers were sometimes convoluted and not clear; for example, it was not always clear as to whether candidates were referring to the resistance of the LDR, fixed resistor or the circuit. Candidates should be encouraged to structure their answers in a logical manner. Few candidates could explain clearly why potential difference across the LDR decreased.
			Total	**4**	
33			R (at any point) = V / I	B1	no mark if reference to slope / gradient of line
			0.6 − 0.65 V R = infinity	B1	
			0.65 − 0.75 V R decreases / falls	C1	
			to $0.75 /(20 \times 10^{-3}) = 38$ Ω	A1	
			0.75 − 0.80 V R decreases at a constant rate	B1	**or** falls to 11 Ω at 0.80 V or similar calculation **or** decreases at 54 ΩV^{-1}
			Total	**5**	
34		i	current = 0.030 (A)	**C1**	**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.
			($I = Anev$); $0.030 = 3.8 \times 10^{-6} \times 5.0 \times 10^{25} \times 1.6 \times 10^{-19} \times v$		
			$v = 9.9 \times 10^{-4}$ (m s^{-1})	**A1**	
		ii	The resistance (of the thermistor or circuit) decreases	**B1**	
			Current / I / ammeter reading increases **because** $I \propto 1/R$ or number	**B1**	**Allow** $V = IR$ (any subject) and V = constant

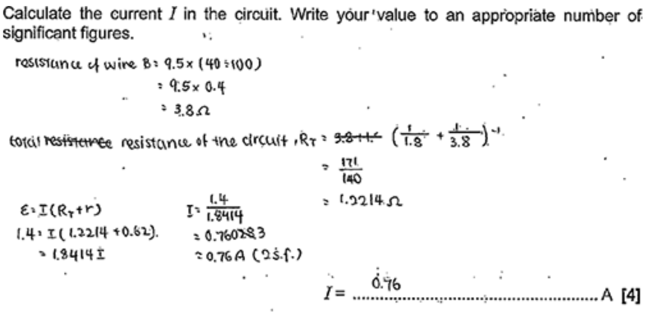
			density (of charge carriers) increases Voltmeter reading does not change (because there is no internal resistance)	**B1**	**Allow** 'more electrons / more charge carriers' **Allow** voltmeter reading stays 3.0 (V) **Examiner's Comments** This question on the heating of a thermistor favoured the top-end 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**	
35		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 Vdecreases)	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**	
36	a		E = y-intercept r = - gradient	B1 B1	E must be the subject R must be the subject **Do not accept** gradient = - r
	b	i	$\left(R=\frac{5.68}{0.025}=\right)230\,\Omega$	A1	**Allow** 227
		ii	$\left(\frac{5.68^2}{\textbf{(c)(i)}}\text{ or }0.025^2\times\textbf{(c)(i)}\text{ or }0.025\times5.68=\right)$ 0.14 × 300 = 42 (J)	C1 A1	**Allow** ECF from (c) **(i)** 0.140 or 0.142 or 0.144 **Allow** 43 (J) (for 0.142 or 0.144)

		iii	$\left(Q = \frac{(c)(ii)}{5.68} \text{ or } 0.025 \times 300 = \right)$ 7.4 or 7.5 C	B1 B1	**Allow** ECF from (c) **(ii)**
			Total	**7**	
37	a	i		**B1**	two arrows needed **not** across resistor; allow a surrounding circle with arrows outside circle
		ii	**1** from graph 3.0 (kΩ) $I = 4.0 / 3.0 = 1.33 \times 10^{-3}$ A **or** $R = 2.0 / 4.0 \times 3.0 \times 10^{3}$ $R = (6.0 - 4.0) / 1.33 \times 10^{-3}$ $= 1.5 \times 10^{3}$ (Ω) **2** at 2.4 V R_{LDR} = 1.0 kΩ giving 2.5 (W m^{-2})	**B1** **C1** **A1** **M1** **A1**	**allow** 3.1 ± 0.1 (kΩ) **accept** 1.3 mA; **accept** potential divider argument **allow** 1.5 kΩ; **special case:** using 2.4 V in place of 4.0 V gives R = 4.5 kΩ; give 1 mark out of 2 **ecf (b)(ii); allow** potential divider or I = 2.4 mA; **for special case:** R_{LDR} = 9.0 kΩ ; give 1 mark out of 2 allow 2.4 to 2.6 W m^{-2} **N.B. remember to record a mark out of 5 here** **Examiner's Comments** More than half of the candidates knew the correct circuit symbol for an LDR. The most common error was to draw an LED. More candidates used a potential divider approach to solve the problem than calculated the current in the circuit; many gaining full marks. Those who misread the question and reversed the voltages required to switch the lamp on and off were given some credit for their answers.
	b		**Level 3 (5 – 6 marks)** Clear planning and correct identification of terminals and position of components *There is a well-developed line of reasoning which is clear and logically structured. The information presented is clear relevant and substantiated.* **Level 2 (3 – 4 marks)** Clear planning and correct identification of some components / terminals *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)** Some planning and / or an attempt at identifying component / terminals	**B1 × 6**	**Use level of response annotations in RM Assessor, e.g. L2 for 4 marks,** **L2^ for 3 marks, etc.** **Indicative scientific points may include:** **Planning** • suitable circuit arrangements / diagrams drawn between two points which could be connected to the box terminals • use of R to limit current, e.g. to find CD terminals • logical plan of connection across terminals e.g. connect circuit to each pair of terminals in turn • identify terminals C and D as the circuit with the largest current / smallest resistance • A and B identified because CD known **or** the circuit including terminals AC / D has the smallest current / largest resistance **Identifying** • $V = IR$ quoted or used in calculations • $R_T = \Sigma R$ used to determine the 220Ω or the 470Ω resistors

			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.*		• For 220 Ω resistor (between AB or BC / D) current is 27 (mA) A **or** 19 (mA) with R • For 470 Ω resistor (between AB or BC / D) current is 13 (mA) **or** 11 (mA) with R • For both resistors (between AC / D) current is 8.7 (mA) **or** 7.6 (mA) with R • For wire (between CD) current is 0.060 A **Examiner's Comments** This level of response (LoR) question had two strands – planning how to determine the positioning of two resistors inside an unlabelled four terminal box and then verifying the values of their resistances. Some candidates concentrated on determining the labelling of the terminals; others assumed the positions and explained how the resistances could be determined. Many candidates made the task more difficult than necessary. For example it was intended that once terminals **C** and **D** had been identified, **C** could only be lower left and not lower right, and hence the positions of **A** and **B** were also identified. A very common circuit used to determine the resistances placed the supply between **A** and **C** with the given resistor **R** between **B** and **D,** leading to calculations requiring combinations of resistors in series and parallel. Many ignored the limiting resistor **R** and probed the box without it, a few stating that the current between **C** and **D** would be zero with the supply across **CD.** Some answers lacked any circuit diagram and some 15% failed to attempt the question. Weaker candidates were confused as to when the resistors were connected in series or in parallel. Generally, the responses were clearer in terms of planning than identifying. Comments such as *and then you can work out the arrangement of the resistors* were common without showing how this could be done. A small number of candidates introduced a voltmeter and others wanted to position the ammeter 'inside' the box.
			Total	**12**	
38	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

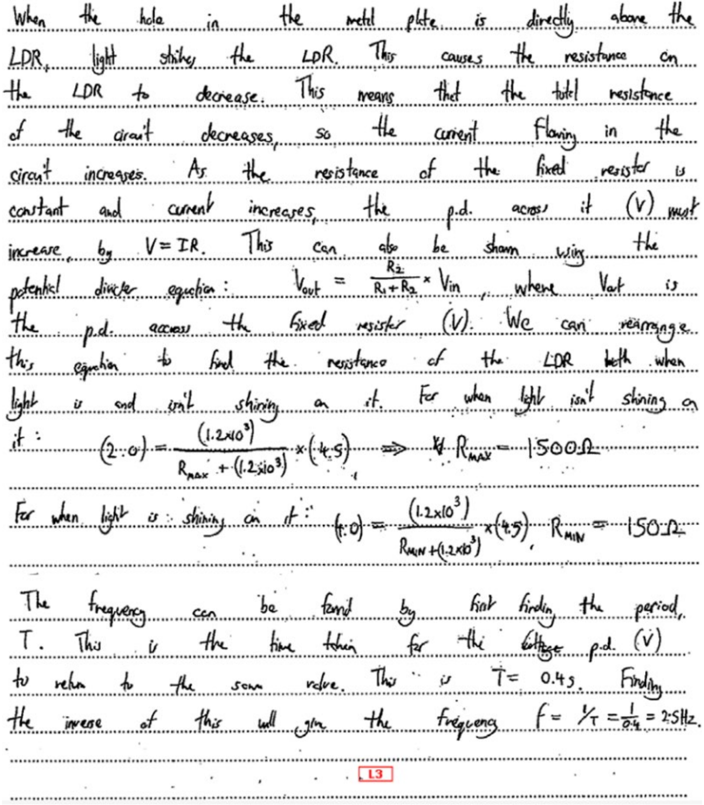
					Examiner's Comments It was pleasing to see many good answers to the determination of the length of the wire. Candidates showed clearly how they determined the area and then substituted correctly into the rearranged equation for resistivity. Some candidates round their answer to one significant figure.
		ii i	(Ohm's law states that) *V* proportional to *I* (provided the physical conditions / temperature remain constant) Since the temperature is not constant, 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**	
3 9			*Please refer to point 10 of the marking instructions of this mark scheme for guidance on how to mark this question.* **Level 3 (5–6 marks)** Typically, circuit including meters is correctly drawn on Fig. 4.2(b). Explanation of action of **both** circuits is correct. Presence of 100 Ω explained. *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)** Typically, circuit including meters is correctly drawn on Fig. 4.2(b). Action of only Fig. 4.2(b) circuit explained correctly. Purpose of 100 Ω stated but value not justified. *There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and*	B1	**Indicative scientific points may include** **circuit diagram** 1. resistor and LED in series 2. ammeter in series and voltmeter in parallel with LED 3. correct symbols for LED, ammeter, voltmeter, etc. 4. correct polarity of LED **action of circuit** 1. circuit completed on Fig. 4.2(b) 2. voltage across **AB** can be varied from 0 to 6 V 3. some justification; e.g. potential divider circuit 4. in Fig. 4.2(a) circuit voltage only varies from 6 to about 5.6 V as resistance can only be varied from 110 to 100 Ω (+ LED)/AW **presence of 100 Ω resistor** 1. the current in the circuit is limited by the resistor so ensures LED cannot burn out 2. at 6 V the potential divider across **AB** gives 2 V across LED as its resistance is about 50 Ω / AW

			supported by some evidence. **Level 1 (1–2 marks)** Typically, circuit including meters is correctly drawn on Fig. 4.2(a). No correct explanations **or** basic information on the action of circuit **or** presence of 100 Ω resistor. *The information is basic and communicated in an unstructured way. The information is supported by limited evidence and the relationship to the evidence may not be clear* **0 marks** No response or no response worthy of credit.		
			Total	**6**	
40		i	(R_B =) 9.5 × 0.40 **or** 3.8 (Ω) (parallel resistance =) $[3.8^{-1} + 1.8^{-1}]^{-1}$ **or** 1.22…(Ω) (total resistance =) 1.22.. + 0.62 **or** 1.84 (Ω) $I = \frac{1.4}{1.22\ldots+0.62}$ I = 0.76 (A)	C1 C1 C1 A1	Possible ECF from R_B Possible ECF from parallel resistance Possible ECF from total resistance **Allow** 3 marks for 0.66 A; R_B = 9.5 Ω used **<u>Examiner's Comments</u>** This circuit question required multiple steps to calculate the current I in the circuit. Firstly, the candidates had to determine the resistance of wire B, then sort out the parallel combination of resistors A and wire B, and eventually deal with the whole circuit which included the internal resistance of 0.62 Ω. The question discriminated well, with almost half of the candidates securing full marks. The responses were often well-structured and demonstrated skilled use of calculators. Some responses were spoilt by premature rounding of numbers, but generally, candidates were sensible in retaining numbers on their calculators for subsequent stages of the calculation. Exemplar 10 below shows an immaculate response from a middle-grade candidate. **Exemplar 10**

					 Calculate the current I in the circuit. Write your value to an appropriate number of significant figures. resistance of wire B = 9.5 × (40 ÷ 100) = 9.5 × 0.4 = 3.8 Ω total ~~resistance~~ resistance of the circuit, R_T = ~~3.8 + 1.8~~ $\left(\frac{1}{1.8} + \frac{1}{3.8}\right)^{-1}$ $= \frac{171}{140}$ = 1.2214 Ω $\varepsilon = I(R_T + r)$ 1.4 = I(1.2214 + 0.62) = 1.8414 I $I = \frac{1.4}{1.8414}$ = 0.760283 ≈ 0.76 A (2 s.f.) I = 0.76 A [4] All the stages of the calculations are easy to see in this well-structured response. This candidate has not rounded any of the numbers between stages – a very admirable strategy. The final response is quoted to 2 significant figures as required. **Misconception** Some of the most common mistakes are summarised below: • Calculating the total resistance using either $(3.8^{-1} + 1.8^{-1} + 0.62^{-1})$-1 or (3.8 + 1.8 + 0.62). • Forgetting to include the internal resistance when calculating the current.
		ii	$P = IV$ **or** $P = I^2R$ **or** $P = \frac{V^2}{R}$ (P_{int} =) $0.76^2 \times 0.62$; (P_{total} =) 1.4×0.76; ratio = $\frac{0.76^2 \times 0.62}{1.4 \times 0.76}$ ratio = 0.34	C1 A1	Possible ECF from **(a)(i)** **Note** there are many other correct methods **Allow** 0.34:1 **Not** an answer expressed as a fraction, e.g 31/92 **Examiner's Comments** Most candidates scored 1 mark for using an appropriate power equation. The main obstacle here for the candidates was what quantities to use for the total power supplied by the cell. Quite often, the internal resistance was omitted and $0.76^2 \times 1.22$ was used for calculating the total power. Top-end candidates used the easier alternative of 1.4 × 0.76.
			Total	**6**	
4 1			**Level 3 (5–6 marks)** Clear explanation, some description **and** both resistance values correct *There is a well-developed line of reasoning which is clear and logically structured. The*	**B1 × 6**	**Indicative scientific points may include:** **Explanation of trace** • The 'trace' is because of light reaching and not reaching LDR

			information presented is relevant and substantiated. **Level 2 (3–4 marks)** Some explanation, limited or no description **and** both resistance values correct **OR** Clear explanation, limited or no description **and** calculations mostly correct / one correct calculation **OR** Clear explanation, some description **and** no calculations *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)** Some explanation **OR** Some description **OR** Some calculation *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		• Resistance of LDR varies with (intensity) of light • In light ○ resistance of LDR is low ○ p.d. across LDR is low ○ p.d across resistor (or V) is high ○ current in circuit is large • In darkness ○ resistance of LDR is high ○ p.d. across LDR is high ○ p.d across resistor (or V) is low ○ current in circuit is small • V_{max} = 4.0 V; V_{min} = 2.0 V • Potential divider equation quoted • Substitution into potential divider equation **Description of determining frequency** • Time between pulses is constant because of constant speed • Time between pulses = 0.4 (s) • $f = 1/T$ • frequency = 2.5 (Hz) **Calculations** • Resistance of LDR is 150 (Ω) in light • Resistance of LDR is 1500 (Ω) in darkness **Examiner's Comments** This was one of the two LoR questions. It required understanding of potential dividers, light-dependent resistor and rotation frequency of a spinning plate. Examiners expect varied responses, and two very dissimilar answers can score comparable marks as long as the criteria set out in the answers' section of the marking scheme are met. Level 3 answers had the correct maximum and minimum resistance values of the LDR, a decent description and explanation of the trace shown in Fig. 17.2, and an outline of how the frequency of the spinning plate was determined. As mentioned earlier, eclectic answers are inevitable – verbose and concise answers can be at Level 3. In Level 2 answers there were generally missed opportunities. Half-done calculation and descriptions either with some errors or lacking in depth. Level 1 answers had some elements of calculations or descriptions. The two exemplars below, illustrate a Level 3 response and a Level 1 response.

Exemplar 7



When the hole in the metal plate is directly above the LDR, light strikes the LDR. This causes the resistance on the LDR to decrease. This means that the total resistance of the circuit decreases, so the current flowing in the circuit increases. As the resistance of the fixed resistor is constant and current increases, the p.d. across it (V) must increase, by $V = IR$. This can also be shown using the potential divider equation: $V_{out} = \frac{R_2}{R_1 + R_2} \times V_{in}$, where V_{out} is the p.d. across the fixed resistor (V). We can rearrange this equation to find the resistance of the LDR both when light is and isn't shining on it. For when light isn't shining on it:

$$(2.0) = \frac{(1.2\times10^3)}{R_{max} + (1.2\times10^3)} \times (4.5) \Rightarrow \cancel{V}\ R_{MAX} = 1500\Omega$$

For when light is shining on it:

$$(1.0) = \frac{(1.2\times10^3)}{R_{MIN} + (1.2\times10^3)} \times (4.5),\ R_{MIN} = 150\Omega$$

The frequency can be found by first finding the period, T. This is the time taken for the ~~voltage~~ p.d. (V) to return to the same value. This is $T = 0.4s$. Finding the inverse of this will give the frequency $f = 1/T = \frac{1}{0.4} = 2.5Hz$.

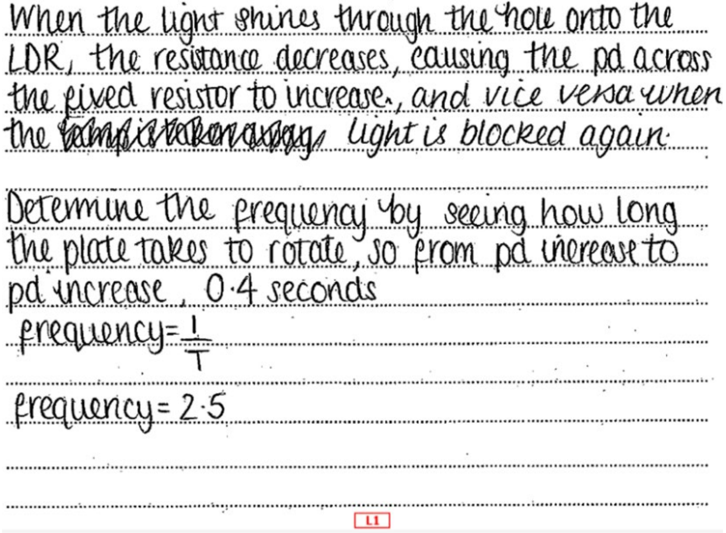
L3

This is a Level 3 response from a top-end candidate who scored 6 marks.

The description of the variation of the resistance of the LDR, the circuit current and the potential difference across the fixed resistor is perfect. The calculations of the LDR resistances are nicely embedded into the general explanation. The calculation of the frequency is all correct. This is a model answer for 6 marks.

Compare and contrast this with the Level 1 response below.

Exemplar 8



When the light shines through the hole onto the LDR, the resistance decreases, causing the pd across the fixed resistor to increase, and vice versa when the ~~lamp is taken away~~ light is blocked again.

Determine the frequency by seeing how long the plate takes to rotate, so from pd increase to pd increase, 0.4 seconds

$frequency = \frac{1}{T}$

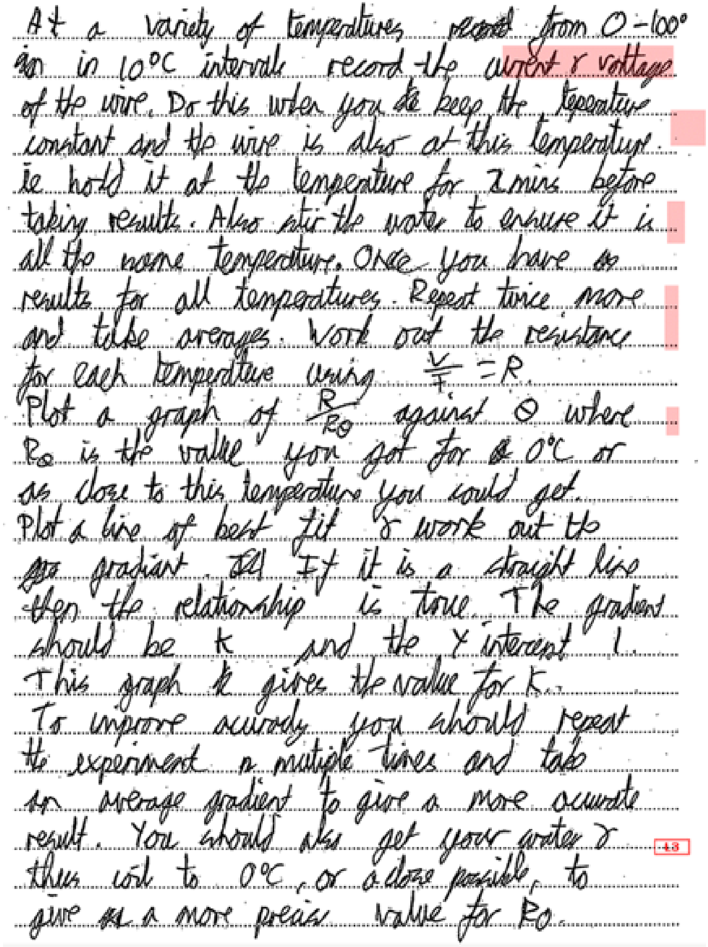
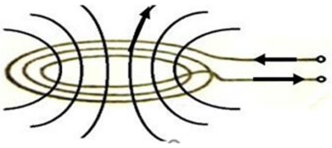
$frequency = 2.5$

L1

This is a Level 1 response from an E-grade candidate.

The description of the variation of the resistance of the LDR is

					correct. However, there are no calculations of the resistance of the LDR, as required in the question. Hence, a significant part of the question has been omitted. According to the marking criteria, this could only score Level 1. The examiner credited 2 marks for this response.
			Total	**6**	
42			**Level 3 (5–6 marks)** Clear description and analysis *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3–4 marks)** Some description and some analysis *There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.* **Level 1 (1–2 marks)** Limited description 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.	**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 **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 ~~record~~ from 0-100° ~~an~~ 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 ~~a~~ 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 ~~a~~ 0°C or as close to this temperature you could get. Plot a line of best fit & work out the ~~gra~~ gradient. ~~Ti~~ 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 & thus coil to 0°C, or a close possible, to give ~~as~~ a more precise value for R_0. L3 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**	
4 3		i		B1 B1	One correct line (or dot and cross) drawn Line must go through centre of coil **Allow** an incomplete line or a complete circle round the coil **Ignore** direction of arrow More than one line drawn All lines drawn must go through centre of coil and follow correct shape and direction of field

<table>
<tr><td></td><td></td><td></td><td></td><td></td><td>Ignore spacing of lines
Ignore any lines to the right of the coil</td></tr>
<tr><td></td><td></td><td>ii</td><td>(the magnetic) flux (of the coil) links the <u>base</u> / <u>saucepan</u>

(the size/direction of) the flux linkage (constantly) <u>changes/alternates</u> (causing an alternating induced e.m.f.)

(induced) <u>current</u> is large because metal/base/ saucepan has low resistance</td><td>B1 x 2</td><td>2 out of 3 possible marking points

Allow (the magnetic) field lines cut the (base of the) <u>saucepan</u>
Allow the (magnetic) field constantly changes/alternates
Allow a bald statement of Faraday’s Law</td></tr>
<tr><td></td><td></td><td>iii</td><td>The resistance of glass-ceramic/the (cook”s) hand is (very) large

So (induced) <u>current</u> (or heating effect of <u>current</u>) is zero/negligible</td><td>M1

A1</td><td>Allow glass-ceramic/hand is an insulator/not a (good) conductor

Do not allow the induced <u>e.m.f</u>. is (very) small</td></tr>
<tr><td></td><td></td><td></td><td>Total</td><td>6</td><td></td></tr>
<tr><td>44</td><td></td><td></td><td>Level 3 (5–6 marks)
E and r calculated correctly and table completed correctly and clear description of P and R

<i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i>

Level 2 (3–4 marks)
Table completed correctly and some description of P and R / some attempt at E and r
OR
E and r calculated correctly
OR
Some attempt at calculating E and r and some description of P and R

<i>There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.</i>

Level 1 (1–2 marks)
Limited calculation of E and r
OR
Table completed correctly
OR
Limited description of relationship between P and R

<i>There is an attempt at a logical structure</i></td><td>B1×6</td><td>Indicative scientific points may include:

Calculating <i>E</i> and <i>r</i>

• $E = Ir + V$
• gradient = (-) r
• y-intercept = E
• Line extrapolated to y-axis
• E = 1.2 (V)
• r = 0.8(0 Ω)

Table and description

• Table completed (ignore SF) – see below
• R increases as V increases (or I decreases)
• P increases and decreases
• Maximum power is when internal resistance is equal to R (0.8 Ω)

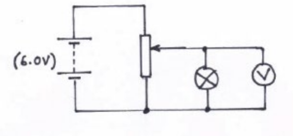
<table>
<tr><th><i>V / V</i></th><th><i>I / A</i></th><th><i>R</i> / Ω</th><th><i>P / W</i></th></tr>
<tr><td>0.20</td><td>1.25</td><td>0.16</td><td>0.25</td></tr>
<tr><td>0.40</td><td>1.00</td><td>0.40</td><td>0.40</td></tr>
<tr><td>0.60</td><td>0.75</td><td>0.80</td><td>0.45</td></tr>
<tr><td>0.80</td><td>0.50</td><td>1.60</td><td>0.40</td></tr>
<tr><td>1.00</td><td>0.25</td><td>4.00</td><td>0.25</td></tr>
</table>

<u>Examiner’s Comments</u>

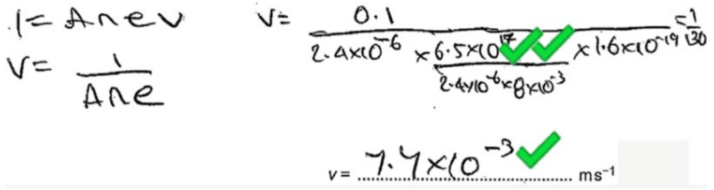
This is the first LoR question on the paper. This question is based on a standard physics practical, so the experimental set up should have been familiar to many candidates. While a holistic approach is taken</td></tr>
</table>

			with a line of reasoning. The information is in the most part relevant. **0 marks** No response or no response worthy of credit		to the marking, there are key points which should be present for the award of given levels. The question is structured in two main parts: the determination of E and r, and then the calculation of R and P for the table. However, each of these parts contain additional instructions which were often ignored by the candidates. For the emf and internal resistance, an explanation of the method used was required, the most usual way would be based around a rearrangement of $E = V + Ir$. For the resistance and power, a qualitative description of how they are related is needed, along with an appreciation that when the internal resistance equals the load resistance the power is at its maximum. For the most part, candidates carried out the calculations well, completing the table and identifying E and r correctly, but did not give suitable and detailed descriptions leading to them being limited to lower levels. Very few discussed the resistance and power relationship at all, despite it being a reasonably simple pattern. It is very important that candidates make note of all that is required in a LoR question if they are to access the higher levels. The vast majority of candidates did sufficient work to place them in Level 2. **Misconception** Many candidates missed opportunities to achieve a higher level by not explaining their reasoning and not describing the pattern of R with P.
			Total	**6**	
4 5			**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	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 = $\lg k$

			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		- $k = 10^{\text{intercept}}$ (or $k = e^{\text{intercept}}$ for natural logs)
			Total	**6**	
46		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**	
47		i	Arrow in anticlockwise direction	B1	**Allow** this mark for correct direction shown on diagram either on or off connecting wires **<u>Examiner's Comments</u>** 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** $(R_T =)\ 0.80 + 0.50 + 1.2$	C1	$E = 2.1$ (V); $R_T = 2.5$ (Ω)

			$4.5 - 2.4 = I \times (0.80 + 0.50 + 1.2)$ $I = 0.84$ (A)	C1 A1	Treat missing 1.2 resistance as TE **Allow** 2 marks for 2.8 (A); E = 6.9 V used **<u>Examiner's Comments</u>** 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 **<u>Examiner's Comments</u>** 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 **<u>Examiner's Comments</u>** 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**	
48		i	Correct circuit with a battery, potential divider, lamp and voltmeter. 	B1	

		i	Correct symbols used for all components.	B1	**Allow**: A cell symbol for a battery
		ii	Description: The temperature of the filament increases. (AW)	B1	
		ii	The resistance of the lamp increases	M1	
		ii	from a non-zero value of resistance.	A1	**Allow** 'when cold the resistance is small'
		ii	Explanation: Resistance increases because electrons/charge carriers make frequent collisions with ions. (AW)	B1	
		iii	($P = VI$) current in **X** is 3 times the current in **Y** Or area of **X** is 4 times smaller than area of **Y**	C1	**Allow** other correct methods.
		iii	$I = Anev$ and ratio = $\frac{3}{0.25}$	C1	
		iii	ratio = 12	A1	
			Total	**9**	
49		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** **Examiner's Comments** 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 **Examiner's Comments** 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**  $I = Anev$ $V = \frac{1}{Ane}$ $V = \frac{0.1}{2.4\times10^{-6} \times \frac{6.5\times10^{17}}{2.4\times10^{-6}\times8\times10^{-3}} \times 1.6\times10^{-19}} = \frac{1}{130}$ v = 7.7×10^{-3} ms^{-1} 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 × 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 × 10^{-3} (m s^{-3})	C1 C1 A1	**Note** do not penalise again for the same POT error **Allow** 1 mark for 4(.0) × 10^5 (m s^{-1}); n = 6.5 × 10^{17} used
			Total	**9**	