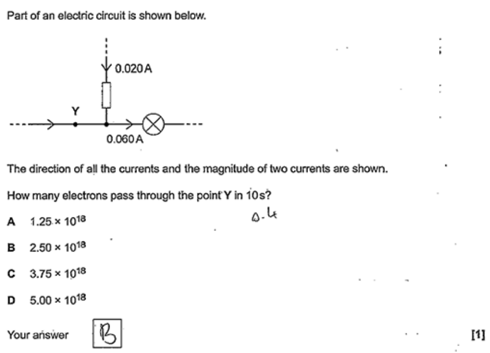
Mark scheme – Charge and Current

Question			Answer/Indicative content	Marks	Guidance
1			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**	
2			B	1	**<u>Examiner’s Comments</u>** This was not an easy question, but most candidates did extremely well in this multi-step calculation. The directions of the currents are important. The current at **Y** and the current in the resistor, must add up to 0.060 A. The charge passing point **Y** in a time of 10 s can be calculated using $\Delta Q = I\Delta t$ and finally the number of electrons can be determined by dividing the charge passing through **Y** by the elementary charge e. Therefore number of electrons = $\frac{(0.060 - 0.020) \times 10}{1.60 \times 10^{-19}} = 2.50 \times 10^{18}$ The key, correct answer, is **B**. The most popular distractor was **C**, in which a current of 0.060 A is assumed; the rest of the distractors were equally favourable. **A** was the answer for a current of 0.020 A and **D** was the answer for a current of 0.080 A. It is worth mentioning that most of the candidates just wrote down the correct answer in the box, without any calculations. On the surface, this looks reckless, but it is an excellent strategy if the numbers are being punched into the calculator correctly. The exemplar 1 below shows a typical correct answer, with numbers jotted down for visual help. **Exemplar 1**  Part of an electric circuit is shown below. 0.020 A Y 0.060 A The direction of all the currents and the magnitude of two currents are shown. How many electrons pass through the point Y in 10 s? A 1.25 × 10^{18} B 2.50 × 10^{18} C 3.75 × 10^{18} D 5.00 × 10^{18} Your answer B [1]

					The candidate has the correct current at **Y**. Without the 0.040 A, the answer would have led to one of the distractors. It is worth pointing out that the final step of the calculation must have been done directly on the calculator. An excellent time-saving approach.
			Total	**1**	
3			electron; ion	B1	both required for 1 mark.
			Total	**1**	
4			**C**	1	
			Total	**1**	
5			B	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.
			Total	**1**	
6			D	1	
			Total	**1**	
7			D	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.
			Total	**1**	
8			**B**	1	
			Total	**1**	
9			A	1	
			Total	**1**	
10			**C**	**1**	
			Total	**1**	

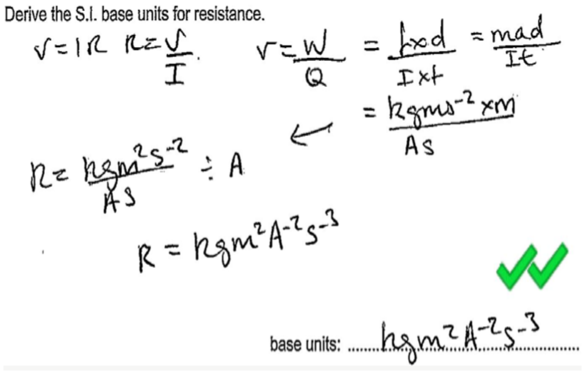
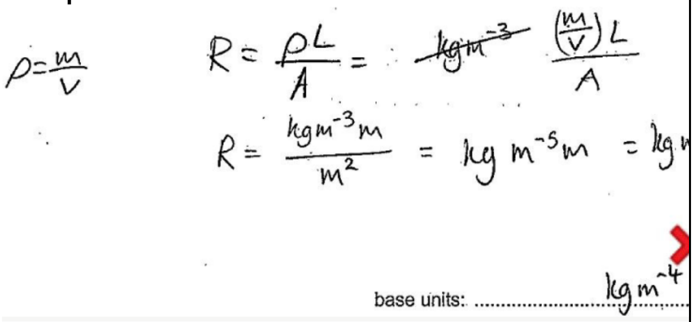
4.1 Charge and Current

11			**A**	**1**	
			Total	**1**	
12			**B**	**1**	**Examiner's Comment** All questions showed a positive discrimination, and the less able candidates could access the easier questions. The questions in Section A require careful reading and execution. Underlining or circling key information may help. Candidates are reminded not to use highlighter pens for this purpose. There is ample space for jotting down ideas and key equation, but it is best to do calculations on calculators to save time. Questions **1, 3,10** and **14** proved to be particularly straightforward, allowing most of the candidates to demonstrate their knowledge and understanding of physics. At the other end of the scale, Questions **5, 9,** and **15** proved to be more challenging. • Question **5** was on the superposition of waves and the relationship intensity∞ amplitude^2. The amplitude of the resultant wave is 0.4a and therefore the intensity of resultant wave must be 0.16I. The most popular distractors were **B** and **C**. Less than half of the candidates got the correct answer of **A**. • Question **9** was about doubling the separation between two oppositely charged parallel plates. The only correct statement is **D**. Electric field strength is p.d. divided by the distance between the plates. Since both quantities double, the electric field strength, must remain the same. • Question **15** was about refraction and the equation nsinη = constant at the boundary between two materials. The ratio $n1/n2$ = sin80°/sin90° = 0.98; the correct is **B**. The most popular distractor was **C**, which was the inverse of the correct answer.
			Total	**1**	
13			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**	
14			C	1	
			Total	**1**	
15			c	1	**Examiner's Comments** This was a well-answered question with most candidates correctly recalling that charge is conserved according to Kirchhoff's first law. A significant number of candidates distracted towards **B**; perhaps because of the unit of charge is the coulomb.
			Total	**1**	
16			C	1	
			Total	**1**	
17			**D**	20	
			Total	**1**	
18			C	1	
			Total	**1**	
19			D	1	
			Total	**1**	
20			**A**	1	
			Total	**1**	
21			**C**	1	
			Total	**1**	
22			**A**	1	
			Total	**1**	
23			**C**	1	
			Total	**1**	

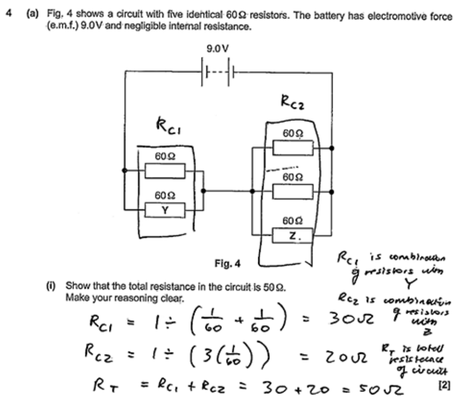
24			D	1	
			Total	**1**	
25	a		(initial charge) $Q = EC_0$ **or** (Q conserved so final) $Q = V(C + C_0)$ (as capacitors are in parallel) so $EC_0 = V(C + C_0)$ (and hence $V = C_0 E / (C + C_0)$)	M1 A1	At least one correct expression for Q for first mark The two correct expressions equated for the second mark **Examiner's Comments** Some candidates obtained $Q = EC_0$ by applying the definition of capacitance at A, but then did not realise that charge would be conserved on switching from A to B. Some chose the wrong formula for capacitors in parallel or attempted to use the potential divider equation.
	b	i	$1/V = 1/E + C/EC_0$ (and compare to $y = c + mx$)	B1	Mark is for rearrangement into linear equation **Examiner's Comments** Some candidates correctly took the reciprocal of both sides of the given equation but were then unable to show a rearrangement into the standard linear form. A common difficulty was an inability to expand the bracket in $\frac{1}{E} \times \frac{(C + C_0)}{C_0}$ to give $\frac{C}{EC_0} + \frac{C_0}{EC_0}$
		ii	$1/EC_0 = 51 = 1/(9.1\ C_0)$ giving $C_0 = 1/(51 \times 9.1)$ F $C_0 = 2.2$ (mF)	B1 B1	$C_0 = 2.1547 \times 10^{-3}$ F Answer must be correct, rounded correctly and given in mF Candidate's answer must be given to 2 SF **Examiner's Comments** Some candidates gave their response to 2 d.p. instead of to 2 s.f. as required.
		iii	(at least) one correct worst fit line drawn gradient calculated correctly using a large triangle uncertainty = C_0 – 1/(wfl gradient x 9.1)	B1 B1 B1 B1	Top and bottom points chosen must be from opposite extremes of uncertainty limits, accurate to within half a small square $\Delta x \geq 1.5 \times 10^{-3}$; **expect** 59±1 or 44±1 (**or** 0.059 **or** 0.044); **allow ECF** from poorly drawn line; readings must be accurate to within half a small square **ECF** from **b(ii)**; **expect** uncertainty of up to 0.4(mF) **ECF** from **b(ii)** **If** no value for C_0 given in b(ii), **allow** any answer given to 1dp **Examiner's Comments**

			uncertainty given is to the same number of decimal places as C_0		Most candidates gained the mark for using a large triangle (spanning more than 1.5 on the x–axis) to determine the gradient of the worst-fit line. Lower ability candidates were unable to gain credit for finding the gradient of their line because they read the scales on the axes incorrectly. Candidates should take a ruler into the examination and be careful about the positioning of the ruler for drawing a worst-fit straight line. A worst-fit line should join opposite extremes of uncertainty limits and pass between all the uncertainty limits. The Practical Skills Handbook is helpful on this topic. Several candidates performed the unnecessary step of calculating the fractional (or percentage) uncertainty instead of using $\Delta C_0 = \pm \lvert C_{0\ best} - C_{0\ worst} \rvert$ directly.
	c		Only effect is to slow the charging and / or discharging (of capacitor(s)) <u>and so</u> the final charges are unchanged / the values for *V* are unchanged / the graph is unchanged / the gradient is unchanged / there is no effect on the experiment (results)	B1	**Allow** and so the experiment takes longer
			Total	**10**	
26			$(R = \frac{V}{I} = \frac{W}{QI};\ Q = It)$ 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**

					 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**  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**	
27	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**	
28		i	because of Kirchhoff's first law **or** statement of this law.	B1	
		ii	Using I = nAev so v is proportional to 1/A giving 5.4×10^{-5} ($m\ s^{-1}$).	B1	**ecf(b)(iii)**
			Total	**2**	
29			Silicon will have a smaller number density, ORA Silicon will have a larger resistivity, ORA	B1 B1	**Allow** semiconductor for silicon; metal for nichrome **<u>Examiner's Comments</u>** 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**	
30	a	i	$F = QE = QV / d$ **or** $E = 5(.0) \times 10^4$ (Vm^{-1}) $F = 9.0 \times 10^{-9} \times 4000 / 8.0 \times 10^{-2}$ (= 4.5×10^{-4} N)	C1 A1	$F = 5.0 \times 10^4 \times 9.0 \times 10^{-9}$ **<u>Examiner's Comments</u>** Many lower ability candidates did not appreciate the uniform nature of the electric field between the plates and attempted to use Coulomb's Law.
		ii	weight; arrow vertically downwards	B1 x 2	All correct, 2 marks; 2 correct, 1 mark 1 mark maximum if more than 3 arrows are drawn **Ignore** position of arrows **Allow** W **or** 0.030(N) (**not** gravity or g) **Allow** T **Allow** F **or** E or 4.5×10^{-4}(N) or electrostatic

			tension; arrow upwards in direction of string electric (force); arrow horizontally to the <u>right</u> (not along dotted line)		**Ignore** repulsion or attraction **Not** electric field / electric field strength / electromagnetic **<u>Examiner's Comments</u>** Most candidates scored a mark for showing the weight and tension forces accurately. Only a small proportion labelled the electric force arrow correctly and drew it as clearly perpendicular to the plates. **AfL** Do not use the word 'gravity' in place of 'weight'
		iii	$W x = F l$ 0.03 x = 4.5 x 10^{-4} x 120 **or** = 4.5 x 10^{-4} x 1.2 x = 1.8 cm **or** x = 0.018 m	M1 M1 A0	**Allow** any valid alternative approach e.g. M1 deflection angle θ = 1° M1 x = 120sinθ 1 mark for each side of the equation **<u>Examiner's Comments</u>** Although most candidates knew the principle of moments, many were unable to apply it correctly in this situation. More practice at this sort of question is recommended.
	b		Electric force/field (strength) increases Ball deflected further from vertical / moves to the right / touches negative plate Ball acquires the charge of the (negative) plate when it touches (Oscillates because) constantly repelled from (oppositely) charged plate	B1 B1 B1 B1	Must be clear which force is increasing Must have the idea of a repeating cycle **<u>Examiner's Comments</u>** The purpose of this question was to challenge the candidates to use their knowledge of electric fields in a novel practical situation. The word 'oscillate' confused many candidates, who tried to explain why the ball would perform simple harmonic motion.
	c		$I = Qf$ **or** $Q = It$ f = 3.2 x 10^{-8}/9.0 x 10^{-9} = 3.6 (Hz)	C1 A1	
			Total	**12**	
31			electrons emitted / s = 1.0 × 10^{-9} / 1.6 × 10^{-19} = 6.25 × 10^{9}	C1	

			Answer	Marks	Guidance
			photons arriving = $6.25 \times 10^{9} \times 20 = 1.25\ 10^{11}$	C1	
			$\varepsilon = 1.25\ 10^{11} \times 4.0 \times 10^{-19} = 5.0 \times 10^{-8}$ (J s^{-1})	A1	**Allow ecf**: 1 out of 3 for correct answer from any quoted number of electrons emitted / s
			Total	**3**	
32			$Q = It$ and $e = 1.6 \times 10^{-19}$ (C)	C1	
			number of electrons = $0.24 \times 10^{-6} \times 5.0/1.6 \times 10^{-19}$	C1	
			number of electrons = 7.5×10^{12}	A1	
			Total	**3**	
33	a	i	$\frac{1}{R} = \frac{1}{60} + \frac{1}{60}$ or $\frac{1}{R} = \frac{1}{60} + \frac{1}{60} + \frac{1}{60}$ or $R = \frac{60}{n}$ or $R = \frac{60 \times 60}{60 + 60}$ 30 Ω + 20 Ω = 50 Ω	M1 A1	**<u>Examiner's Comments</u>** This question was generally answered well although, a number of candidates did not take due care when writing the mathematical expressions. **Exemplar 6**  The candidate's response is logically structured showing the effective resistance of the two combinations of resistors and then clearly showing the adding of the two effective resistances together. This answer gained both marks.
		ii	$\frac{30}{50} \times 9$ or $I = \frac{9}{50} = 0.18$ A 5.4 V	C1 A1	**<u>Examiner's Comments</u>** For this question, many candidates incorrectly stated that the potential difference was 4.5 V. Other candidates tried determining the current but did not make clear their working. The simplest solution was to use the potential divider relationship.
		iii	$\left(I = \frac{5.4}{60} =\right)$ 0.090 A (0.09 x 120 =) 11	C1 A1	**Allow ECF** from **(ii)** **Allow** 10.8

			C or coulomb	B1	**Note** 0.18 C scores two marks provided 0.09 A is seen **Note** 21.6 C scores one mark (for the correct unit) **Examiner's Comments** The majority of the candidates gained a mark for the unit of charge on this question. A common incorrect answer was 21.6 C where candidates had used the total current in the circuit rather than the current of 0.09 A in resistor Y. Some candidates did not change the time in minutes to a time in seconds.
		iv	(11 x 5.4 or 0.09 x 5.4 x 120)= 59 or 58 (J)	A1	**Note** 58(.3) if 10.8 C used **Allow ECF** from **(ii)** and/or **(iii)** **Not** 60 **Examiner's Comments** Candidates who multiplied the charge by the potential difference easily gained the mark in this question. Other candidates who used different methods often made mistakes.
	b		I = *nAve* or *v* α *I* larger current through **Y** than **Z** ORA drift velocity in **Y** is 1.5 times drift velocity in **Z** ORA	B1 B1 B1	**Allow** any correct rearrangement of $I = nAve$ **Allow** I_Y = 0.090 A and I_Z = 0.060 A OR I_Y / I_Z = 1.5 ORA **Examiner's Comments** In this question, many candidates correctly quoted the equation and stated that the mean drift velocity was directly proportional to the current. The majority of the candidates realised that there was a larger current in resistor Y than resistor Z; however, few candidates realised that the current was 1.5 times larger and therefore the mean drift velocity was 1.5 times larger.
	c		n = number of (free) charge carriers per unit volume / per cubic metre / m^{-3} The larger the value of n, the better the conduction / greater the current ORA Copper has a larger n than carbon which has a larger n than ceramic ORA	B1 B1 B1	**Allow** free electrons for free charge carriers **Not** electrons **Allow** copper is a conductor / most conductive or semiconductor does not conduct as well as copper etc. **Allow** values for n **Examiner's Comments** In this question, many candidates did not score the mark for explaining that the number density was the number of free charge carriers per unit volume. Some candidates incorrectly defined it as the number of electrons as opposed to free electrons, while other candidates stated that it was per unit area. The majority of the candidates gained two marks on this question. They explained that copper was a conductor or the larger the value of the number density the better the conduction and then related the three materials correctly. A number of

					candidates correctly stated example number densities. Some candidates' explanations were too vague.
			Total	**14**	
3 4		i	I = nAev; $v = 60 \times 10^{-3}/1.2 \times 10^{23} \times 1.6 \times 10^{-19} \times 5.0 \times 0.2 \times 10^{-6}$ v = 3.1 (m s^{-1})	**C1** **C1** **A1**	**allow** any subject
		ii	$V = 80 \times 10^{-3} \times 3.1 \times 5.0 \times 10^{-3}$ $= 1.2 \times 10^{-3}$ (V)	**A1**	**ecf (b)(i); allow** 1.2 mV; 1.3×10^{-3} (V) **Examiner's Comments** This exercise of choosing a formula, substituting values in correct units and evaluating was done well with about three quarters of the candidates gaining full marks.
			Total	**4**	
3 5		i	2.76 − 2.3 = 0.46 eV (so only 0.5% of energy/AW)	B1	**allow** 2.8 − 2.3 = 0.5 eV and 3.0 − 2.3 = 0.7 eV possible **ecf** from **(b)**
		ii	$n = 2000 \times 4^9$ (= 5.24×10^8) $Q = ne = 8.4 \times 10^{-11}$ (C) $I = 8.4 \times 10^{-11} / 2.5 \times 10^{-9}$ average current = 0.034 (A)	C1 C1 A1	**allow ecf** for wrong n **allow** 34 m(A); answer is 1.7×10^{-5} A if 2000 omitted (2/3) **Examiner's Comments** Almost all of the candidates attempted this last section of the paper with some success. In part (i) most candidates showed that they understood the theory behind the question and subtracted the appropriate two numbers from part (b) to gain the mark. Part (ii) was done well with a significant number obtaining the correct answer. Another large group forgot that 2000 electrons were released and performed the calculation for only a single electron being multiplied up and so forfeited the final mark.
			Total	**4**	
3 6			Q = 79e and q = 2e $F = (1/4\pi\varepsilon_0)Qq/r^2$ $= 79 \times 2 \times (1.6 \times 10^{-19})^2 / [4\pi \times 8.85 \times 10^{-12} \times (6.8 \times 10^{-14})^2]$ = 7.9 (N)	C1 C1 C1 A1	**Apply ECF** for wrong charge(s), e.g. Q and / or q = e, or Q = 79 and / or q = 2, etc **Examiner's Comments** The most common error here was to use incorrect values for the charges on the two ions. Even so, most candidates were able to gain most of the marks with ECF.

			Total	**4**	
3 7		i	I = Q/t = 650/5 = 130 A	A1	
		ii	n = I/e = 130/1.6 × 10^{-19} = 8.13 × 10^{20}	A1	**ecf(b)(i)**
		ii i	I = 10^{29}Aev giving 8.13 × 10^{20} = 10^{29}Av	C1	**ecf(b)(ii)**
		ii i	v = 8.13 × 10^{20} / 10^{29} × 3.0 × 10^{-4} = 2.7 × 10^{-5} (m s^{-1}).	A1	
			Total	**4**	
3 8		i	current = 0.030 (A) (*I = Anev);* 0.030 = 3.8 × 10^{-6} × 5.0 × 10^{25} × 1.6 × 10^{-19} × *v* *v* = 9.9 × 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* ∝ *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**	

<table>
<tr><td>39</td><td></td><td>i</td><td>Similarity – same unit (AW)</td><td>B1</td><td>Allow ‘both defined as energy (transformed) per unit charge’ or ‘both defined as work done per unit charge’</td></tr>
<tr><td></td><td></td><td>i</td><td>Difference – For e.m.f, energy is transformed from chemical / other forms to electrical and for p.d., energy is transformed to heat / other forms from electrical</td><td>B1</td><td>Allow any pair from:
<table><tr><td>e.m.f.</td><td>p.d.</td></tr><tr><td>Energy (transformed) to electrical</td><td>Energy (transformed) from electrical or Energy (transformed) to heat /other forms</td></tr><tr><td>Charges gain energy</td><td>Charges lose energy</td></tr><tr><td>Work done on charges</td><td>Work done by charges</td></tr></table>
Examiner's Comments

Most candidates knew that e.m.f. and p.d. were both measured in volts (V). A small number of candidates thought that ‘volt’ was the same as ‘voltage’. This question benefitted those who taken time to revise thoroughly. The modal mark was one, but a significant number of candidates scored two marks for their flawless answers.</td></tr>
<tr><td></td><td></td><td>ii</td><td>$n = \frac{9.6 \times 10^{16}}{1.2 \times 10^{-6} \times 6.0 \times 10^{-3}}$ or $n = 1.3(3...) \times 10^{2}$

($I = Anev$)</td><td>C1</td><td></td></tr>
<tr><td></td><td></td><td>ii</td><td>$0.003 = 1.2 \times 10^{-6} \times 1.33... \times 10^{25} \times 1.6 \times 10^{-19} \times v$</td><td>C1</td><td>Note Any subject for this equation</td></tr>
<tr><td></td><td></td><td>ii</td><td>$v = 1.2 \times 10^{-3}$ (m s^{-1})</td><td>A1</td><td>Allow 1 mark for $1.6(3) \times 10^{5}$ (m s^{-1}); $n = 9.6 \times 10^{16}$ used

Examiner's Comments

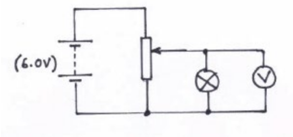
Almost all candidates were familiar with the equation $I = Anev$. However, only the top-end candidates realised that the number density of the charge carriers (electrons) had to be calculated from the number of electrons given and the volume of the resistor. The majority of candidates incorrectly assumed n to be 9.6×10^{16} m^{-3} when it should have been 1.3×10^{25} m^{-3}. Examiners awarded one mark for those candidates who arrived at the answer 1.6×10^{5} m s^{-1} using the incorrect value of n.</td></tr>
<tr><td></td><td></td><td></td><td>Total</td><td>5</td><td></td></tr>
<tr><td>40</td><td></td><td>i</td><td>$\frac{0.045}{1.6 \times 10^{-19}}$

number of electrons = 2.8×10^{17}</td><td>C1
A1</td><td></td></tr>
<tr><td></td><td></td><td>ii</td><td>$A = \pi \times (0.12 \times 10^{-3})^2$ or $4.5(2) \times 10^{-8}$ (m^2)
$0.045 = \pi \times (0.12 \times 10^{-3})^2 \times 6.3 \times 10^{28} \times 1.6 \times 10^{-19} \times v$
$v = 9.9 \times 10^{-5}$ (m s^{-1})</td><td>C1
C1
A1</td><td>Allow 2 marks for 2.5×10^{-5} (m s^{-1}); 0.24 mm and POT error</td></tr>
<tr><td></td><td></td><td></td><td>Total</td><td>5</td><td></td></tr>
</table>

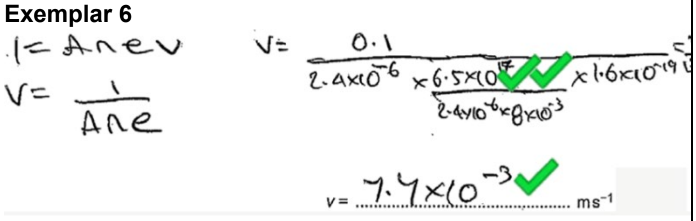
4 1	a		E = y-intercept r = - gradient	B1 B1	E must be the subject R must be the subject **Do not accept** gradient = - r
	b	i	$\left(R = \frac{5.68}{0.025} =\right) 230\ \Omega$	A1	**Allow** 227
		ii	$\left(\frac{5.68^2}{\textbf{(c)(i)}} \text{ or } 0.025^2 \times \textbf{(c)(i)} \text{ or } 0.025 \times 5.68 =\right) 0.14$ 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	$\left(Q = \frac{\text{(c)(ii)}}{5.68} \text{ or } 0.025 \times 300 =\right) 7.4$ or 7.5 C	B1 B1	**Allow** ECF from (c) **(ii)**
			Total	**7**	
4 2		i	$R = \frac{150}{1.5^2}$ 67 Ω	C1 A1	**Allow** $V = \frac{150}{1.5} = 100\ \text{V}$ and $R = \frac{100}{1.5}$
		ii	Q = 1.5 × 5.0 × 60 × 60 or 27000 $N = \frac{1.5 \times 5.0 \times 60 \times 60}{1.6 \times 10^{-19}}$ = 1.7×10^{23}	C1 A1	**Note** use of 150 (W) does not score 1.7×10^{25} 1.68×10^{23} 4.7×10^{19} scores one mark **Not** 1.7×10^{25} (uses 150 W)
		iii	$v = \frac{1.5}{7.9 \times 10^{28} \times 4.1 \times 10^{-9} \times 1.6 \times 10^{-19}}$ 0.029 (m s^{-1})	C1 A1	
			Total	**6**	
4 3			**Level 3 (5 – 6 marks)** Clear expansion of three statements *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 expansion of two statements **or** Limited attempt at all three *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 attempt at one or two statements	B1 x 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:** **statement 1** • fusion reactions are occurring • which change H into He • and mass is lost which releases energy • energy released = $c^2 \Delta m$ • Δm per second = luminosity / c^2 **statement 2** • average k.e. of each proton is $\frac{3}{2}kT$ • high T means protons are travelling at high speed • so fast enough to overcome repulsive forces • and get close enough to fuse • p.e. = $e^2/4\pi\varepsilon_0 r$ so T must be high enough for $\frac{3}{2}kT > e^2/4\pi\varepsilon_0 r$

			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.*		• r is approximately 3fm **statement 3** • k.e. ∝ T so average energy at 10^7 K is only one thousandth of the average energy at 10^{10} K when protons might fuse • but M-B distribution applies so at the high energy end there will be a few p with enough energy • quantum tunnelling across potential barrier is possible • small probability of many favourable collisions to boost energy of p • 4 p must fuse to produce He; it is complicated process making probability of fusion much less • number of p in Sun is so huge that, even with such a small probability, 4 x 10^9 kg of p still interact s^{-1} • a larger probability means lifetime of the Sun would be shorter **<u>Examiner's Comments</u>** This was one of the two LoR questions. It required understanding of fusion, mass-energy equivalence, the Maxwell-Boltzmann distribution, and the relationship between mean kinetic energy and temperature for particles in an ideal gas. Responses to the following questions were being sought: 1. Why is the Sun losing mass? 2. Why is an extremely high temperature needed for fusion in stars? 3. Why does fusion occur in the Sun even though its temperature is 1,000 times less than that required by theory? Two dissimilar responses could score comparable marks if the criteria set out in the answer section of the marking scheme were met. Level 3 responses gave a clear answer to all three of the questions, whereas Level 2 responses generally had clear answers to only two. In Level 1, limited answers to only one or two of the above questions were given.
			Total	**6**	
4 4		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		C1 C1 A0	There is no ECF from **(b)(i)**

			1 $t = 78 \times 3600$ $(I =) \frac{2.5 \times 10^{-7}}{78 \times 3600}$ $I = 8.9 \times 10^{-13}$ (A) $(R =) \frac{6000}{9.0 \times 10^{-13}}$ **or** 6.7×10^{15} (Ω) **or** $V = IR$ and $R = \frac{\rho L}{A}$ **2** $\frac{6000}{9.0 \times 10^{-13}} = \frac{\rho \times 0.38}{1.1 \times 10^{-4}}$ $\rho = 1.9 \times 10^{12}$ (Ω m)	C1 C1 A1	**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**	
45		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 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 **<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**	
46		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**	
47		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 **Examiner's Comments** 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 × 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**	