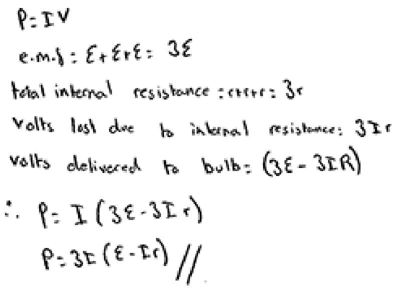
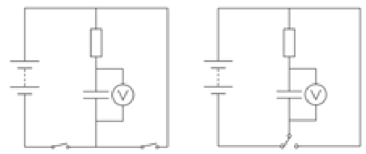
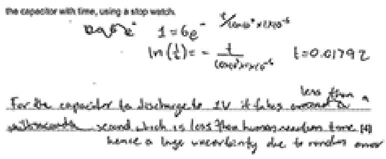
Mark scheme

Question			Answer/Indicative content	Marks	Guidance
1			$\varepsilon = Ir + IR$ Or $\varepsilon = Ir + V$ or $V = \varepsilon - Ir$ Total internal resistance in circuit = 3*r* and Total emf in circuit = 3ε Clear steps leading to given equation	B1 M1 A1	Any correct rearrangement **Not** reference to 3I **Allow** $3\varepsilon = 3Ir + IR$ Or $3\varepsilon = 3Ir + V$ ***Use of $P=I^2R$*** $\varepsilon I = I^2r + I^2R$ $\varepsilon I = I^2r + P$ $P = I(\varepsilon - Ir)$ $P = I(3\varepsilon - 3Ir)$ ***Use of $P = IV$*** Total pd = $3(\varepsilon - Ir)$ $P = IV_T = 3I(\varepsilon - Ir)$ **<u>Examiner's Comments</u>** Most candidates achieved 1 mark for this question, for stating the correct expression for e.m.f, ε, e.g. ε = Ir + V with some candidates showing clearly that the power, P delivered to the bulb is given by the expression P = 3I(ε - Ir). Responses that were given 1 mark did not give clear working to express their understanding that the e.m.f. ε and internal resistance, r, were increased by 3. Often, candidates would just give an unqualified expression for P, e.g. P = 3 x I(ε - Ir), but from this expression it was not clear whether the factor of 3 was for current I or ε and r despite the correct application of P=IV. The responses that achieved 3 marks showed a clear rationale in their working and that for the 3 cells in series the total e.m.f. was 3ε, and the total internal resistance was 3r. These candidates then showed clear steps in finding an expression for the potential difference across the bulb using ε = Ir + V to be, e.g. V = 3ε - 3Ir. By showing clear working, it was evident that candidates understood that the potential difference across the bulb was equal to the total terminal potential difference across

					the three cells in series. These candidates then correctly substituted their expression for the potential difference into an equation for power, e.g. P=IV to show the power P delivered to the bulb given in the stem of the question. Exemplar 1  Exemplar 1 demonstrates clear working and rationale to show the given expression for the power P delivered to the bulb. The response is given 3 marks.
			Total	3	
2			Circuit diagram Battery as power source **and** Voltmeter in parallel with thermistor **and** Ammeter in series with thermistor Record temperature (with a thermometer) and corresponding current and pd readings (as the temperature falls) Take at least 5 readings **or** take readings at regular intervals Calculates resistance using R=V/I	B1 B1 B1 B1	All circuit symbols correct **Ignore** other components drawn in the circuit diagram e.g. variable resistor **Allow** stated temperature intervals for recording temperature **Allow** voltage for potential difference Correct rearrangement required **<u>Examiner's Comments</u>** Overall, candidates performed well on this question with most achieving at least 1 mark and some achieving over 2 marks. Most candidates were given marks for a correctly drawn circuit diagram (including current circuit symbols for the components required for the investigation) and for a correct rearrangement of V=IR to be able calculate the resistance. Some candidates would describe that measurements would need to be read from the ammeter and voltmeter, which was insufficient as the measurements of current and

					potential difference needed to be specified to achieve the mark.
			Total	**4**	
3	a		Circuit showing (6V) supply in series with a capacitor and resistor, with a voltmeter in parallel with the capacitor. Switch/switches allowing discharging of the capacitor through the resistor.	B1 B1	No labels required. **ALLOW** any suitable symbol for d.c. supply **ALLOW** this mark if resistor and capacitor in parallel if switch will allow the discharge Examples of correct circuit for both marks e.g.  **<u>Examiner's Comments</u>** Many candidates were able to correctly draw the supply, capacitor, and resistor in series with a voltmeter in parallel for a single mark. The position of a switch/switches to allow a discharge was less simple and many candidates had a single switch in series with their components. There are several ways to correctly draw this, and examiners allowed the use of double throw type switches as long as the idea was clear. Placing the capacitor and resistor in parallel with the supply may have allowed access to the second marking point as it would allow the discharge but not the charging. As always, clarity of the diagram makes it easier for examiners to understand. Several candidates appeared not to know the symbol for the capacitor and used a capital C in a circle. Less than one fifth of candidates were able to correctly draw the required diagram.

	b		Charge = $1.0 \times 10^{-6} \times 6.0$ = **6.0×10^{-6}** (C)	A1	**ALLOW** correct answer to 1 significant figure **<u>Examiner's Comments</u>** The vast majority of candidates were able to calculate this correctly and the main reason for not awarding the mark tended to be from a power of ten error.
	c		(CR =) $1 \times 10^{-6} \times 10 \times 10^{3}$ CR / Time constant / τ = 0.010 (s) Time constant / τ is time taken to fall to 1/e (37%) of initial value The time it takes to record the variation of pd / the capacitor to discharge is far less than (human) <u>reaction time</u> OR $V = V_0 e^{-\left(\frac{t}{CR}\right)}$ to give $0.6 = 6.0e^{-\left(\frac{t}{1.0\times10^{-6}\times10\times10^{3}}\right)}$ t = 0.023 (s) 0.6 is the voltage when it has fallen to 10% of the initial voltage The time it takes to record the variation of pd / for the capacitor to discharge is far less than human <u>reaction time</u> OR $V = V_0 e^{-\left(\frac{t}{CR}\right)}$ to give $V = 6.0e^{-\left(\frac{0.02}{1.0\times10^{-6}\times10\times10^{3}}\right)}$ V = 0.81 V 0.02 s is a very short amount of time The time it takes to record the variation of pd / for the capacitor to discharge is far less than human <u>reaction time</u>	C1 A1 B1 B1 (C1) (A1) (B1) (B1) (C1) (A1) (B1) (B1)	**ALLOW** POT error for capacitance if same as in (b) **ALLOW** 1sf **ALLOW** t for τ **NOT** fallen <u>by</u> 37% Substitution into exponential decay equation to fall to a value of V less than $0.9V_0$ (<5.4V). **ALLOW** calculation in log form e.g ln 0.6 = ln 6.0 - t/0.01 Justification/explanation for using a given voltage Substitution into exponential decay equation with a time less than 0.1s (t < 0.1s). **ALLOW** calculation in log form lnV = ln 6.0 - 0.02/0.01 Justification/explanation for using a given time **<u>Examiner's Comments</u>** Candidates were credited with calculations that produced a time or voltage that showed the time for decay was rapid. There were many possible routes to an answer and candidates were credited with any method that would produce a correct solution. As the question also included an explanation, it was often necessary to justify candidates' values for further

					credit rather than simply determine a numerical answer. The calculations were, in general, completed well and a good number of candidates were able to score 2 or more marks. Explanations in terms of reaction time were quite rare and often a vague answer such as ‘the time is short’ or ‘human error’ was given. Many candidates also related it to the precision of the stopwatch rather than the limitations of their use due to human reaction time. Exemplar 2  In this response the candidate has chosen to determine the time taken to fall to 1 V. The calculation has been done correctly for the first 2 marks (although there is no unit, it is clear what *t* is). The third marking point has not been satisfied – a comment would be needed (however brief) on why 1 V was chosen. The final marking point is given for the idea that this is time is less than human reaction time.
	d		Use an oscilloscope / data logger with a voltmeter probe	B1	**ALLOW** connect a voltmeter to a datalogger **<u>Examiner’s Comments</u>** While changing the value of the resistor or capacitor would increase the charging time, that would alter ‘this experiment’ and as such was not credited. In the context of this question, it is how the variation can be determined using the given values. Few candidates appreciated this, however there were significant numbers who knew that an oscilloscope could be used in place of the voltmeter.

	e	i	$V = V_0 e^{-(\frac{t}{CR})}$ to give $4.12 = 6.0\, e^{-(\frac{t}{1.0 \times 10^{-6} \times 10 \times 10^{3}})}$ = **3.76 x 10^{-3}** (s)	C1 A1	**ALLOW** in terms of logs eg ln 4.12 = ln 6.0 $^{-\frac{t}{0.01}}$ Correct to at least 2 significant figures **IGNORE** minus sign in final answer **Examiner's Comments** Most candidates were able to calculate the correct time for the discharge, by taking substituting values into the logarithmic equation. Common errors included incorrect taking of logs by division rather than subtraction (depending on their original set-up) and power of ten errors or transcription errors in the values of *C* or *R*. As with many calculations, those who spent a little time setting out the working carefully were more likely to get the correct answer.
		ii	Change in energy = ½ CV_1^2 - ½ CV_2^2 = (½ x 1x10^{-6} x 6^2) – (½ x 1x10^{-6} x 4.12^2) = 9.5 x10^{-6} (J) rate = 9.5 x10^{-6} / 3.76 x 10^{-3} = **2.53 x 10^{-3}** (Js^{-1})	C1 C1 A1	**ALLOW** POT error from (e)(i) Ecf from (e)(i) Correct to at least 2 significant figures **Examiner's Comments** Only around one third of candidates were able to correctly calculate this answer. By far the most common error was to calculate the change in energy using the difference in voltages (using 1.88 V) rather than calculating the separate energies and then subtracting. Several candidates left their answer at this point, rather than going on to divide by their value for the time.
			Total	**13**	
4		i	f (= 1/T) = 1 / (40 × 10^{-3}) f = 25 (Hz)	B1 B1	**Allow** f = 1/T **and** T = 40 × 10^{-3} (s) **Examiner's Comments** It is important to show how the information from the graph has been used to calculate the frequency. The

					correct answer did not score full marks unless some working had been shown.
		ii	**EITHER** Calculation of Q_o / e time constant (read from graph) = 14 (ms) **OR** Use of $Q = Q_0 e^{-t/CR}$ time constant = 14 (ms)	C1 A1 (C1) (A1)	**Allow** any initial value of charge e.g. 8.0 / e = 2.9 (μC) **or** 37% × 8.0 = 3.0 (μC) **Allow** 14±1 (ms) e.g. $2.0 = 8.0e^{-0.02/CR}$ gives CR = 0.02 / ln4 Using the decay equation may incur two POT errors **<u>Examiner's Comments</u>** The question specifies using the discharging section of the graph. Some candidates tried to use the charging section, but this proved more difficult. Using the definition of the time constant, we need to find how long it takes for the charge to fall from any initial value to 37% (1/*e*) of that value. Many candidates chose 8μC for their initial value, but this is not vital. 37% of 8μC is 2.9μC. The charge is 8μC at 20ms and 2.9μC at 34ms, so the time taken is 34 − 20 = 14ms. A common alternative approach was to insert values from the graph into the equation $Q = Q_0 e^{-t/CR}$ This gave the same result, but sometimes resulted in a POT error because of the need to give the answer in milliseconds.
		iii	tangent drawn to graph <u>at steepest part of curve</u> maximum current in range 5.0×10^{-4} to 7.0×10^{-4} (A)	M1 A1	Judge by eye, no daylight between curve and tangent **Allow** a negative answer **Allow** answer to 1sf **<u>Examiner's Comments</u>** Many candidates lost marks here because they did not realise that, to calculate the *maximum* current in the resistor, they had to draw the

					steepest possible tangent to the graph.
		iv	vertical axis labelled as current with the correct unit **and** at least one positive and one negative scale marking **and** scale should allow for their maximum current to be plotted exponential decay of current in each section sign of current alternates at 20, 40, 60 and 80 ms	B1 M1 A1	For example *I* / mA, *I* (mA), *I* /10^{-4} A, current in mA etc All scale markings shown must be correct **Allow** any curve with a decreasing gradient in each section **Ignore** value of minimum current but **not** zero **Ignore** sign of current for this marking point All curves should start at the correct maximum current value. However, If **B1** mark has not been scored, **allow** any value of maximum current as long as it remains consistent across all four sections **<u>Examiner's Comments</u>** Since $I = \Delta Q/\Delta t$, the graph of *I* against *t* can be found from the gradient of the graph of *Q* against *t*. The gradient is positive from 0 − 20 ms and negative from 20 − 40ms; this represents the current flowing one way around the circuit while the capacitor charges and then the opposite way while it discharges. Since the gradient is never zero, the value of the current is never zero either. **Tasks that caused problems in 6(b)(iv)** • drawing an exponential decay, particularly in the negative section of the graph (most drew a sinusoidal curve). • converting the maximum current into mA or μA. • labelling the vertical axis and drawing on a sensible scale. **Assessment for learning**

					Centres should consider providing more practice in drawing graphs without the aid of graph-plotting software.
			Total	**9**	
5		i	Graph from 1.5 V at **0/A** to 0 V at **L/B** Curve of decreasing gradient	M1 A1	**Allow** curve of increasing gradient/straight line **<u>Examiner's Comments</u>** Many candidates were given no marks for this question and there was a significant number of candidates who omitted the question. Typical incorrect responses were to draw a line showing a directly proportional relationship between *V* and *L*. Very few candidates were given 2 marks for correctly showing a decreasing gradient.
		ii	At **A** / *x* = 0, *V* = 1.5 V and at **B** / x = *L*, *V* = 0.75 V/p.d is shared/halved Total resistance increases so current decreases (as length of wire **L** and resistor of **R** are in series)	B1 B1	**Allow** *V* (across **R**) decreases as *x* increases (as **S** moves from **A** to **B**) **Allow** Explanation of potential divider e.g. At **B** resistance of length of wire = resistance of **R** **<u>Examiner's Comments</u>** Over half of candidates were given no marks for this question as they would often confuse the potential difference *V* across the fixed resistor with the potential difference across the resistance wire and because they had not determined that when the connecting wire BC was removed the resistance wire and fixed resistor were in series. If candidates were given 1 mark it was for correctly describing the relationship between *V* and *x* but with little or confused understanding of a potential divider.
			Total	**4**	
6	a		$A = \frac{48 \times 10^{-8} \times 11.8}{31}$ or 1.827×10^{-7} $d^2 = \frac{4 \times 1.827 \times 10^{-7}}{\pi}$ or 2.326×10^{-7}	C1 C1	**Allow** 5.82×10^{-8} (determines r^2) for 1 mark **Allow** 2.4×10^{-4} (determines r) for 2 marks

			4.8×10^{-4} (m)	A1	**Examiner's Comments** Many candidates scored all three marks on this question. High scoring candidates often determined the cross-sectional area of the wire before determining the diameter. Some candidates omitted to take a square root or determined the radius of the wire.
	b	i	Correct symbols circuit for components including <u>four</u> cells Circuit diagram: ammeter connected in series with battery and ring A and voltmeter in parallel with ring A / battery.	B1 B1	**Ignore** other circuit components (e.g. rheostat) **Note** if variable resistor added to circuit then voltmeter must be in parallel with ring A. **Examiner's Comments** It was expected that the correct circuit symbols would be used. A small number of candidates were unable to position the ammeter and voltmeter correctly.
		ii	$R\left(=\frac{6.2}{0.34}\right) = 18\ (\Omega)$	A1	**Allow** 18.2 (Ω) **Examiner's Comments** The majority of the candidates answered this question correctly. Although it is a simple question, candidates should be advised to show their working.
		iii	$\frac{0.02}{0.34}(\times 100)$ or $\frac{0.2}{6.2}(\times 100)$ Percentage uncertainty (= 5.9 + 3.2) = 9.1 %	C1 A1	**Allow** max/min methods, e.g. $\frac{6.4}{0.32}$ or $\frac{6.0}{0.36}$ **Allow** 9 (%) **Do not allow** bald 10(%) **Examiner's Comments** This question was answered well by the large majority of candidates. Many correctly worked out the percentage uncertainty in the current and added it to the percentage uncertainty in the potential difference. This was the simplest method. A few candidates used maximum/minimum methods. In this case it needed to be maximum

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