Mark scheme

Question			Answer/Indicative content	Marks	Guidance
1			**D**	1	**Examiner's Comments** Some candidates correctly identified the statement defining e.m.f as answer D. The most common distractor was answer A, as candidates confused the definition of e.m.f as the energy transferred per coulomb of charge with per volt.
			Total	**1**	
2			**A**	1	**Examiner's Comments** This should have been a straightforward starting question for all the candidates in identifying the correct S.I. base unit but only some gave the correct response of A. The most common distractor was B.
			Total	**1**	
3			C	1	**Examiner's Comments** Approximately half of the candidates were able to correctly identify the order. Many set out the calculations to the side before putting them in rank order and this generally proved successful. Most of the incorrect responses showed little or no working, leading to the assumption that there may have been some guesswork involved.
			Total	**1**	
4			$3 \times 1.6 \times 10^{-19}$ 4.8×10^{-19} (J)	C1 A1	**Examiner's Comments** Candidates performed well on this question as most candidates correctly applied the equation $W = VQ$ to calculate the work done on an electron and its corresponding charge as it moved from the metal plate to the electrode with a potential difference of

					3 V from the battery connected in the circuit.
			Total	**2**	
5		i	Work done = $1.60 \times 10^{-19} \times 5 \times 10^{3}$ = **8.0×10^{-16}** (J)	A1	**ALLOW** correct answer to 1 significant figure **Examiner's Comments** The vast majority of candidates were able to carry out this simple calculation; most errors came from an incorrect conversion of kV rather than lack of knowledge of the calculation.
		ii	$W = ½ mv^2 = 8 \times 10^{-16} = ½ \times 9.11 \times 10^{-31} \times v^2$ = 4.2 x 107 ms^{-1} $\lambda = h/mv = 6.63\times10^{-34} / 9.11 \times 10^{-31} \times 4.2 \times 10^{7}$ = **1.7×10^{-11}** (m) OR Momentum of electrons = $\sqrt{2 \times m_e \times W}$ $= \sqrt{2 \times 9.11 \times 10^{-31} \times 8 \times 10^{-16}}$ = (3.82×10^{-23} $kgms^{-1}$) $6.63 \times 10^{-34} / 3.82 \times10^{-23}$ = **1.74×10^{-11}** (m)	C1 A1 (C1) (A1)	Substitution leading to velocity Ecf from (c)(i) **ALLOW** correct answer to 1 significant figure Ecf from (c)(i) **ALLOW** correct answer to 1 significant figure **Examiner's Comments** Around one half of candidates were able to correctly calculate the de Broglie wavelength. This is potentially difficult for the average candidate to carry out in a single calculation, so it is very helpful to show the working in a slightly extended calculation. Most candidates calculated the electron speed first from the kinetic energy equation and then correctly substituted it. Several candidates used the proton rest mass in place of the electron rest mass, but the majority of incorrect responses came from using the speed of light for the speed. This is a physics error which can score no marks.
		iii	(For diffraction to occur) the gap needs to be approximately the same size as the wavelength so spacing should be 1.74×10^{-11} m	B1	Reason and value required. **ALLOW** suggested value spacing as (c)(ii) same power of ten **Examiner's Comments**

					The justification for the spacing is in the context of the question and so must relate to their previously calculated value. Around half of the candidates correctly gave a value and supporting reason, which needed to relate their wavelength to the process of diffraction. Common incorrect answers included values of around 1fm (irrespective of their calculation) presumably from their knowledge of the nuclear radius.
			Total	**4**	
6		i	f (= 1/T) = 1 / (40 × 10^{-3}) f = 25 (Hz)	B1 B1	**Allow** f = 1/T **and** T = 40 × 10^{-3} (s) **<u>Examiner's Comments</u>** 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**	
7	a	i	$a = \frac{VQ}{dm}$ OR $a = \frac{EQ}{m}$ OR KE = ½ mv^2 and $v^2 = u^2 + 2as$ OR $KE = F \times d$ and F = $m \times a$ $a = \frac{0.30 \times 1.6 \times 10^{-19}}{6.0 \times 10^{-3} \times 9.11 \times 10^{-31}}$ / $a = \frac{50 \times 1.6 \times 10^{-19}}{9.11 \times 10^{-31}}$ / (Use of KE = ½ mv^2) = 4.8 × 10^{-20} = ½ × 9.11 × 10^{-31} × v^2 and (use of $v^2 = u^2 + 2as$ =) v^2 = (1.05 × 10^{11}) = 2 × a × 6 × 10^{-3} (± 0^2) (Use of $KE = F \times d$) = 4.8 × 10^{-20} = F × 6 × 10^{-3} and (use of $F = m \times a$) F = (8.0 × 10^{-18}) = 9.11 × 10^{-31} × a a = 8.78 …. × 10^{12} (ms^{-2})	C1 M1 A1	**Allow** u and v interchangeably throughout **Allow** calculation of E = (0.30 / 6 × 10^{-3}) = 50 (V m^{-1}) or v = 3.2 × 10^5 (ms^{-1}) or v^2 = 1.05 × 10^{11} $(ms^{-1})^2$ or F = 8.0 × 10^{-18} (N) for C1 mark Substitution mark – in any arrangement. Expect full substitutions including numerical value of m_e if appropriate Method 1: direct calculation of a Method 2: using KE = ½ mv^2 and $v^2 = u^2 + 2as$ Method 3: using $KE = F \times d$ and $F = m \times a$

					Note must be more than 2 SF (not paper SF penalty) **Ignore** negative sign **<u>Examiner's Comments</u>** There were many different routes to showing the acceleration, and marks were given for each method or part method. No one method was seen significantly more than others, and some candidates used a variety of pathways to come to their answer. The main principle in the question (and the subsequent one) where the candidate is being asked to "show that" a given value is correct is that the examiner must be convinced that the candidate has clearly demonstrated that they have carried out the calculation and evaluated it on their calculator. The instructions which examiners used was: first marking point for providing one (or two) equations that would lead to the solution, or calculation of an intermediate value; second marking point for a full substitution into one or more equations; third marking point for using this full substitution to produce an answer to more sf than given in the question. As the second marking point was deemed to be an M mark, the full substitution needed to be seen to gain the A mark. A small number of (often higher end) candidates did not show the full substitution, often missing out the value of m_e in their calculation, and another common error was to not show the extra significant figure. Over half of the candidates were able to achieve full marks on this question and it generally discriminated well. **Assessment for learning** When a question asks a candidate to "show that" a given value is correct,

					the following two points should be considered: • Each stage of the calculation should be clearly shown. Preferably setting out any equation first, and then showing a full substitution of all values into that equation • If the value calculated by the candidate would correctly round to the given value, then the candidate should show their calculated value to at least one more significant figure than the given value. Both of these are evidence that the complete calculation has taken place and that the candidate has not somehow artificially generated the required value. This advice should be viewed as "best practice" rather than a rigid set of rules. Reverse arguments are often possible where a candidate can work backwards from their given value, however this is not the advised approach.
		ii	(Use of $KE = ½ mv^2$) = $4.8 \times 10^{-20} = ½ \times m \times v^2$ OR ($u^2 = v^2 - 2as$) = $0^2 - [2 \times (-)\ 8.8 \times 10^{12} \times s]$ Full substitution leading to $v = 3.2\ldots \times 10^5$ (ms^{-1})	C1 A1	**Allow** u and v interchangeably Numerical value of m_e must be used if using *KE* method **Note** must be more than 1 SF (not paper SF penalty) **Note** 3.25 is acceptable for A1, but not 3.3 **<u>Examiner's Comments</u>** The vast majority of candidates were able to clearly show that the speed of the photoelectron could be calculated as $3.2 \times 10^5\ ms^{-1}$, most often through substitution into the kinetic energy formula. As in Question 19 (b) (i), it is important to show all variables and constants used in the equation for full

					marks and to give the answer to at least one more d.p. than given in the question, to show the calculation has taken place. An alternative solution using an equation of motion and the acceleration given (or calculated) in Question 19 (b) (i) would yield the same result.
		iii	$t = \frac{3.2 \times 10^5}{8.8 \times 10^{12}}$ $t = 3.6 \times 10^{-8}$ (s)	C1 A1	**Allow** correct full substitution into any suvat equation **Allow** 3×10^5 for v **Ignore** signs of substituted values **Expect** values between 3.4×10^{-8} and 3.8×10^{-8} (s) **No ecf** from (b)(i) or (b)(ii) **<u>Examiner's Comments</u>** Only around half of the candidates were able to obtain answers within the required range. Candidates used a variety of rounded or none-rounded values from prior calculations, so a generous range of responses was given to allow for this. A common error among less successful responses was to simply use speed = distance/time usually leading to 2.0×10^{-8} s. Those using $s = ut + ½ at^2$ often encountered problems in solving the equation as it could lead to imaginary roots and tended to produce solutions way outside of the accepted values. However, marks could be given for setting up the calculation correctly.
		iv	Any line with negative slope starting from 0, 4.8×10^{-20} A straight line finishing at 6.0,0	M1 A1	½ square tolerance. **ALLOW** a curve with negative gradient. **ALLOW** a region of zero gradient, but not whole line ½ square tolerance on axis intercepted **<u>Examiner's Comments</u>** Nearly all candidates appreciated that this line would start at 4.8×10^{-20} J and decrease to zero at 6.0 mm. However, the vast majority drew a curved line of decreasing gradient. This may well have come from a

					confusion from $KE \propto v^2$ and attempting to draw a parabola.
	b		Energy of photon increases (max) kinetic energy / speed (of electrons) increases / (some) electrons (now) reach **C and** there is a current or reading (on ammeter)	B1 B1	**Do not allow** increased *kinetic* energy of photons **Do not allow** explanation in terms of increased number of **emitted** electrons (per second) **Allow** photoelectrons for electrons **Examiner's Comments** There were several misconceptions in candidates' responses to this question. Many candidates did not appreciate that the increased frequency would result in electrons of greater KE and thought that it was the increased energy of the photons crossing the 6.0mm gap that caused an ammeter reading. A significant number of candidates also described increasing frequency causing an increase in *kinetic* energy of photons, and some also linked the increasing frequency to a greater number of photons or photoelectrons.
			Total	**11**	
8	a		e.m.f → (chemical) to electrical and p.d. → from electrical (to thermal / heat) **or** e.m.f → charges/electrons gain energy and p.d. → charges/electrons lose energy	B1	**Allow** e.m.f. is work done on charges and pd is work by charges **Allow** battery for e.m.f and resistor for p.d. **Allow** less p.d. (than e.m.f.) due to energy transferred in internal resistance (must be clear that it is internal or cell resistance and not any other circuit resistance). **AW** **Examiner's Comments** The important word in this question is energy and so any response needs to be framed with this in mind. This is directly from the specification point 4.2.2 (e). Many candidates stated differences between the magnitudes of the e.m.f. and p.d. without referring to energy and so could not be given a

					mark. There were many good responses, and the simplest was to state how the electrical energy is transferred in each case.
	b		length (of wire)	B1	**Examiner's Comments** This was correctly answered by the majority of candidates; it was clear that some had not read the question and answered along the lines of changing the number of turns/coils, presumably thinking about a rheostat. Another common incorrect answer was temperature.
	c	i	$E = V + Ir$ / $E = IR + Ir$ / $E = I(R + r)$ Clear manipulation leading to $\frac{1}{I} = \frac{R}{E} + \frac{r}{E}$	M1 A1	**Allow** ε for E throughout **Expect** at least one line of intermediate correct algebra leading to correct expression, explicitly shown. **Examiner's Comments** Many candidates were able to do this relatively simple manipulation. The circuit diagram should alert the candidates that this question is based on internal resistance and allow them to select one of the appropriate starting points. Some less successful responses chose other routes, such as $I = I_1 + I_2$, but then quickly found themselves unable to go further, unless by using incorrect algebra.
		ii	**1** $I^{-1} = 0.8$ (A^{-1}) / $I = 1.25$ (A) P (= $1.25^2 \times 3.0$) = 4.7 (W) **2** (Intercept =) 0.20 (A^{-1}) r = (0.20 × 5.0) = 1.0 (Ω)	C1 A1 M1 A1	**Allow** I = 1.3 (A). **Expect** at least 2sf. **No ecf** from graph misread. **Allow** 5.1 (W) from use of 1.3 (A) Value of 0.2 anywhere in calculation implies correct reading of intercept. **Allow** ± 0.02. **Allow** current = 5 (A) implies intercept correctly read **Do not allow** substitutions into $E = IR + Ir$ other than using the intercept. **Allow** 1 SF answer **Alternative** r = (E / I = 5 / 5) = 1.0 (Ω)

					Examiner's Comments The vast majority of candidates were able to complete 1 correctly – there were few misreads from the graph, although some candidates took the reading of 0.8 as the current rather than the inverse of the current. There were also a few arithmetic slips with some candidates correctly setting out their calculation, such as $P = 1.25^2 \times 3.0$, but then not squaring the current. 2 was answered slightly less successfully and although the reading of the intercept was taken, some candidates could go no further.
			Total	**8**	
9			D	1	**Examiner's Comments** This question was generally answered well with candidates giving the correct answer D by selecting and applying the equation $W = VQ$ and that the charge of one electron is 1.60×10^{-19} C.
			Total	**1**	
10			Both measured in Volts / same units	B1	**Allow** V for volt **Allow** they are both voltages/they are both measured with a voltmeter **Examiner's Comments** Most candidates performed well and correctly stated a similarity that p.d. and e.m.f have the same unit of the volt, V.
			Total	**1**	