1)

a		charge (stored) ✓ per unit potential difference ✓ [**or** $C = Q/V$ where Q = charge (stored by one plate) ✓ V = pd (across plates) ✓]	**2**
b	i	$C\left(=\frac{Q}{V}\right)=\frac{13.2\times10^{-6}}{6.0}$ ✓ = 2.2 × 10^{-6} (F) ✓ (or 2.2 μF)	**2**
b	ii	when t = time constant Q = 0.63 × 13.2 = 8.3 (μC) ✓ [**or** = 0.63 × 13(.0) (from graph) = 8.2 (μC)] reading from graph gives time constant = 15 (± 1) (ms) ✓	**2**
b	iii	resistance of resistor = $\left(=\frac{\text{time constant}}{C}\right)=\frac{15\times10^{-3}}{2.2\times10^{-6}}$ = 6820 (Ω) ✓	**1**
b	iv	gradient = current ✓	**1**
c	i	maximum current = $\left(=\frac{V}{R}\right)=\frac{6.0}{6820}$ = 0.88 (mA) ✓ [**or** value from initial gradient of graph: allow 0.70 – 1.00 mA for this approach]	**1**
c	ii	curve starts at marked I_{max} on I axis and has decreasing negative gradient ✓ line is asymptotic to t axis and approaches ≈ 0 by t = 60 ms ✓	**2**
		Total	**11**

2)

(a)	(i)	initial discharge current $\left(= \frac{V}{R} = \frac{6.0}{1.0 \times 10^5}\right)$ = 6.0 × 10^{-5} (A) ✓	**1**
(a)	(ii)	time constant is time for V to fall to (1/e) [or 0.368] of initial value ✓ pd falls to (6.0/e) = 2.21 V when t =time constant ✓ reading from graph gives time constant = 22 (± 1) ✓ unit: s ✓ (ΩF not acceptable) [**alternatively** accept solutions based on use of $V = V_0 e^{-t/RC}$ eg 1.5 = 6.0 $e^{-30/RC}$ ✓ gives $RC = \frac{30}{\ln(6.0/1.5)}$ ✓= 22 ✓ s✓]	**4**
(a)	(iii)	capacitance of capacitor $C = \left(\frac{\text{time constant}}{\text{R}} = \frac{22}{1.0 \times 10^5}\right)$ = 2.2 × 10^{-4} (F) = 220 (μF) ✓	**1**
(a)	(iv)	energy ∝ V^2 (or energy = ½ CV^2) ✓ ∴ $\frac{E_2}{E_1}$ = 0.10 gives = $\frac{V_2}{V_1}$ $(0.10)^{1/2}$ ✓ (= 0.316) ∴ V_2 = 0.316 × 6.0 = 1.90 (V) ✓ reading from graph gives V_2 = 1.90 V when t = 25 s ✓ [**alternatively** accept reverse argument: ie when t = 25 s, V_2 = 1.9 V from graph ✓ final energy stored = ½ × 2.2 × 10^{-4} × 1.9^2 = 3.97 × 10^{-4} (J) and initial energy stored = 3.96 × 10^{-3} (J) ✓ which is 10 × greater, so 90% of initial energy has been lost ✓] [**alternatively**, using exponential decay equation: use of $V = V_0 e^{-t/R}$ with t = 25 s and RC = 22 s gives V = 1.93 V ✓ energy ∝ V^2 (or energy = ½ CV^2) gives $\frac{E_2}{E_1} = \left(\frac{1.93}{6.0}\right)^2$ = 0.103 ✓ ∴ fraction of stored energy that is lost = $\frac{E_2 - E_1}{E_1} = 1 - \frac{E_2}{E_1}$ = 0.90 ✓]	**3**
(b)	(i)	initial energy stored is 4 × greater ✓ because energy ∝ V^2 (and V is doubled) ✓	**2**
(b)	(ii)	time to lose 90% of energy is unchanged because time constant is unchanged (or depends only on R and C) ✓	**1**
		Total	**12**

3)

3(a)(i)	determine area under the graph [or determine area between line and time axis] ✓		1	
3(a)(ii) *as seen*	line starts at very low current (within bottom half of first square) ✓ **either** line continuing as (almost) horizontal straight line to end ✓✓ **or** very slight exponential decay curve ✓ which does not meet time axis ✓ **OR** suitable verbal comment that shows appreciation of difficulty of representing this line on the scales involved ✓✓✓	*Use this scheme for answers which treat the information in the question literally.*	3	
3(a)(ii) *as intended*	line starts at half of original initial current ✓ slower discharging exponential (ie. smaller initial gradient) than the original curve ✓ correct line that intersects the original curve (**or** meets it at the end) ✓	*Use this scheme for answers which assume that both resistance values should be in Ω or kΩ.* ½ initial current to be marked within ±2mm of expected value.	3	
3(b)(i)	energy stored (= ½ CV^2) = ½ × 0.12 × 9.0^2 ✓ (= 4.86 (J)) 4.86 = 3.5 Δh ✓ gives Δh = (1.39) = 1.4 (m) ✓ to 2SF only ✓	SF mark is independent. Students who make a PE in the 1st mark may still be awarded the remaining marks: treat as ECF.	4	
3(b)(ii)	energy is lost through heating of wires **or** heating the motor (as capacitor discharges) ✓ energy is lost in overcoming frictional forces in the motor (or in other rotating parts) ✓ [**or** any other well-expressed sensible reason that is valid eg. capacitor will not drive motor when voltage becomes low ✓]	Allow heating of circuit **or** I^2R heating. Location of energy loss (wires, or motor, etc) should be indicated in each correct answer. Don't allow losses due to sound, air resistance or resistance (rather than heating of) wires.	max 2	
Total			10	

4)

4	a	i	$Q(=It) = 4.5\times10^{-6}\times60$ **or** $= 2.70\times10^{-4}$ (C) ✓ $C\left(=\frac{Q}{V}\right)=\frac{2.70\times10^{-4}}{4.4}$ ✓ $= 6.1(4)\times10^{-5}$ = 61 (μF) ✓	3	
4	a	ii	since V_C was 4.4V after 60s, when t = 30s V_C = 2.2 (V) ✓ [**or** by use of $Q = It$ and $V_C = Q/C$] ∴ pd across R is (6.0 – 2.2) = 3.8 (V) ✓ $R\left(=\frac{V}{I}\right)=\frac{3.8}{4.5\times10^{-6}}$ $= 8.4(4)\times10^5$ (Ω) ✓ (=844 kΩ)	3	In alternative method, $Q = 4.5\times10^{-6}\times30 = 1.35\times10^{-4}$ (C) $V_C = 1.35\times10^{-4} / 6.14\times10^{-5} = 2.2$ (V) (allow ECF from wrong values in (a)(i))
4	b		**The candidate's writing should be legible and the spelling, punctuation and grammar should be sufficiently accurate for the meaning to be clear.** The candidate's answer will be assessed holistically. The answer will be assigned to one of three levels according to the following criteria. **High Level (Good to excellent): 5 or 6 marks** The information conveyed by the answer is clearly organised, logical and coherent, using appropriate specialist vocabulary correctly. The form and style of writing is appropriate to answer the question. *The candidate gives a coherent and logical description of the flow of electrons taking place during the charging and discharging processes, indicating the correct directions of flow and the correct time variations. There is clear understanding of how the pds change with time during charging and during discharging. The candidate also gives a coherent account of energy transfers that take place during charging and during discharging, naming the types of energy involved. They recognise that the time constant is the same for both charging and discharging.* **Intermediate Level (Modest to adequate): 3 or 4 marks** The information conveyed by the answer may be less well organised and not fully coherent. There is less use of specialist vocabulary, or specialist vocabulary may be used incorrectly. The form and style of writing is less appropriate. *The candidate has a fair understanding of how the flow of electrons varies with time, but may not be entirely clear about the directions of flow. Description of the variation of pds with time is likely to be only partially correct and may not be complete. The candidate may show reasonable understanding of the energy transfers.*	max 6	A **High Level** answer must contain correct physical statements about at least **two** of the following for **both** the charging and the discharging positions of the switch:- • the direction of electron flow in the circuit • how the flow of electrons (or current) changes with time • how V_R and/or V_C change with time • energy changes in the circuit An **Intermediate Level** answer must contain correct physical statements about at least **two** of the above for **either** the charging or the discharging positions of the switch. A **Low Level** answer must contain a correct physical statement about at least **one** of the above for **either** the charging or the discharging positions of the switch. Any answer which does not satisfy the requirement for a Low Level answer should be awarded 0 marks.

			Low Level (Poor to limited): 1 or 2 marks The information conveyed by the answer is poorly organised and may not be relevant or coherent. There is little correct use of specialist vocabulary. The form and style of writing may be only partly appropriate. *The candidate is likely to confuse electron flow with current and is therefore unlikely to make effective progress in describing electron flow. Understanding of the variation of pds with time is likely to be quite poor. The candidate may show some understanding of the energy transfers that take place.* **Incorrect, inappropriate or no response: 0 marks** No answer, or answer refers to unrelated, incorrect or inappropriate physics. **The explanation expected in a competent answer should include a coherent selection of the following points concerning the physical principles involved and their consequences in this case.** ***Charging*** • electrons flow from plate **P** to terminal **A** and from terminal **B** to plate **Q** (ie. from plate **P** to plate **Q** via **A** and **B**) • electrons flow in the opposite direction to current • plate **P** becomes + and plate **Q** becomes – • the rate of flow of electrons is greatest at the start, and decreases to zero when the capacitor is fully charged • V_R decreases from E to zero whilst V_C increases from zero to E. • at any time $V_R + V_C = E$ • time variations are exponential decrease for V_R and exponential increase for V_C • chemical energy of the battery is changed into electric potential energy stored in the capacitor, and into thermal energy by the resistor (which passes to the surroundings) • half of the energy supplied by the battery is converted into thermal energy and half is stored in the capacitor		
			Discharging • electrons flow back from plate **Q** via the shorting wire to plate **P** • at the end of the process the plates are uncharged • the rate of flow of electrons is greatest at the start, and decreases to zero when the capacitor is fully discharged • V_C decreases from $-E$ to zero and V_R decreases from E to zero • at any time $V_C = -V_R$ • both V_C and V_R decrease exponentially with time • electrical energy stored by the capacitor is all converted to thermal energy by the resistor as the electrons flow through it and this energy passes to the surroundings • time constant of the circuit is the same for discharging as for charging		

5)

a	i	required pd ($= 2.5 \times 10^6 \times 12 \times 10^{-3}$) = $3.0(0) \times 10^4$ (V) ✓	1	
a	ii	charge required Q (= CV) = $3.7 \times 10^{-12} \times 3.00 \times 10^4$ ✓ ($= 1.11 \times 10^{-7}$ C) time taken $t\left(=\frac{Q}{I}\right)=\frac{1.11\times10^{-7}}{3.2\times10^{-8}}$ = 3.5 (3.47) (s) ✓	2	Allow ECF from incorrect V from (a)(i).
b	i	time increases ✓ (larger C means) more charge required (to reach breakdown pd) **or** $t=\frac{CV}{I}$ **or** time $\propto$ capacitance ✓	2	**Mark sequentially** i.e. no explanation mark if effect is wrong.
b	ii	spark is brighter (**or** lasts for a longer time) ✓ more energy (**or** charge) is stored **or** current is larger **or** spark has more energy ✓	2	**Mark sequentially.**

6)

a	i	energy stored by capacitor (= ½ CV^2) = ½ × 70 × 1.2^2 ✓ (= 50.4) = 50 (J) ✓ to **2 sf** only ✓	**3**
a	ii	energy stored by cell (= IVt) = 55 × 10^{-3} × 1.2 × 10 × 3600 ✓ (= 2380 J) $\frac{\text{energy stored by cell}}{\text{energy stored by capacitor}} = \frac{2380}{50}$ = 48 (ie about 50) ✓	**2**
b		capacitor would be impossibly large (to fit in phone) ✓ capacitor would need recharging very frequently [**or** capacitor could only power the phone for a short time] ✓ capacitor voltage [**or** current supplied or charge] would fall continuously whilst in use ✓	**max 2**
		Total	**7**

7)

a		$(Q = Q_0 e^{-t/RC}$ gives$)$ $1.0 = 4.0e^{-300/RC}$ ✓ from which $\frac{300}{RC} = \ln 4$ ✓ and time constant RC = 220 (216) (ms) ✓ [***Alternative answer:*** time constant is time for charge to decrease to Q_0/e [**or** 0.37 Q_0] ✓ 4.0/e = 1.47 ✓ reading from graph gives time constant = 216 ± 10 (ms) ✓]	3	In alternative scheme, 4.0/e = 1.47 subsumes 1[st] mark. Also, accept $T_{½}$ = 0.693 RC (or = ln 2 RC) for 1[st] mark.
b		current is larger (for given V)(because resistance is lower) [**or** correct application of $I = V/R$] ✓ current is rate of flow of charge [**or** correct application of $I = \Delta Q/\Delta t$] ✓ larger rate of flow of charge (implies greater rate of discharge) [**or** causes larger rate of transfer of electrons from one plate back to the other] ✓ [***Alternative answer:*** time constant (or RC) is decreased (when R is decreased) ✓ explanation using $Q = Q_0e^{-t/RC}$ **or** time constant explained ✓]	max 2	Use either first or alternative scheme; do not mix and match. Time constant = RC is insufficient for time constant explained.

8)

(a)	**The candidate's writing should be legible and the spelling, punctuation and grammar should be sufficiently accurate for the meaning to be clear.** The candidate's answer will be assessed holistically. The answer will be assigned to one of the three levels according to the following criteria. **High Level (good to excellent) 5 or 6 marks** The information conveyed by the answer is clearly organised, logical and coherent, using appropriate specialist vocabulary correctly. The form and style of writing is appropriate to answer the question. The candidate provides a comprehensive and logical description of the sequence of releasing the ball and taking measurements of initial and final voltages. They should identify the correct distance measurement and show a good appreciation of how to use these measurements to calculate the time and acceleration from them. Time should be found from capacitor discharge, using known C and R values. Repeated readings would be expected in any answer worthy of full marks, but five marks may be awarded where repetition is omitted. **Intermediate Level (modest to adequate) 3 or 4 marks** The information conveyed by the answer may be less well organised and not fully coherent. There is less use of specialist vocabulary, or specialist vocabulary may be used incorrectly. The form and style of writing is less appropriate. The candidate provides a comprehensive and logical description of the sequence of releasing the ball and taking measurements of the initial and final voltages. They are likely to show some appreciation of the use of suvat equations to calculate the acceleration, although they may not recognise the need to measure a distance. **Low Level (poor to limited) 1 or 2 marks** The information conveyed by the answer is poorly organised and may not be relevant or coherent. There is little correct use of specialist vocabulary. The form and style of writing may only be partly appropriate. The candidate is likely to have recognised that initial and final voltages should be measured, but may not appreciate the need for any other measurement. They may present few details of how to calculate the acceleration from the voltage measurements. **The explanation expected in a competent answer should include a coherent selection of the following points.** **Measurements** • initial pd across C (V_0) from voltmeter (before releasing roller) • distance s along slope between plungers • final pd across C (V_1) from voltmeter • measurements repeated to provide a more reliable result **Analysis** • time t is found from $V_1 = V_0 e^{-t/RC}$, giving $t = RC \ln (V_0/V_1)$ • from $s = ut + ½ at^2$ with $u = 0$, acceleration $a = 2s/t^2$ • repeat and find average a from several results	**max 6**

(b)	(i)	$RC = 22 \times 10^{-6} \times 200 \times 10^{3}$ [or = 4.4 (s)] ✓ (4.40) $5.8 = 12.0\ e^{-t/4.40}$ ✓ gives $t = 4.40 \ln (12.0/5.8) = 3.2$ (3.20) (s) ✓	**3**
(b)	(ii)	$a\left(=\frac{2s}{t^2}\right) = \frac{2 \times 2.5}{3.20^2}$ ✓ = 0.49 (0.488) (m s^{-2}) ✓	**2**
		Total	**11**