1)

Question			Expected Answer	Mark	Additional Guidance
	(a)		coulomb per volt	B1	**Allow**: 1 F = 1 CV^{-1}
	(b)	(i)	Electrons flow 'clockwise' / negative to positive These are deposited on (plate) **A** (and hence becomes negatively charged) or These are removed from (plate) **B** (and hence become positively charged)	B1 B1	**Not**: **A** becomes negative / **B** becomes positive
		(ii)1	$Q = C \times V = 5.4 \times 10^{-9} \times 12$ charge = 6.48×10^{-8} (C)	B1	
		(ii)2	energy = $\frac{1}{2}V^2C = \frac{1}{2} \times 12^2 \times 5.4 \times 10^{-9}$ energy = 3.89×10^{-7} (J)	B1	Possible ecf if Q used from **(ii)1**
	(c)	(i)	$R = \frac{12}{3.24 \times 10^{-6}}$ resistance = 3.7×10^6 (Ω)	M1 A0	**Allow**: 'R = 12/3.24μ' (= 3.7 MΩ)
		(ii)	time constant = CR = $5.4 \times 10^{-9} \times 3.7 \times 10^6$ or 0.02 (s) $I = I_0 e^{-t/CR} = 3.24 \times e^{-(0.080/0.020)}$ current = 0.059 (μA)	C1 A1	**Allow**: ecf for time constant **Allow**: 1 mark for 5.9×10^{-n}
	(d)		(Total) resistance of circuit halved / time constant is halved Rate of discharge is doubled / (initial) current is doubled	B1 B1	
			Total	10	

2)

Question			Answers	Marks	Guidance
	(a)		capacitance = charge/p.d. or capacitance = charge per (unit) p.d.	B1	**Allow**: voltage instead of p.d. **Note**: Do not allow mixture of quantity and unit, e.g. 'charge per (unit) volt'
	(b)	(i)	$C_{parallel}$ = 240 (μF) $C_T = (240 \times 120)/(240 + 120)$ or $C_T = (240^{-1} + 120^{-1})^{-1}$ total capacitance = 80 (μF)	C1 C1 A0	**Allow** :1 mark if C_T is not the subject, e.g: $\frac{1}{C_T} = \frac{1}{240} + \frac{1}{120}$
		(ii)	$E = \frac{1}{2}V^2C$ $E = \frac{1}{2} \times 6.0^2 \times 80 \times 10^{-6}$ energy = 1.4×10^{-3} (J) or 1.44×10^{-3} (J)	C1 A1	Possible ecf **Allow**: 1 mark for an answer 1.44×10^{n} ($n \neq -3$)
		(iii)1	6.0/e = 2.2 (V) (as on graph) Or 6.0 × 0.37 = 2.2 (V) (as on graph) Or At 20 (s), V = 2.2 (V), 2.2/6.0 = 0.37 (or e^{-1})	B1	**Allow**: Graph reading within ± 0.2 V
		(iii)2	CR = 20 $R = \frac{20}{80 \times 10^{-6}}$ $R = 2.5 \times 10^5$ (Ω)	C1 A1	**Allow**: Follow through with CR value from **(iii)1**
			Total	**8**	

3)

Question			Answer	Marks	Guidance
	(a)		(farad = 1) coulomb per (unit) volt	B1	**Allow**: C V^{-1}
	(b)	(i)	1/C	B1	**Allow**: 'inverse of *C*'
		(ii)	work (done) / energy	B1	
	(c)		**Diagram**: All 3 capacitors connected in **series** $\frac{1}{C}=\frac{1}{100}+\frac{1}{200}+\frac{1}{500}$ / $\frac{1}{C}=1.7\times10^{-2}$ capacitance = 59 (μF)	B1 C1 A1	**Note**: Correct symbol must be used for capacitor and at least one of the capacitance values (without the unit) must be shown **Allow**: Answer to 1 sf **Note**: Answer to 3sf is 58.8 (μF) **Allow**: 1.7 × 10^{-2} (μF) scores 1 mark from the C1A1
	(d)	(i)	Q = 0.040 × 60 charge = 2.4 (C)	C1 A1	**Allow**: 1 mark for 2.4 × 10^{n}, n ≠ 0 (POT error)
		(ii)	energy = $\frac{1}{2}\times\frac{2.4^2}{0.10}$ energy = 29 (J)	C1 A1	Possible ecf from **(d)(i)** **Note**: Answer to 3 sf is 28.8 (J) Allow full credit for correct use of ½ VQ or ½ V^2C; the final p.d is 24 (V)
			Total	**10**	

4)

Question			Expected Answers	Marks	Additional guidance
	(a)		capacitance = charge / potential difference	B1	**Allow:** p.d. and voltage **Not:** charge per volt or coulombs per p.d
	(b)	**(i)**	$V = Q/C$ and Q = constant in series circuit $V=\frac{450}{450+150}\times6.0$ potential difference = 4.5 (V)	C1 A1	**Allow:** 1 mark for an answer of 1.5 (V) **Note**: Using **(b)(ii)**, alternative marking scheme V = 6.75 × 10^{-4}/150 × 10^{-6} C1 V = 4.5 V A1
		(ii)	charge = 150 × 10^{-6} × 4.5 charge = 6.75 × 10^{-4} (C)	B1	Possible e.c.f. **Note**: Using **(b)(iii)** ... Q = 6.0 × 1.125 × 10^{-4} = 6.75 × 10^{-4} (C)
		(iii)	$\frac{1}{C}=\frac{1}{150}+\frac{1}{450}$ (working in μF) capacitance C_T = 1.125 × 10^{-4} (F) or 113 μ(F)	B1	**Possible alternative:** capacitance = 6.75 × 10^{-4}/6.0 capacitance = 1.125 × 10^{-4} (F) or 113 μ(F) Possible e.c.f. from **(ii)**
	(c)	**(i)**	time constant = CR time constant = 1.125 × 10^{-4} × 45 × 10^{3} time constant = 5.06 (s)	M1 A0	**Note:** The mark is for multiplying correct C and R values Possible e.c.f. from**(b)(iii)**
		(ii)	Graph starting from 6.0 (V) Correct shaped curve Approximately correct value of V at CR	B1 B1 B1	**Note:** The (exponential decay) curve must not touch or cut the time axis **Note:** V is 2 to 2.5 (V) at $t \approx 5$ s

Question			Expected Answers	Marks	Additional guidance
		(iii)	$\frac{1}{2}\times 4.5^2\times 150\times 10^{-6}$ and $\frac{1}{2}\times 1.5^2\times 450\times 10^{-6}$ ratio = $\frac{0.5\times 4.5^2\times 150\times 10^{-6}}{0.5\times 1.5^2\times 450\times 10^{-6}}$ ratio = 3 Or ½ Q^2/C_{150} and ½ Q^2/C_{450} ratio = C_{450} / C_{150} ratio = 3	C1 A1 C1 A1	**Allow:** with or without the 10^{-6} Possible e.c.f. from **(b)(i)** and **(b)(ii)** **Allow:** full credit for correct use of either ½QV or ½ Q^2/C
		(iv)	The ratio remains constant The charge / Q is the same for both capacitors	B1 B1	
			Total	**13**	

5)

Question			Answers	Marks	Guidance
	(a)		The time taken for the p.d / current / charge to decrease to 1/e of its (initial) value.	B1	**Allow** 37% instead of 1/e. **Not** time constant = CR on its own.
	(b)		Any suitable values with units, eg: 5 MΩ and 1 μF.	B1	
	(c)	(i)	$R = \frac{4.9\times 10^{-7}\times 5.0}{\pi\times(0.06\times 10^{-3})^2}$ or R = 217 (Ω) time constant = 0.010 × 217 time constant = 2.2 (s)	C1 C1 A1	**Note**: An incorrect equation here for A prevents this and any subsequent marks. **Allow** 2 marks for 0.54 (s) – diameter of 0.12 mm used instead of radius 0.06 mm.
		(ii)	Electrons are removed from **X** or electrons are deposited on **Y**. **X** becomes positive or **Y** becomes negative (The size of charge is the same because) an equal number of electrons are removed and deposited (on the plates).	B1 B1 B1	**Allow** electrons move anticlockwise (in the circuit). There is no ecf from the previous B1 mark.
		(iii)	E = ½ × 0.010 × 12^2 or E = 0.72 (J) m = 8900 × [π × $(0.06\times 10^{-3})^2$ × 5.0] or 5.0(3) × 10^{-4} (kg) 5.03 × 10^{-4} × 420 × $\Delta\theta$ = 0.72 increase in temperature = 3.4 (°C)	C1 C1 C1 A1	 **Note**: An incorrect equation here for m or V prevents this and any subsequent marks. Correct substitution into $mc\Delta\theta$ = 0.72; **allow** any subject. **Note**: Do not penalise using diameter here again if already penalised in **(c)(i)**.
		(iv)	Energy or V^2 increases by a factor of 4. The (change in temperature) increases by a factor of 4 (because $\Delta\theta \propto E$).	B1 B1	**Allow** the label E or W for energy. **Allow** $\Delta\theta$ = 13.6 (°C) for this B1 mark - possible ecf from **(iii)**.
			Total	**14**	

6)

Question			Answer	Marks	Guidance
	(a)	(i)	Correct shape of (exponential) decay curve (labelled **L**)	B1	**Note**: The curve must show a gradient of decreasing magnitude as time increases and appear to have a finite value of V at $t = 0$ **Ignore** any levelling of the curve or $V = 0$ towards the end
		(ii)	Correct shape of curve (labelled **H**)	B1	**Note**: As **(i)** and this curve must show a smaller time constant than **(i)**; the initial V can be different **Note**: One of the curves must be labelled
		(iii)	Correct explanation in terms of constant-ratio for V values for fixed intervals of t	B1	**Allow** V is halved every half-life; V decreases to 0.37 (of its initial value) after every time constant **Note**: This can be scored on a suitably labelled sketch graph in either **(iii)** or Fig. 4.1
	(b)	(i)	(time constant = $6.9 \times 10^{-6} \times 240$) time constant = 1.7×10^{-3} (s)	B1	**Note**: Answer to 3 sf 1.66×10^{-3} (s)
		(ii)	charge = $6.9 \times 10^{-6} \times 1.4$ (= 9.66×10^{-6} C) (Δt = 1/120 = 0.0083 s) current = $\frac{6.9\times10^{-6}\times1.4}{0.0083}$ current = 1.2×10^{-3} (A)	C1 C1 A1	Possible ecf from **(b)(i)** for value of total capacitance **Note**: Answer to 3 sf 1.16×10^{-3} (A) **Allow**: 2 marks for $9.66 \times 10^{-6} \times 60 = 5.8 \times 10^{-4}$ (A); Δt = 1/60 s used **Allow**: 2 marks for $9.66 \times 10^{-6} \times 240 = 2.3 \times 10^{-3}$ (A); Δt = 1/240 s used
		(iii)	The capacitors do not fully discharge (AW) Any one from: • Period (of switching) is (halved to) 4.2×10^{-3} (s) (and this time is comparable to the time constant) • The time constant (of the circuit) and period of mechanical switch are comparable / similar	B1 B1	
			Total	**9**	

7)

Question			Answer	Marks	Guidance
	(a)		Series branch: Using $(100^{-1} + 300^{-1})^{-1}$ and C = 75 (μF) capacitance = 500 + 75 capacitance = 575 (μF)	C1 A1	Possible ecf, if capacitance of series branch is incorrect
	(b)	(i)	**Time constant method:** 37% of 6.0 V is 2.2 V. The time taken to reach 2.2 V is equal to the time constant time constant = 60 (s) / CR = 60 (s) $500 \times 10^{-6} \times R = 60$ $R = \frac{60}{500\times10^{-6}}$ resistance = 1.2×10^{5} (Ω) **Substitution method:** Correct values for p.ds and t substituted into $V = V_0 e^{-\frac{t}{CR}}$ Correct values substituted into $\ln(V/V_0) = -\frac{t}{CR}$ resistance = 1.2×10^{5} (Ω)	C1 C1 A1 C1 C1 A1	**Note**: Allow full credit for other correct methods **Allow**: time constant in the range 58 s to 62 s Deduct 1 mark for misreading graph followed by ecf **Note**: If C value from **(a)** is used, then deduct 1 mark followed by ecf **Eg**: $2.2 = 6.0e^{-\frac{60}{CR}}$ - values read to ± 1 small square **Eg:** $\ln(2.2/6.0) = -\frac{60}{500\times10^{-6}\times R}$ **Note**: If C value from **(a)** is used, then deduct 1 mark followed by ecf. Using 575 (μF) gives 1.04×10^{5} (Ω)
		(ii)	Correct p.ds from graph: 6 (V) and 3.6 (V) $\frac{1}{2}\times500\times10^{-6}\times6.0^2$ or $\frac{1}{2}\times500\times10^{-6}\times3.6^2$ energy is 9.00×10^{-3} (J) and 3.24×10^{-3} (J) energy lost = 5.76×10^{-3} (J) or 5.8×10^{-3} (J)	C1 C1 A1	**Allow** V value to be in the range 3.5 V to 3.7 at 30s **Note**: Do not penalise 10^n error from **(b)(ii)** again here **Allow** 1 mark for: $\frac{1}{2}\times500\times10^{-6}\times(6.0-3.6)^2 = 1.44\times10^{-3}$ (J) **Note**: Do not penalise use of 575 μF again. This gives a value of 6.62×10^{-3} (J)
			Total	**8**	

8)

Question			Expected Answers	Marks	Additional Guidance
	a		Capacitance = charge per (unit) potential difference	B1	Allow: capacitance = charge / potential difference, charge/pd, charge/voltage but not charge / volt, coulomb /pd (no mixture of quantities and units. Allow 'over' instead of per
	b	(i)	Q = CV = 4.5 μ x 6.3 = 28.(35) (μC)	B1	Allow: 28 (≥ 2 sf)
		(ii)	$E = ½ CV^2 = 0.5 \times 4.5 \times \mu \times (6.3)^2$ $= 8.9(3) \times 10^{-5}$ (J) / 89.3 μ(J)	C1 A1	Allow use of E = ½ QV and the Q value from **(b)(i)** Q=28 E= 8.82 and Q=28.4 E=8.946 Allow ecf from **(b)(i)** penalise power of ten error (-1)
	c	(i)	Electrons / they move in an anticlockwise direction Charge on plates decreases / electrons neutralise positive charge p.d. decreases exponentially	B1 B1 B1	Alternatives for anticlockwise: from / lower plate around the circuit, from / lower plate through the resistor to top plate implied Capacitor discharges / loses charge
		(ii)	(dissipated as heat) in the resistor / wires	B1	
	d	(i)	Total capacitance = 1.5 + 4.5 = 6(.0) (μF)	A1	Allow one SF
		(ii)	Original charge on 4.5 μF capacitor is conserved (28.35 μC) V = (28.35 μ) / (1.5 + 4.5) μ = 4.7 (V)	C1 A1	ecf from **(b)(i) and (d)(i)**
			Total	**[11]**	

9)

Question			Answer	Marks	Guidance
	(a)	(i)	Any two from: Correct direction of movement of electrons Electrons deposited on **Y** / removed from **X** An equal number of electrons removed and deposited on plates (AW)	B1 × 2	
		(ii)1	$Q = 40 \times 10^{-6} \times 100$ (= 4.0×10^{-3} C) $4.0 \times 10^{-3} = 1.6 \times C$ $C = 2.5 \times 10^{-3}$ (F)	C1 C1 A1	**Allow**: 2 marks for 2.5×10^{n} (F), where $n \neq -3$ (POT error)
		(ii)2	Graph starts at origin and has positive gradient A straight line graph that passes between 1-2 V at 100 s	M1 A1	
	(b)	(i)	$CR = 4.7 \times 10^{-6} \times 220$ (= 1.03×10^{-3} s) $4.00 = 6.00e^{-\frac{t}{1.03\times10^{-3}}}$ $t = -\ln(4.00/6.00) \times 1.03 \times 10^{-3}$ time = 4.2×10^{-4} (s)	C1 C1 A1	**Note**: Answer to 3 sf is 4.19×10^{-4} (s) **Allow**: 2 marks for $t = -lg(4.00/6.00) \times 1.03 \times 10^{-3} = 1.8 \times 10^{-4}$ s
		(ii)	speed = $\frac{0.100}{4.2\times10^{-4}}$ speed = 240 (m s^{-1})	B1	Possible ecf from **(b)(i)**
			Total	**11**	

10)

Question			Expected Answers	Marks	Additional Guidance
	a		Capacitance = charge per (unit) potential difference	B1	Allow: capacitance = charge / potential difference, charge/pd, charge/voltage but not charge / volt, coulomb /pd (no mixture of quantities and units. Allow 'over' instead of per
	b	(i)	Q = CV = 4.5 μ x 6.3 = 28.(35) (μC)	B1	Allow: 28 (≥ 2 sf)
		(ii)	$E = ½ CV^2 = 0.5 \times 4.5 \times \mu \times (6.3)^2$ $= 8.9(3) \times 10^{-5}$ (J) / 89.3 μ(J)	C1 A1	Allow use of E = ½ QV and the Q value from **(b)(i)** Q=28 E= 8.82 and Q=28.4 E=8.946 Allow ecf from **(b)(i)** penalise power of ten error (-1)
	c	(i)	Electrons / they move in an anticlockwise direction Charge on plates decreases / electrons neutralise positive charge p.d. decreases exponentially	B1 B1 B1	Alternatives for anticlockwise: from / lower plate around the circuit, from / lower plate through the resistor to top plate implied Capacitor discharges / loses charge
		(ii)	(dissipated as heat) in the resistor / wires	B1	
	d	(i)	Total capacitance = 1.5 + 4.5 = 6(.0) (μF)	A1	Allow one SF
		(ii)	Original charge on 4.5 μF capacitor is conserved (28.35 μC) V = (28.35 μ) / (1.5 + 4.5) μ = 4.7 (V)	C1 A1	ecf from **(b)(i) and (d)(i)**
			Total	**[11]**	