PRESTON MANOR

A Level Physics Exam Packs

Capacitors

Name:

Form:

Question	Mark

Answer **all** the questions.

1 **(a)** Define *capacitance*.

....

.... **[1]**

(b) Fig. 1.1 shows a circuit consisting of a resistor and a capacitor of capacitance 4.5 μF.

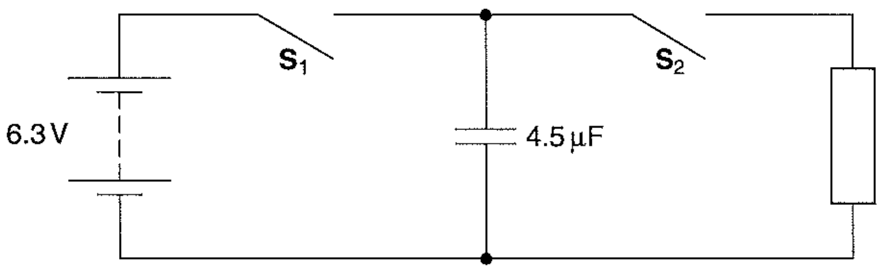

Fig. 1.1

Switch S_1 is closed and switch S_2 is left open. The potential difference across the capacitor is 6.3 V.

Calculate

(i) the charge stored by the capacitor

charge = ... μC **[1]**

(ii) the energy stored by the capacitor.

energy = ... J **[2]**

(c) Switch $\mathbf{S}_1$ is opened and switch $\mathbf{S}_2$ is closed.

(i) Describe and explain in terms of the movement of electrons how the potential difference across the capacitor changes.

....

....

....

.... **[3]**

(ii) The energy stored in the capacitor decreases to zero. State where the initial energy stored in the capacitor is dissipated.

....

.... **[1]**

(d) Fig.1.2 shows the 4.5 μF capacitor now connected in parallel with a capacitor of capacitance 1.5 μF. Both switches are open and both capacitors are uncharged.

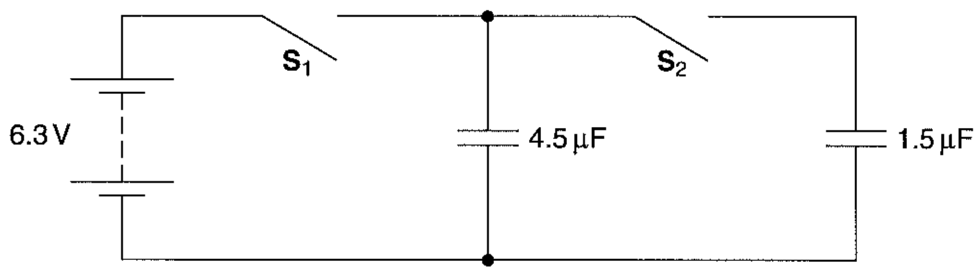

Fig. 1.2

Switch $\mathbf{S}_1$ is closed. The potential difference across the 4.5 μF capacitor is now 6.3 V. Switch $\mathbf{S}_1$ is opened and then switch $\mathbf{S}_2$ is closed.

(i) Calculate the total capacitance of the circuit when $\mathbf{S}_2$ is closed.

capacitance = ... μF **[1]**

(ii) Calculate the final potential difference across the capacitors.

potential difference = ... V **[2]**

[Total: 11]

Question			Expected Answers	Marks	Additional Guidance
1	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)	$Q = CV = 4.5\ \mu \times 6.3 = 28.(35)\ (\mu C)$	B1	Allow: 28 (≥ 2 sf)
		(ii)	$E = \frac{1}{2} CV^2 = 0.5 \times 4.5 \times \mu \times (6.3)^2$ $= 8.9(3) \times 10^{-5}$ (J) / 89.3 μ(J)	C1 A1	Allow use of $E = \frac{1}{2} QV$ 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]**	

2 **(a)** Define *capacitance.*

....

.... **[1]**

(b) Fig. 2.1 shows two capacitors of capacitance 150 μF and 450 μF connected in series with a battery of e.m.f. 6.0 V. The battery has negligible internal resistance.

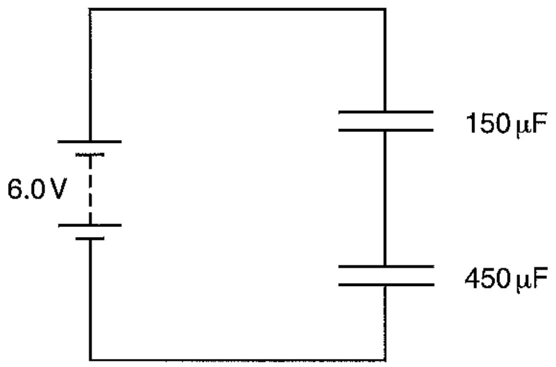

Fig. 2.1

For the circuit shown in Fig. 2.1, calculate

(i) the potential difference across the 150 μF capacitor

potential difference = ... V **[2]**

(ii) the charge stored by the 150 μF capacitor

charge = ... C **[1]**

(iii) the total capacitance of the circuit.

capacitance = ... F **[1]**

(c) The fully charged capacitors shown in **(b)** are disconnected from the battery. The capacitors are then connected in series with a resistor **R** of resistance 45 kΩ and an open switch **S** as shown in Fig. 2.2.

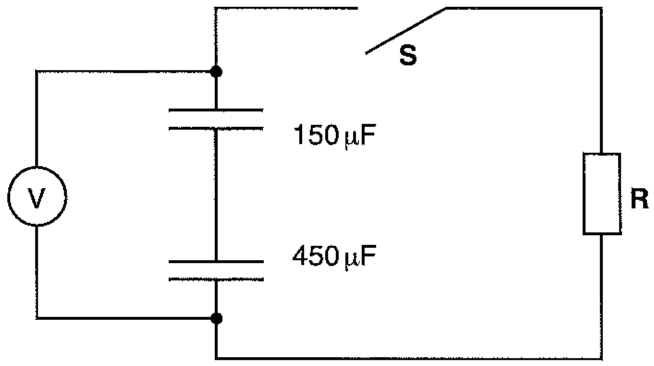

Fig. 2.2

The p.d. V across the capacitors is measured with a voltmeter of infinite resistance.
The switch **S** is closed at time t = 0 and measurements of V are made at regular time intervals.

(i) Show that the time constant for the circuit is about 5 s.

[1]

(ii) On Fig. 2.3 sketch the variation of p.d. V with time t.

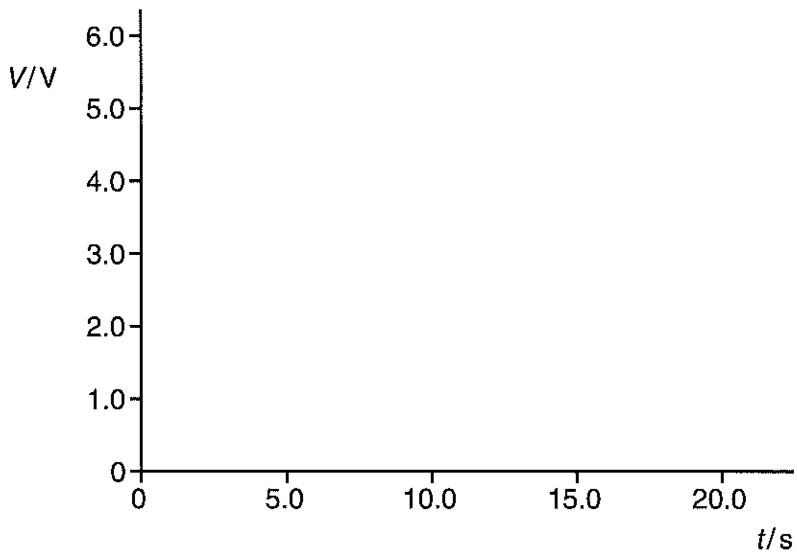

Fig. 2.3

[3]

(iii) At time $t = 0$ calculate the ratio

$$\frac{\text{energy stored by the } 150\,\mu\text{F capacitor}}{\text{energy stored by the } 450\,\mu\text{F capacitor}}.$$

ratio = ... **[2]**

(iv) State and explain how the ratio varies with time.

....

....

.... **[2]**

[Total: 13]

Question			Expected Answers	Marks	Additional guidance
2	(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 $V = \frac{450}{450+150} \times 6.0$ potential difference = 4.5 (V)	C1 A1	**Allow:** 1 mark for an answer of 1.5 (V) **Note**: Using **(b)(ii)**, alternative marking scheme $V = 6.75 \times 10^{-4}/150 \times 10^{-6}$ C1 V = 4.5 V A1
		(ii)	charge = $150 \times 10^{-6} \times 4.5$ charge = 6.75×10^{-4} (C)	B1	Possible e.c.f. **Note**: Using **(b)(iii)** ... $Q = 6.0 \times 1.125 \times 10^{-4} = 6.75 \times 10^{-4}$ (C)
		(iii)	$\frac{1}{C} = \frac{1}{150} + \frac{1}{450}$ (working in μF) capacitance $C_T = 1.125 \times 10^{-4}$ (F) or 113 μ(F)	B1	**Possible alternative:** capacitance = $6.75 \times 10^{-4}/6.0$ capacitance = 1.125×10^{-4} (F) or 113 μ(F) Possible e.c.f. from **(ii)**
	(c)	(i)	time constant = CR time constant = $1.125 \times 10^{-4} \times 45 \times 10^{3}$ 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)	$\frac{1}{2}\times 4.5^2\times 150\times 10^{-6}$ <u>and</u> $\frac{1}{2}\times 1.5^2\times 450\times 10^{-6}$ 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 $\frac{1}{2}Q^2/C_{150}$ and $\frac{1}{2}Q^2/C_{450}$ 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 $\frac{1}{2}QV$ or $\frac{1}{2}Q^2/C$
		(iv)	The ratio remains constant The charge / Q is the same for both capacitors	B1 B1	
			Total	**13**	

2 **(a)** Define the *farad*.

.... **[1]**

(b) Fig. 2.1 shows a capacitor **C** of capacitance 5.4 nF connected to a battery. The switch $\mathbf{S_1}$ is closed and the capacitor is charged to a p.d. of 12 V.

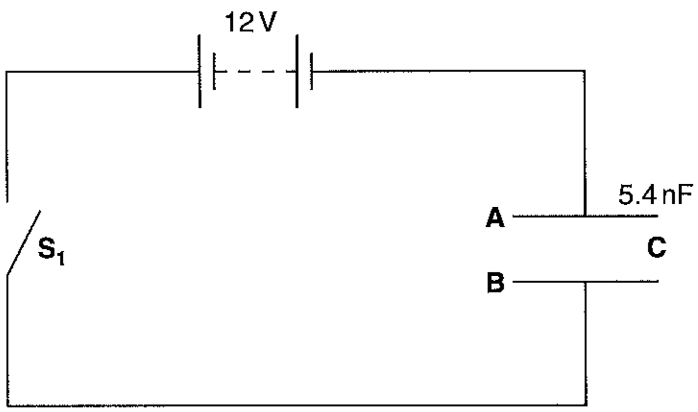

Fig. 2.1

The plates of the capacitor are labelled **A** and **B**.

(i) Explain how the plates of the capacitor become charged in terms of the movement of charged particles in the circuit.

....

....

....

.... **[2]**

(ii) Calculate

1 the charge stored by the capacitor

charge = ... C **[1]**

2 the energy transferred to the capacitor.

energy = ... J **[1]**

(c) Fig. 2.2 shows the capacitor **C** connected to a resistor **R**.

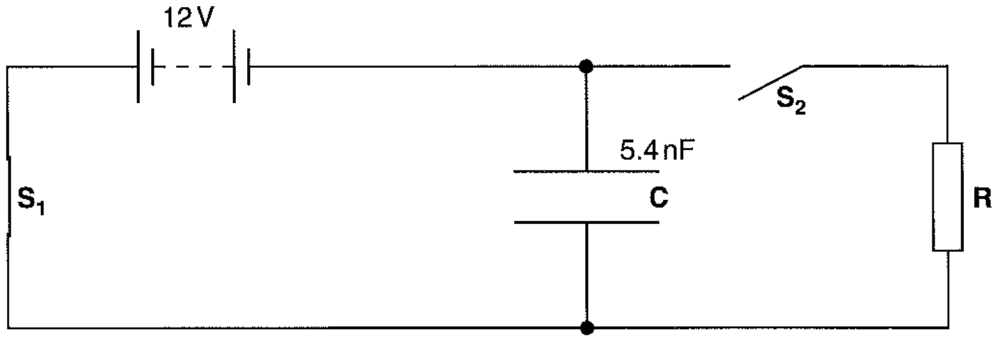

Fig. 2.2

The switch $\mathbf{S_1}$ is now opened and switch $\mathbf{S_2}$ is closed. The current in the resistor **R** is monitored. The initial current through **R** is 3.24 μA.

(i) Show that the resistance of the resistor **R** is 3.7 MΩ.

[1]

(ii) Calculate the current through **R** after a time $t = 0.080$ s.

current = ... μA **[2]**

(d) Explain the effect on the initial rate of discharge of the capacitor when a second resistor of resistance 3.7 MΩ is connected in parallel with the resistor **R**.

....

....

....

.... **[2]**

Total: [10]

Question			Expected Answer	Mark	Additional Guidance
2	(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	

Answer **all** the questions.

1 **(a)** Fig. 1.1 shows a circuit consisting of two parallel plates **A** and **B** connected to a high voltage power supply.

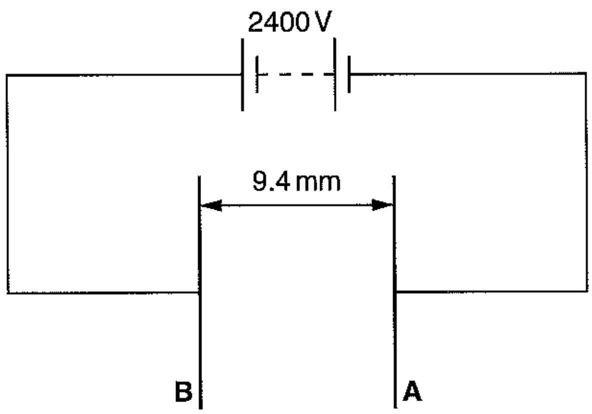

Fig. 1.1

The separation of the plates is 9.4 mm and the p.d. across the plates is 2400 V. There is a vacuum between the plates. Electrons are accelerated from plate **A** to plate **B**.

Calculate

(i) the force acting on an electron when it is between the plates

force = ... N **[2]**

(ii) the gain in kinetic energy of an electron when it travels from **A** to **B**

kinetic energy = ... J **[2]**

(iii) the speed of the electron when it reaches plate **B**. Assume that the speed of the electron is initially zero at plate **A**.

speed = ... $m\ s^{-1}$ **[1]**

(b) The separation between the plates is doubled but the p.d. across the plates is kept the same. Explain how this would affect the answer to **(a)(ii)**.

....

....

....

.... **[2]**

[Total: 7]

Question			Expected Answer	Mark	Additional Guidance
1	(a)	(i)	$E = \frac{V}{d} = \frac{2400}{9.4 \times 10^{-3}}$ $E = 2.55 \times 10^5$ (V m^{-1}) force = $E \times Q = 2.55 \times 10^5 \times 1.60 \times 10^{-19}$ force = 4.09×10^{-14} (N)	C1 A1	**Allow** 1 mark for 4.1×10^{-n}, $n \neq 14$ **Allow** 2sf answer of 4.1×10^{-14} (N) Alternative: $F = \frac{Ve}{d} = \frac{2400 \times 1.60 \times 10^{-19}}{9.4 \times 10^{-3}}$ C1 force = 4.08(5) $\times 10^{-14}$ (N) A1 [Allow: 4.08×10^{-14} (N)]
		(ii)	KE = $e \times V$ or KE = $F \times d$ KE = $1.6 \times 10^{-19} \times 2400$ or KE = $4.09 \times 10^{-14} \times 9.4 \times 10^{-3}$ KE = 3.84×10^{-16} (J)	C1 A1	**Allow** 2 sf answer Possible ecf if answer from **(a)(i)** is used
		(iii)	KE = $\frac{1}{2}mv^2$ $v = \sqrt{\frac{2 \times 3.84 \times 10^{-16}}{9.11 \times 10^{-31}}}$ speed = 2.9(0) $\times 10^7$ (m s^{-1})	B1	Possible ecf if answer from **(a)(ii)** is used
	(b)		There is no change (to the gain in KE) work done or KE = Fd, F or E is halved <u>and</u> d is doubled or work done or KE = VQ and V is the same or work done or KE = VQ and this does not depend on distance	M1 A1	
			Total	7	

Answer **all** the questions.

1 **(a)** Capacitance is measured in farads. Define the *farad*.

....

.... **[1]**

(b) Fig. 1.1 shows the graph of potential difference V against charge Q stored for a capacitor of capacitance C.

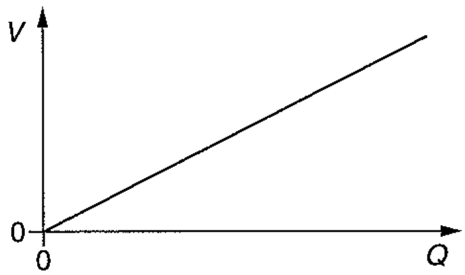

Fig. 1.1

State the quantity represented by the

(i) gradient of the graph

.... **[1]**

(ii) area under the graph.

.... **[1]**

(c) You are given three capacitors of capacitances 100 μF, 200 μF and 500 μF. Calculate the **minimum** total capacitance of these three capacitors in a combination. Show how the capacitors are connected.

capacitance = ... μF **[3]**

(d) A 0.10 F capacitor is charged at a constant rate with a **steady current** of 40 mA for a time of 60 s. Calculate the final

(i) charge stored by the capacitor

charge = ... C **[2]**

(ii) energy stored by the capacitor.

energy = ... J **[2]**

[Total: 10]

Note about significant figures:

If the data given in a question is to 2 sf, then allow answers to 2 or more sf.
If an answer is given to fewer than 2 sf, then penalise once only in the entire paper.
Any exception to this rule will be mentioned in the Guidance.

Question			Answer	Marks	Guidance
1	(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}, $n\neq0$ (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 **(a)** Define *capacitance*.

....

.... [1]

(b) Fig. 4.1 shows an arrangement of three identical capacitors connected to a 6.0V battery.

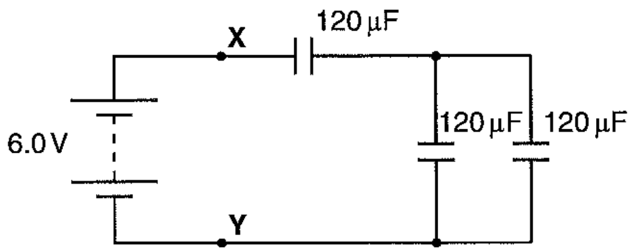

Fig. 4.1

Each capacitor has a capacitance of 120 μF.

(i) Show that the total capacitance of the circuit is 80 μF.

[2]

(ii) Calculate the total energy stored by the capacitors.

energy = ... J **[2]**

(iii) The battery is disconnected from the circuit shown in Fig. 4.1. The p.d. between points **X** and **Y** remains at 6.0V. A fixed resistor of resistance R is now connected between **X** and **Y**. Fig. 4.2 shows the variation of the p.d. V across the resistor with time t.

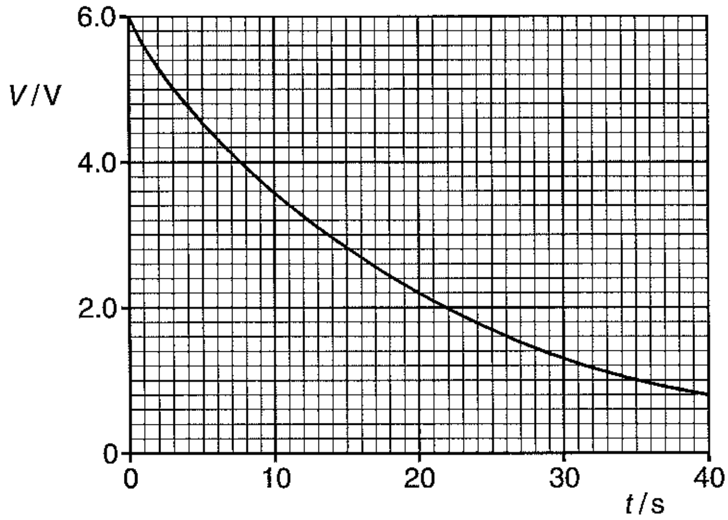

Fig. 4.2

1 Use Fig. 4.2 to show that the circuit has a time constant of 20 s.

[1]

2 Hence, calculate the resistance R of the resistor.

R = ... Ω **[2]**

[Total: 8]

Question			Answers	Marks	Guidance
4	(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**	

Answer **all** the questions.

1 **(a)** Fig. 1.1 shows a circuit with a capacitor of capacitance C.

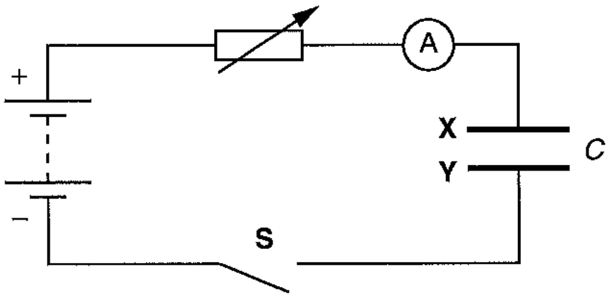

Fig. 1.1

The switch **S** is closed. The resistance of the variable resistor is manually adjusted so that the current in the circuit is kept **constant**.

(i) Explain in terms of movement of electrons how the capacitor plates **X** and **Y** acquire an equal but opposite charge.

....

....

....

....

.... **[2]**

(ii) The initial charge on the capacitor is zero. After 100 s, the potential difference across the capacitor is 1.6 V. The constant current in the circuit is 40 μA.

1 Calculate the capacitance C of the capacitor.

C = ... F **[3]**

2 On Fig. 1.2, sketch a graph to show the variation of potential difference V across the capacitor with time t.

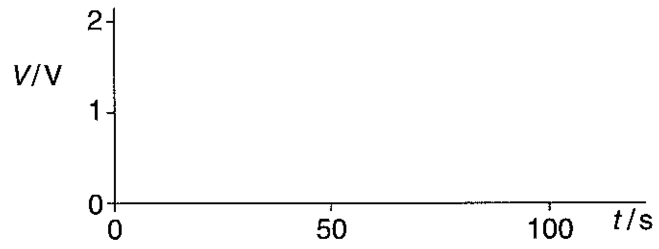

Fig. 1.2 **[2]**

(b) Fig. 1.3 shows an arrangement used to determine the speed of a bullet.

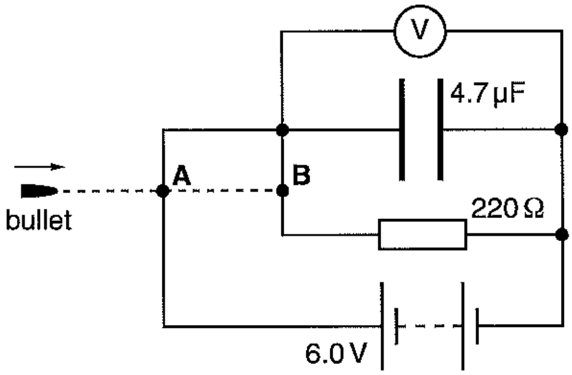

Fig. 1.3

The value of the resistance of the resistor and the value of the capacitance of the capacitor are shown in Fig. 1.3. The voltmeter reading is initially 6.0V. The bullet first breaks the circuit at **A**. The capacitor starts to discharge **exponentially** through the resistor. The capacitor stops discharging when the bullet breaks the circuit at **B**. The final voltmeter reading is 4.0V.

(i) Calculate the time taken for the bullet to travel from **A** to **B**.

time = ... s **[3]**

(ii) The separation between **A** and **B** is 0.10m. Calculate the speed of the bullet.

speed = ... $m s^{-1}$ **[1]**

[Total: 11]

Question			Answer	Marks	Guidance
1	(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) $4.00 = 6.00e^{-\frac{t}{1.03 \times 10^{-3}}}$ $t = -\ln(4.00/6.00) \times 1.03 \times 10^{-3}$ 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 = $\frac{0.100}{4.2 \times 10^{-4}}$ speed = 240 (m s^{-1})	B1	Possible ecf from **(b)(i)**
			Total	**11**	

Answer **all** the questions.

1 **(a)** Fig. 1.1 shows an arrangement of capacitors.

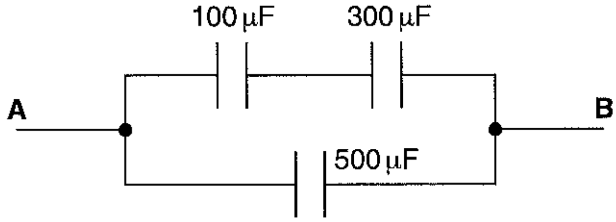

Fig. 1.1

Determine the total capacitance between **A** and **B**.

capacitance = ... μF **[2]**

(b) A capacitor of capacitance 500 μF is charged to 6.0 V. A student places her thumb and first finger across the terminals of the capacitor as shown in Fig. 1.2. This provides a high resistance path across the terminals of the capacitor causing it to discharge.

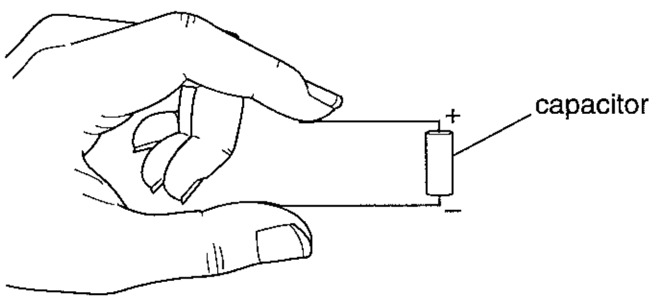

Fig. 1.2

Fig. 1.3 shows the variation of potential difference V across the capacitor with time t.

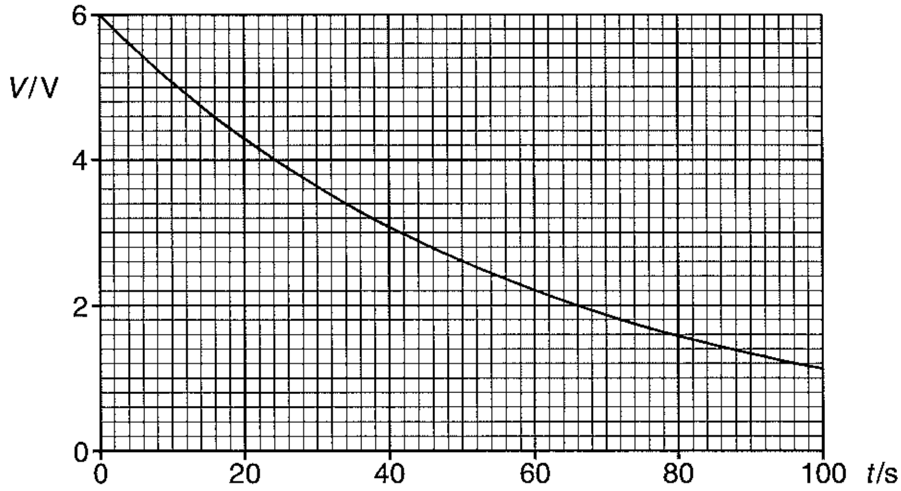

Fig. 1.3

(i) Use Fig. 1.3 to calculate the resistance across the terminals of the capacitor.

resistance = ... Ω **[3]**

(ii) Calculate the energy lost by the capacitor from time $t = 0$ to $t = 30$ s.

energy lost = ... J **[3]**

[Total: 8]

Question			Answer	Marks	Guidance
1	(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) $500 \times 10^{-6} \times R = 60$ $R = \frac{60}{500 \times 10^{-6}}$ 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:** $\ln(2.2/6.0) = -\frac{60}{500 \times 10^{-6} \times R}$ **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) $\frac{1}{2} \times 500 \times 10^{-6} \times 6.0^2$ or $\frac{1}{2} \times 500 \times 10^{-6} \times 3.6^2$ 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: $\frac{1}{2} \times 500 \times 10^{-6} \times (6.0 - 3.6)^2 = 1.44 \times 10^{-3}$ (J) **Note**: Do not penalise use of 575 μF again. This gives a value of 6.62×10^{-3} (J)
			Total	**8**	

4 **(a)** Define the *time constant* of a capacitor-resistor discharge circuit.

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....

.... [1]

(b) A student designs a circuit with a time constant of 5.0 s. State suitable values for resistance *R* and capacitance *C* for this circuit.

R = ... *C* = ... [1]

(c) Fig. 4.1 shows a circuit with a capacitor of capacitance 0.010 F.

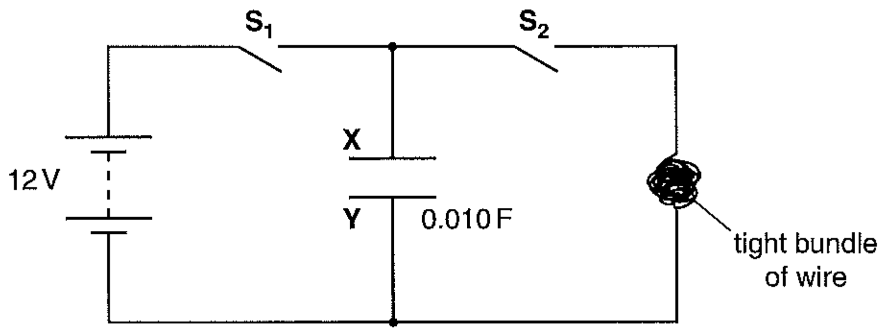

Fig. 4.1

A tight bundle of wire is made from 5.0 m of insulated wire of diameter 0.12 mm and resistivity $4.9 \times 10^{-7}\,\Omega\,m$. The material of the wire has density $8900\,kg\,m^{-3}$ and specific heat capacity $420\,J\,kg^{-1}\,K^{-1}$.

(i) Calculate the time constant of the circuit.

time constant = ... s [3]

(ii) Switch S_2 is open. Switch S_1 is closed. Explain in terms of the movement of electrons how **X** and **Y** acquire equal but opposite charge.

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.... **[3]**

(iii) Switch S_1 is opened. The potential difference across the capacitor is 12 V. Switch S_2 is now closed. Assume that all the energy stored by the capacitor is used to heat up the bundle of wire. Calculate the increase in the temperature of the bundle of wire.

increase in temperature = ... °C **[4]**

(iv) State and explain how your answer to **(iii)** would change when a 24 V power supply is used to carry out the experiment.

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.... **[2]**

[Total: 14]

Question			Answers	Marks	Guidance
4	(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)	$E = \frac{1}{2} \times 0.010 \times 12^2$ or $E = 0.72$ (J) $m = 8900 \times [\pi \times (0.06 \times 10^{-3})^2 \times 5.0]$ or $5.0(3) \times 10^{-4}$ (kg) $5.03 \times 10^{-4} \times 420 \times \Delta\theta = 0.72$ 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**	

4 **(a)** A charged capacitor is connected across the ends of a negative temperature coefficient (NTC) thermistor kept at a fixed temperature. The capacitor discharges through the thermistor. The potential difference V across the capacitor is maximum at time $t = 0$.

(i) On the axes of Fig. 4.1, carefully sketch a graph to show how the potential difference V across the capacitor varies with time t. Label this graph **L**.

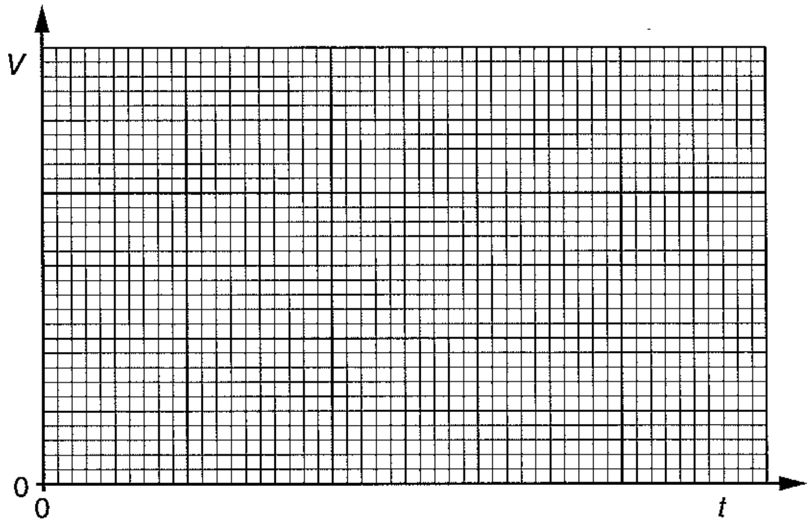

Fig. 4.1 **[1]**

(ii) The temperature of the thermistor is increased to a higher fixed value. On Fig. 4.1, sketch another graph to show the variation of V with t when the same charged capacitor is discharged across the ends of the hotter thermistor. Label this graph **H**. **[1]**

(iii) Explain how you can show that the graph sketched in **(i)** has a constant-ratio property (exponential decay).

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.... **[1]**

(b) Fig. 4.2 shows an electrical circuit.

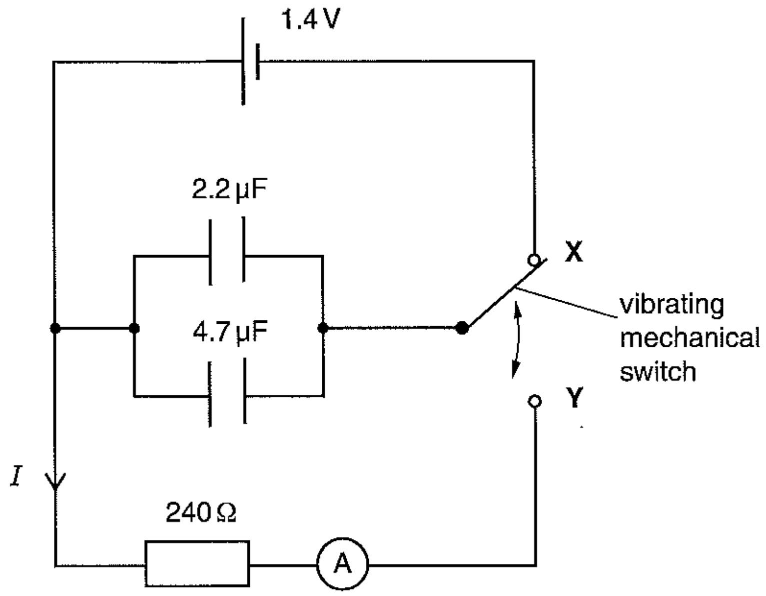

Fig. 4.2

The cell has e.m.f. 1.4 V and negligible internal resistance. The values of the capacitors and the resistor are shown in Fig. 4.2. A mechanical switch vibrates between contacts **X** and **Y** at a frequency of 120 Hz.

(i) Calculate the time constant of the circuit.

time constant = ... s **[1]**

(ii) Calculate the value of the average current I in the resistor. Assume that the capacitors are fully discharged between each throw of the switch.

I = ... A **[3]**

(iii) The frequency of vibration of the mechanical switch is doubled. Explain why the average current in the circuit is not doubled.

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.... **[2]**

Question 5 starts on page 12

Question			Answer	Marks	Guidance
4	(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 = $\frac{6.9 \times 10^{-6} \times 1.4}{0.0083}$ 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	