1(a) 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]

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

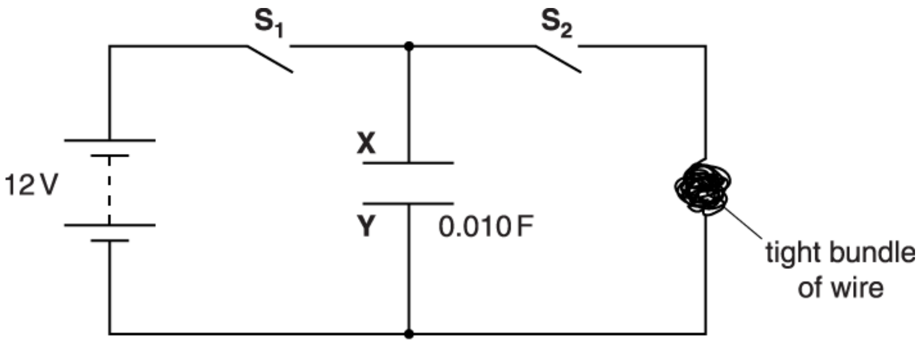

Fig. 4.1

A tight bundle of wire is made from 5.0 m of insulated wire of diameter 0.12 mm and resistivity 4.9×10^{-7} Ω 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 12V. 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 24V power supply is used to carry out the experiment.

____

____

____

____ [2]

2(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**.

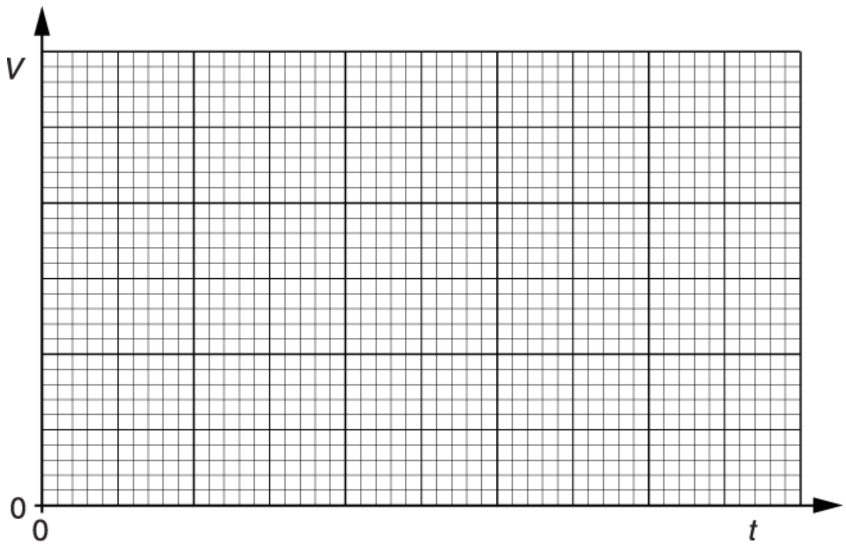


Fig. 4.1

[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).

--- **[1]**

(b) Fig. 4.2 shows an electrical circuit.

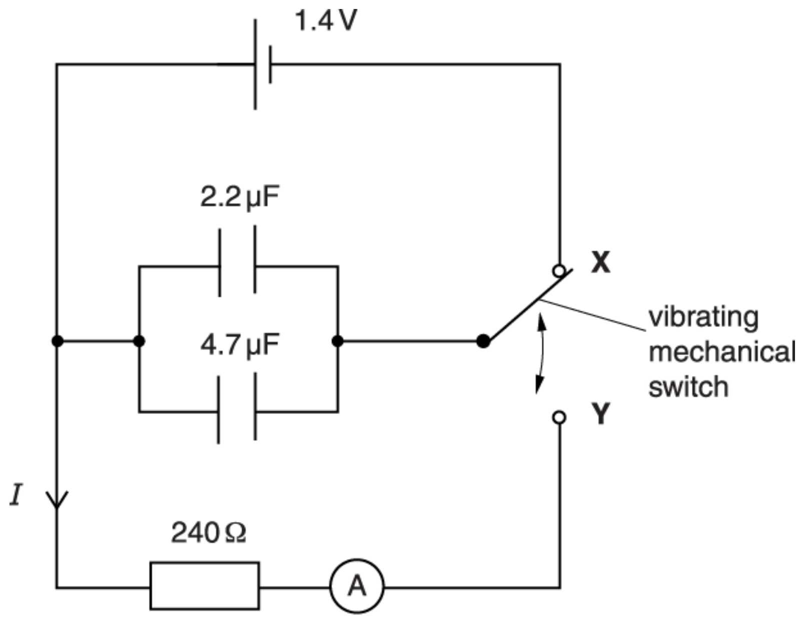


Fig. 4.2

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.

____

____

____

____ **[2]**

3(a) **Fig. 20.1** shows a capacitor and a switch connected in series to a cell.

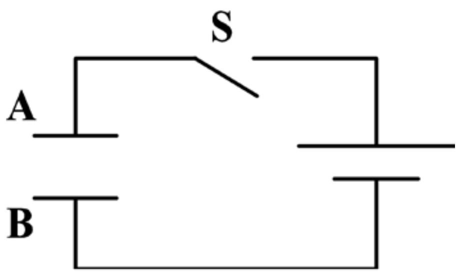


Fig. 20.1

The switch **S** is closed.

Describe and explain how the capacitor plates **A** and **B** acquire opposite charges.

--- **[2]**

(b) **Fig. 20.2** shows an arrangement of capacitors connected to a battery.

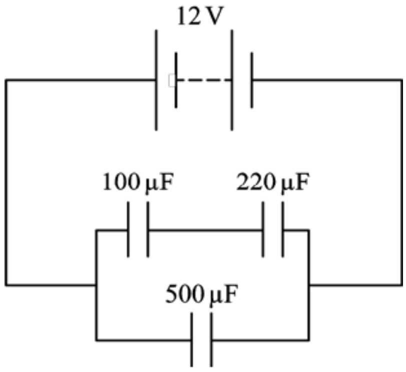


Fig. 20.2

The e.m.f. of the battery is 12 V.

Calculate the total energy *E* stored by the capacitors in this circuit.

E = ________________ J **[4]**

(c) Fig. 20.3 shows a capacitor-resistor circuit.

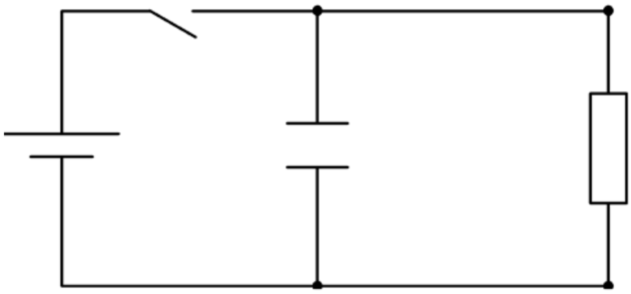


Fig. 20.3

Describe how the time constant of this circuit can be determined experimentally in the laboratory.

--- **[3]**

4 A capacitor consists of two parallel plates separated by air. The capacitor is connected across a d.c. supply. The charged capacitor is then disconnected and the separation between the plates is doubled.

Which statement is correct about the charge stored by the capacitor?

A The charge is the same.
B The charge doubles.
C The charge halves.
D The charge quarters.

Your answer [ ]

[1]

5 Four capacitors of capacitance 10 μF, 20 μF, 30 μF and 40 μF are connected in **series** to a battery.

Which capacitor has the **largest** potential difference across it?

A 10 μF capacitor
B 20 μF capacitor
C 30 μF capacitor
D 40 μF capacitor

Your answer ☐

[1]

6(a) This question is about capacitors.

Fig. 4.1 shows two capacitors **A** and **B** connected in series to a battery.

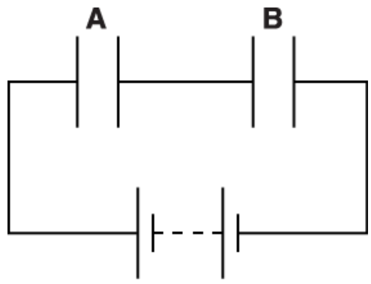


Fig. 4.1

The capacitance of **B** is twice the capacitance of **A**.

Explain why the potential difference across capacitor **A** is twice the potential difference across capacitor **B**.

--- [2]

(b) Fig. 4.2 shows a circuit with an arrangement of capacitors and resistors.

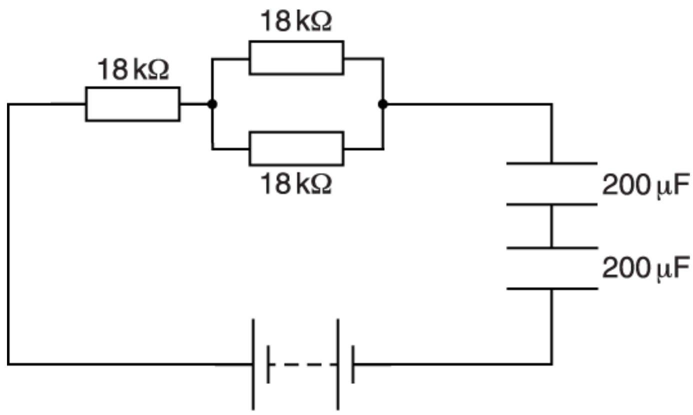


Fig. 4.2

Calculate the time constant of the circuit.

time constant = ______________________________ s **[3]**

(c) A charged capacitor of capacitance 1200 μF is connected across the terminals of a resistor of resistance 40 kΩ.

Fig. 4.3 shows the variation of the current *I* in the resistor against time *t*.

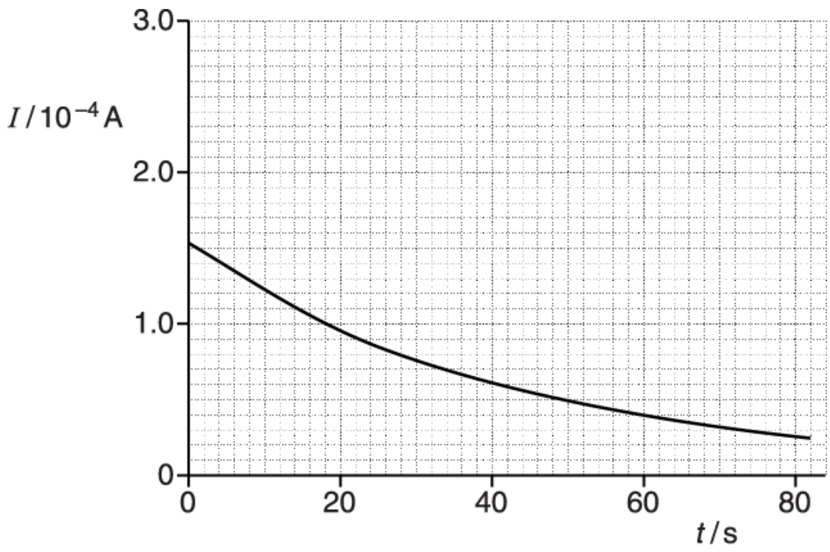


Fig. 4.3

(i) Use Fig. 4.3 to calculate the initial charge stored by the capacitor.

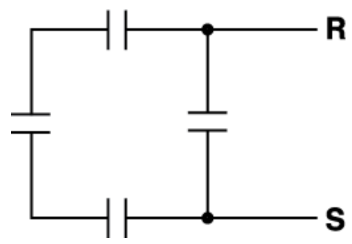
charge = ______________________________ C **[2]**

(ii) The capacitor is charged again to the same initial potential difference. It is now discharged across two 40 kΩ resistors connected in **parallel**.

On Fig. 4.3 draw carefully a graph to show the variation of the current *I* in the combination of resistors with time *t*.

[2]

7 The diagram below shows a circuit connected by a student.



The capacitance of each capacitor is 300 pF.
What is the total capacitance between points **R** and **S**?

A 75 pF
B 230 pF
C 400 pF
D 1200 pF

Your answer

[1]

8(a) Fig. 20.1 shows a capacitor connected to a power supply.

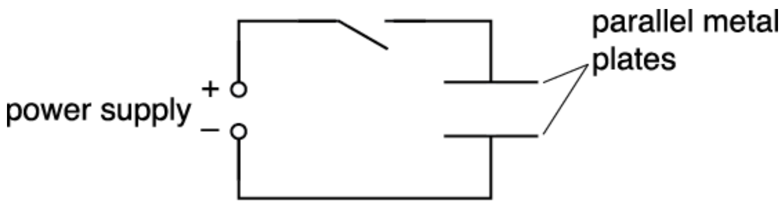


Fig. 20.1

The capacitor consists of two parallel metal plates separated by air.

The switch is closed to charge the capacitor.

The switch is then opened and the separation between the charged plates is **doubled**.

State and explain what happens to the energy stored by the capacitor.

---

[3]

(b) A student is carrying out an experiment in the laboratory to determine the capacitance *C* of a capacitor. Fig. 20.2 shows the circuit used by the student.

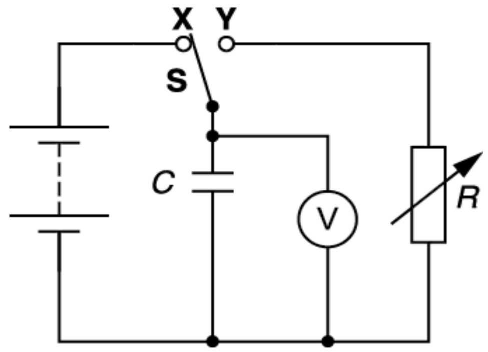


Fig. 20.2

The switch **S** is first connected to **X** to charge the capacitor. The switch is then moved to **Y** at time $t = 0$. The time *T* taken for the potential difference *V* across the capacitor to halve is determined for different values of resistance *R*.

(i) Fig. 20.3 shows the graph of *T* against *R* as plotted by the student.

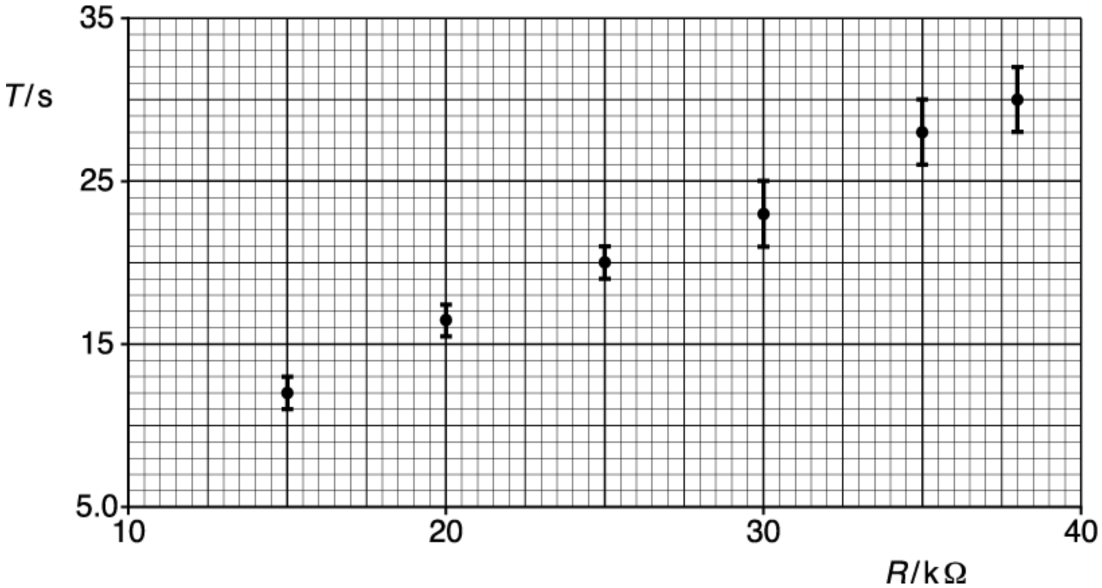


Fig. 20.3

1 Draw a straight line of best fit.

[1]

2 Use $V = V_0 e^{-t/CR}$ to show that $T = -\ln(0.5)CR$.

[2]

3 Determine a value for the capacitance C.

C = ____________________________ F **[3]**

(ii) Describe, without doing any calculations, how you can use Fig. 20.3 to determine the percentage uncertainty in C.

____

____

____

____ **[2]**

9 A nucleus of hydrogen-3 ($^{3}_{1}H$) is unstable and it emits a beta-minus particle (electron).

The emitted beta-minus particle enters a region of uniform magnetic field.
Fig. 22.1 shows the path of the particle **before** it enters the magnetic field.

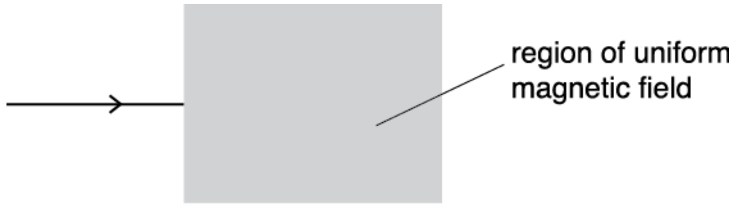


Fig. 22.1

The direction of the magnetic field is into the plane of the paper.
Describe and explain the path of the particle in the magnetic field.

-- [2]

10(a) A student designs an investigation to learn more about an old instrument called a hot wire ammeter.

A fine resistance wire stretched between two retort stands sags when heated by the current being measured. This sag is converted into a reading on a non-linear scale.

A current-carrying wire is clamped at each end as shown in Fig. 2.1.

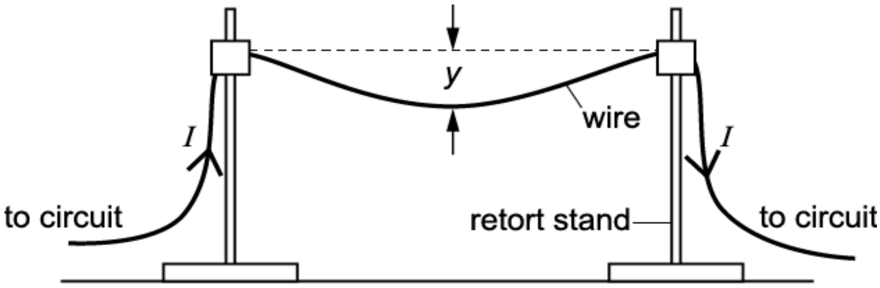


Fig. 2.1

The deflection y at the centre of the wire is measured for various currents I in the wire.
It is suggested that y and I are related by the equation

$$y = aI^b$$

where a and b are constants. This equation can also be written as

$$\lg y = \lg a + b \lg I.$$

A graph is plotted of lg y on the y-axis against lg I on the x-axis. State expressions for the gradient and y-intercept in terms of a and b.

gradient = ________________________________

y-intercept = ________________________________

[1]

(b) For different values of the current I, the vertical deflection y is recorded. A table of results is shown with further columns giving values of lg (I / 10^{-2} A) and lg (y / mm), including the absolute uncertainties.

I / 10^{-2} A	y / mm	lg (I / 10^{-2} A)	lg (y / mm)
50	2.6 ± 0.2		
60	3.4 ± 0.2	1.78	0.53 ± 0.03
70	4.4 ± 0.2	1.85	0.64 ± 0.02
80	5.4 ± 0.2	1.90	0.73 ± 0.02
90	6.6 ± 0.2	1.95	0.82 ± 0.01
95	7.2 ± 0.2	1.98	0.86 ± 0.01

(i) Complete the missing values in the table, including the absolute uncertainty for lg (y / mm).

[2]

(ii) Fig. 2.2 shows the axes for a graph of lg (y / mm) on the y-axis against lg (I / 10^{-2} A) on the x-axis. The last four points have been plotted including error bars for lg (y / mm). By plotting the two remaining points, complete the graph. Draw a line of best fit.

[2]

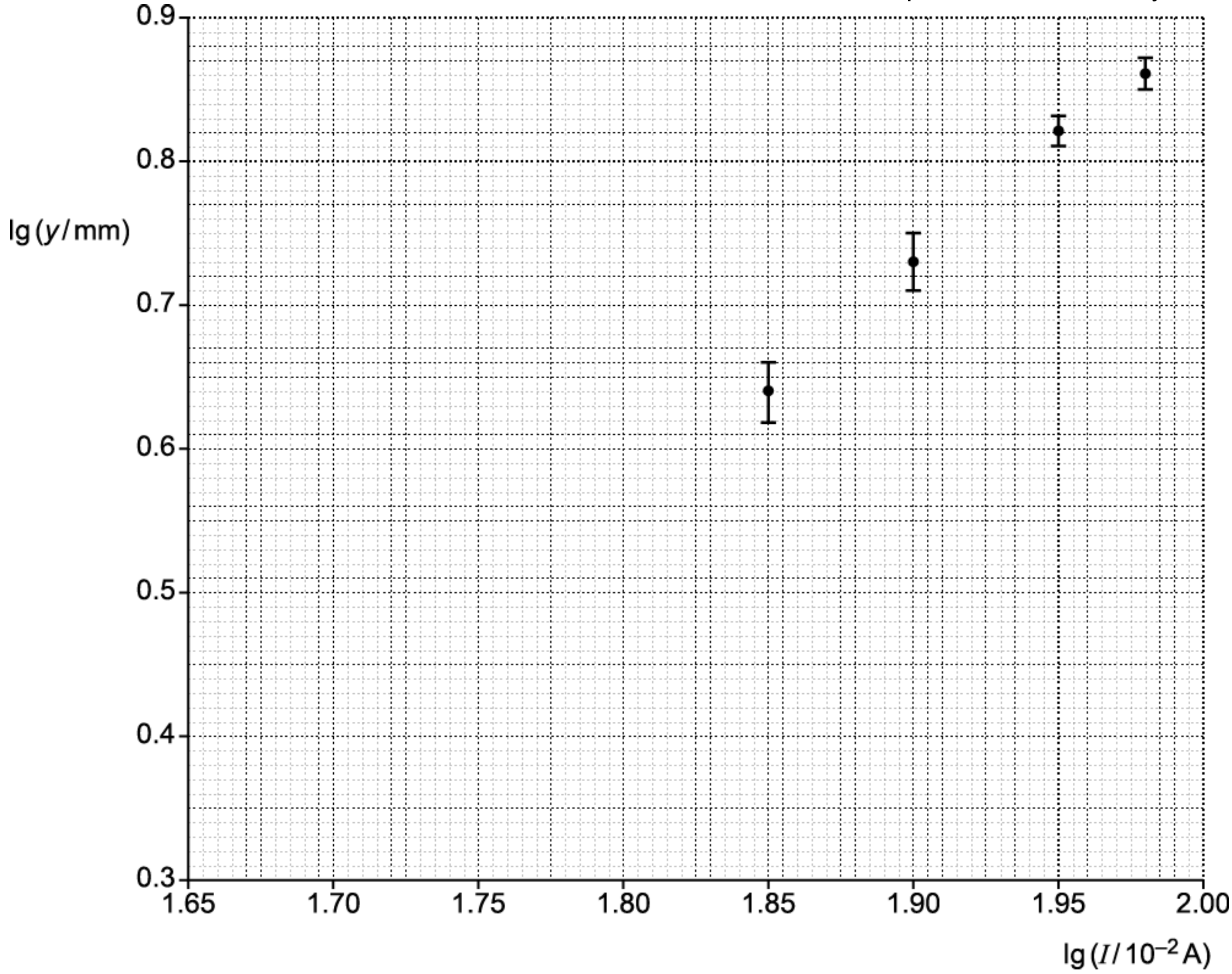

0.9
0.8
lg (y / mm)
0.7
0.6
0.5
0.4
0.3
1.65
1.70
1.75
1.80
1.85
1.90
1.95
2.00
lg (I / 10⁻² A)

Fig. 2.2

(c)

(i) Use the line of best fit through the data points in Fig. 2.2 to determine numerical values of

1 *b*

b = _______________ **[1]**

2 *a*.

a = _______________ **[2]**

(ii) Determine the absolute uncertainty in the value of *b*.

uncertainty in *b* = ± _______________ **[2]**

11(a) This question is about investigating the charging and discharging of capacitors.

Two students are given the circuit shown in Fig. 6.1. It consists of two resistors and two uncharged capacitors, a 10 V supply and a two-way switch **S**.

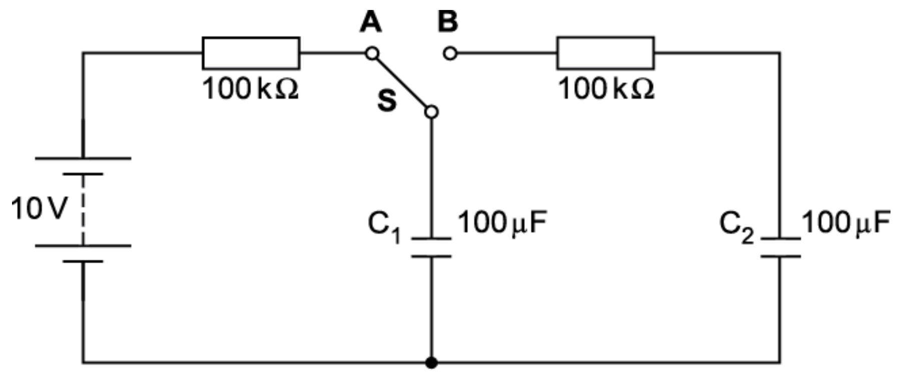


Fig. 6.1

The first student is asked to investigate the charging of the capacitor C_1 when **S** is connected to **A**. She selects an ammeter of range 0 to 100 μA reading to 2 μA and a stopwatch reading to 0.1 s.

Discuss whether she has made a sensible choice of equipment for this experiment.

--- **[4]**

(b) A student is asked to investigate the change of potential difference (voltage) V with time t across each capacitor from the instant that **S** is moved from **A** to **B**.

(i) Explain why the final potential difference across each capacitor is 5.0 V.

--- **[2]**

(ii) Predict the outcome of the experiment by sketching **two** graphs on Fig. 6.2 to display the results that the student should obtain for each capacitor. Label them C_1 and C_2.

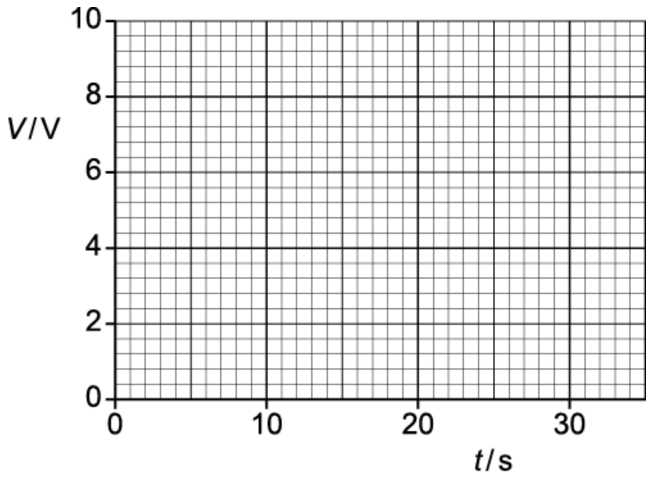
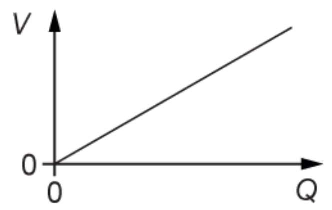


Fig. 6.2

[3]

12 The graph below shows the variation of potential difference V with charge Q for a capacitor.



Which row is correct for the gradient of the graph and the area under the graph?

	Gradient of graph	Area under the graph
A	capacitance^{-1}	work done
B	capacitance^{-1}	permittivity
C	capacitance	power
D	capacitance	energy

Your answer [1]

13 A capacitor discharges through a resistor. At time t = 0, the charge stored by the capacitor is 600 μC. The capacitor loses 5.0 % of its charge every second.

What is the charge **left** on the capacitor at time t = 4.0 s?

A 111 μC

B 120 μC

C 480 μC

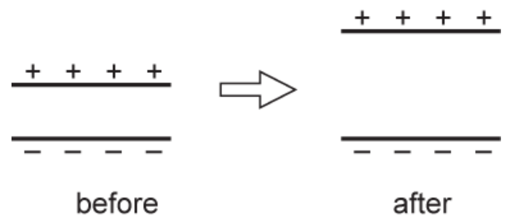
D 489 μC

Your answer [1]

14 Two isolated parallel capacitor plates have an equal and opposite charge.

The separation between the plates is doubled.

The charge on each plate remains the same but the potential difference between the plates doubles.



Which statement is correct?

A The capacitance of the capacitor doubles.

B The energy stored by the capacitor is halved.

C The permittivity of free space doubles.

D The electric field strength between the plates remains the same.

Your answer **[1]**

15(a)

A capacitor of capacitance 7.2 pF consists of two parallel metal plates separated by an insulator of thickness 1.2 mm. The area of overlap between the plates is 4.0×10^{-4} m^2. Calculate the permittivity of the insulator between the capacitor plates.

permittivity = ____________________ F m^{-1} **[2]**

(b) Fig. 21 shows a circuit.

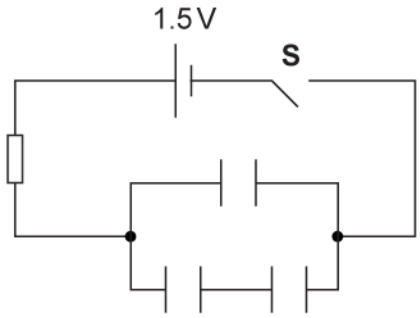


Fig. 21

The capacitance of each capacitor is 1000 μF. The resistance of the resistor is 10 kΩ. The cell has e.m.f. 1.5 V and negligible internal resistance.

(i) Calculate the total capacitance *C* in the circuit.

C = ____________________ μF **[2]**

(ii) The switch **S** is closed at time *t* = 0. There is zero potential difference across the capacitors at *t* = 0. Calculate the potential difference *V* across the resistor at time *t* = 12 s.

V = ____________________ V **[2]**

16(a) A student is investigating how the discharge of a capacitor through a resistor depends on the resistance of the resistor.

The equipment is set up as shown in Fig. 3.1.

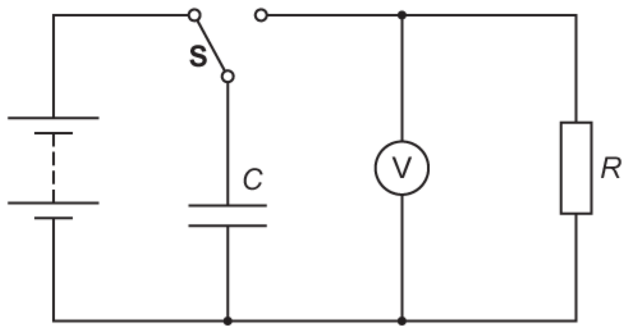


Fig. 3.1

The student charges the capacitor of capacitance *C* and then discharges it through a resistor of resistance *R* using switch **S**. After a time $t = 15.0$ s the student records the potential difference *V* across the capacitor. The student repeats this procedure for different values of *R*.

It is suggested that *V* and *R* are related by the equation

$$V = V_0 e^{-\frac{t}{CR}}$$

where V_0 is the initial potential difference across the capacitor and *t* is the time over which the capacitor has discharged.

The student decides to plot a graph of ln (*V* / V) on the *y*-axis against $\frac{1}{R}$ on the *x*-axis to obtain a straight line graph. Show that the magnitude of the gradient is equal to $\frac{15}{C}$

[2]

(b) Values of R and V at t = 15.0 s are given in the table below.

R / kΩ	V / V	$\left(\frac{1}{R}\right)$ / 10^{-6} Ω^{-1}	ln (V / V)
56	3.0 ± 0.2	18	
68	3.7 ± 0.2	15	1.31 ± 0.06
100	5.0 ± 0.2	10	1.61 ± 0.04
150	6.4 ± 0.2	6.7	1.86 ± 0.03
220	7.3 ± 0.2	4.5	1.99 ± 0.03
330	8.1 ± 0.2	3.0	2.09 ± 0.03

(i) Complete the missing value of ln (V / V) and its absolute uncertainty in the table above. **[1]**

(ii) Use the data to complete the graph of Fig. 3.2. Four of the six points have been plotted for you. **[2]**

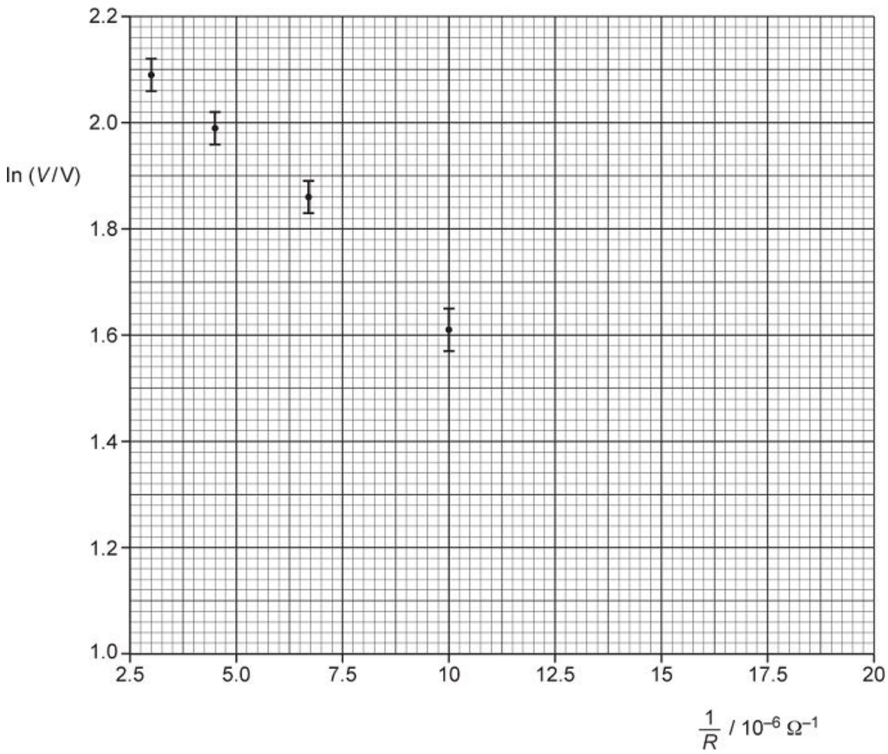


Fig. 3.2

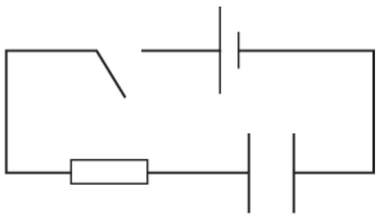
(iii) Use the graph to determine a value for *C*. Include the absolute uncertainty and an appropriate unit in your answer.

C = _________ ± _________ unit _________ **[4]**

(c) Determine the value of *R*, in kΩ, for which the capacitor discharges to 10% of its original potential difference in 15.0 s. Show your working.

R = ____________________ kΩ **[2]**

17 A capacitor is charged through a resistor.



The cell has e.m.f. 1.50 V and negligible internal resistance.
The capacitor is initially uncharged. The time constant of the circuit is 100 s.
The switch is closed at time *t* = 0.

What is the potential difference across the capacitor at time *t* = 200 s?

A 0.20 V
B 0.55 V
C 0.95 V
D 1.30 V

Your answer **[1]**

18(a) A student wishes to determine the permittivity ε of paper using a capacitor made in the laboratory.

The capacitor consists of two large parallel aluminium plates separated by a very thin sheet of paper.

The capacitor is initially charged to a potential difference V_0 using a battery. The capacitor is then discharged through a fixed resistor of resistance 1.0 MΩ.

The potential difference V across the capacitor after a time t is recorded by a data-logger. The student uses the data to draw the ln V against t graph shown in Fig. 22.

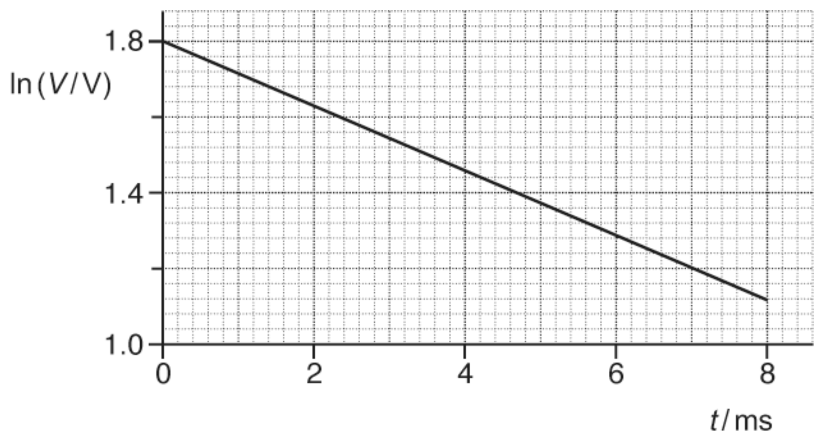


Fig. 22

Show that the magnitude of the gradient of the line shown in Fig. 22 is equal to

$$\frac{1}{CR}$$

where C is the capacitance of the capacitor and R is the resistance of the resistor.

[2]

(b) Use Fig. 22 to determine the capacitance *C* of the capacitor. Describe how the student can then use this value of *C* to determine a value for ε.

In your description, mention any additional measurements required on the capacitor.

[6]

19 Fig. 3.1 shows the design of a ‘mechanical’ torch.

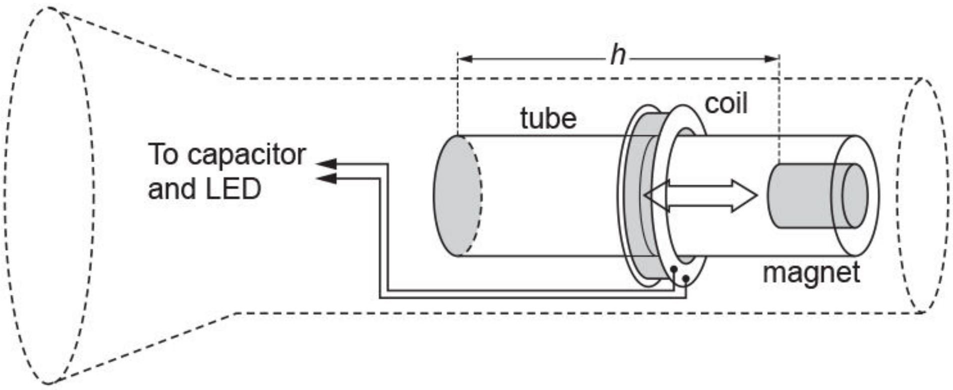


Fig. 3.1

There is no battery in the torch. Instead, when the torch is inverted, the magnet falls a short vertical distance *h* through the coil of wire, as shown in Fig. 3.2. This induces an electromotive force (e.m.f.) across the ends of the coil. The e.m.f. is used to store charge in a capacitor, which lights a light-emitting diode (LED) when it discharges.

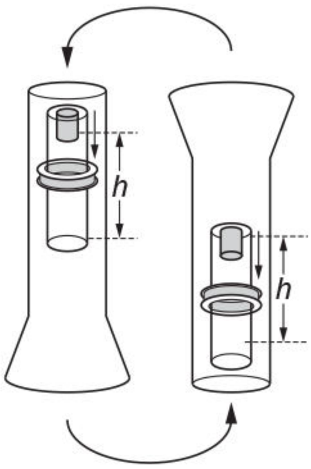


Fig. 3.2

Fig. 3.3 shows the variation with time of the e.m.f. generated as the magnet falls the distance *h.*

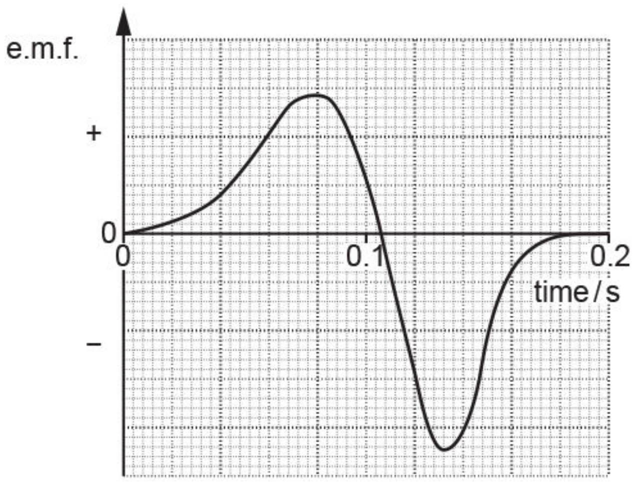


Fig. 3.3

When the torch is inverted, the pulses of e.m.f. shown in Fig. 3.3 cause a capacitor of capacitance 0.12 F to become charged.

Each positive **and** each negative pulse adds 9.0×10^{-3} C to the charge stored in the capacitor.

(i) The torch is inverted 80 times.

Calculate the total energy stored in the capacitor.

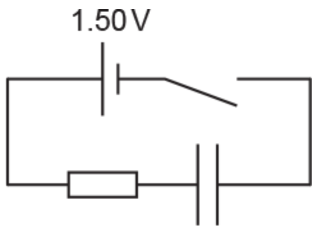
total energy = ... J **[3]**

(ii) When the torch is switched on, the energy stored in the capacitor lights a 50 mW LED.

Estimate the time for which the LED lights.

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

20 A capacitor is charged through a resistor.



The cell has electromotive force (e.m.f.) 1.50 V and negligible internal resistance.
The time constant of the circuit is 10 s. The switch is closed at time t = 0. At time t, the potential difference across the resistor is 0.60 V.

Which expression is correct?

A $0.60 = 1.50e^{-0.10t}$

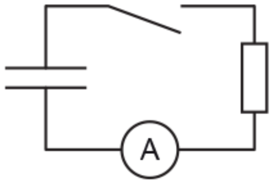
B $0.90 = 1.50e^{-0.10t}$

C $0.60 = 1.50e^{-10t}$

D $0.60 = 1.50(1 - e^{-10t})$

Your answer [1]

21 A capacitor is discharged through a resistor.



The capacitor is fully charged at time $t = 0$. The time constant of the circuit is 10 s. The switch is closed at time $t = 0$. The current in the resistor is I.

Which row is correct?

	Current I at $t = 0$	Current I at $t = 10$ s
A	maximum	0
B	maximum	37% of the current at $t = 0$
C	0	63% of the current at $t = \infty$
D	0	37% of the current at $t = \infty$

Your answer [1]

22 Fig. 22.1 shows two horizontal metal plates in a vacuum.

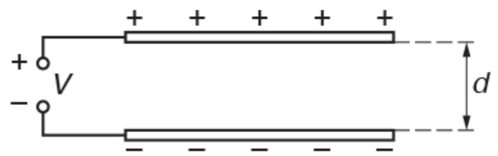


Fig. 22.1

The plates are connected to a power supply. The potential difference *V* between the plates is constant. The magnitude of the charge on each plate is *Q*. The separation between the plates is *d*.

Fig. 22.2 shows the variation with *d* of the charge *Q* on the positive plate.

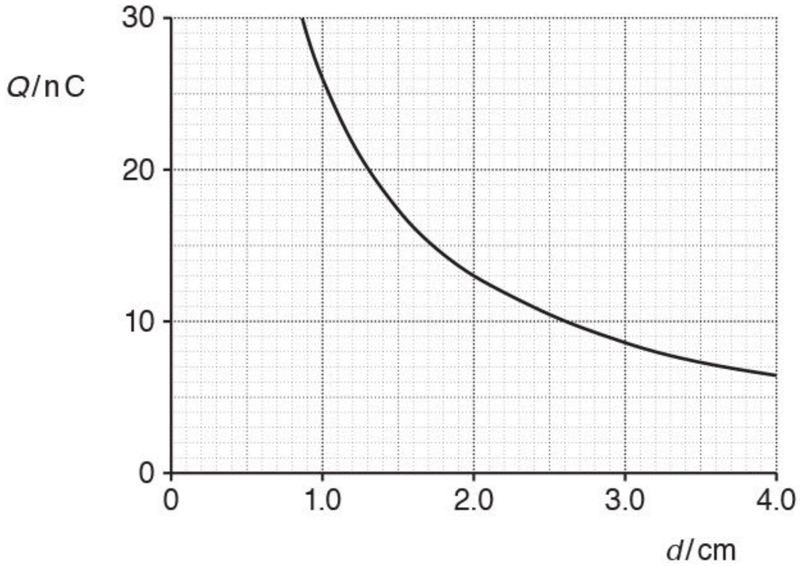


Fig. 22.2

(i) Use Fig. 22.2 to propose and carry out a test to show that *Q* is inversely proportional to *d*.

Test proposed:

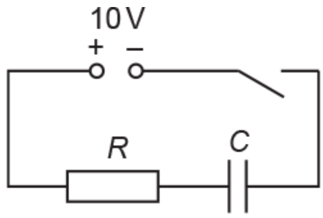
Working:

[2]

(ii) Use capacitor equations to show that *Q* is inversely proportional to *d*.

[2]

23 The diagram below shows a circuit used to charge a capacitor.



The power supply has electromotive force (e.m.f.) 10 V and negligible internal resistance.

The capacitor has capacitance *C* and the resistor has resistance *R*.

The switch is closed at time $t = 0$.

The table below shows potential difference *V* across the resistor at various values of time *t*.

V / V	10	6.3	5.0	3.7
t / s	0	2.8	4.2	6.0

What is the product $C \times R$ for this circuit?

A 0 s
B 2.8 s
C 4.2 s
D 6.0 s

Your answer [1]

24 A capacitor discharges through a resistor.

At time $t = 0$ the potential difference *V* across the capacitor is V_0.

At time $t = 2.0$ s, $V = 0.90\ V_0$.

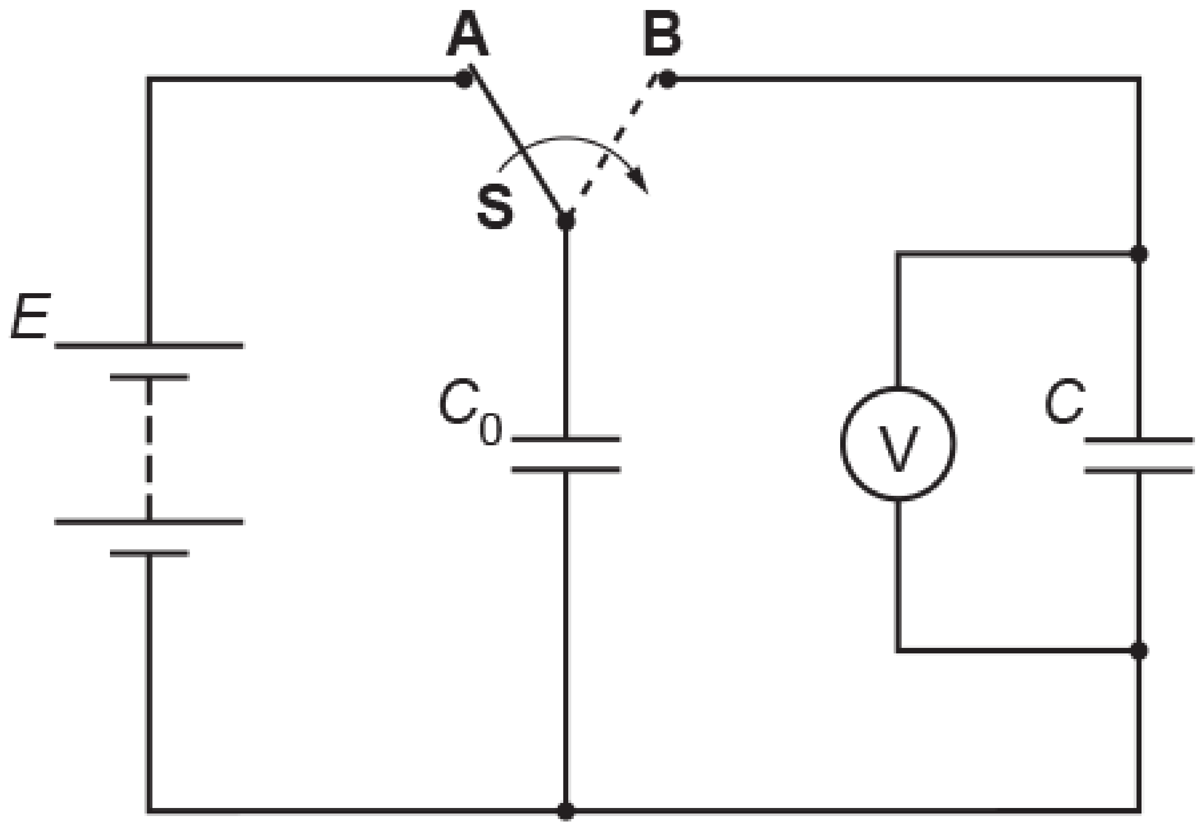
Which statement is **not** correct?

A At $t = 4.0$ s, $V = 0.81\ V_0$.
B The capacitor is fully discharged after $t = 10$ s.
C The potential difference across the resistor is the same as that for the capacitor.
D The potential difference *V* decreases exponentially with time *t*.

Your answer [1]

25(a) The diagram below shows a circuit containing two capacitors which are both initially uncharged. The battery has e.m.f. E and negligible internal resistance.

The switch **S** is first moved to position **A** until the capacitor of capacitance C_0 is fully charged.



The switch **S** is then moved to position **B**. The initial charge stored by the capacitor of capacitance C_0 is shared between the two capacitors.
The final reading on the voltmeter is V.

Show that $V = \frac{C_0}{C + C_0} E$.

[2]

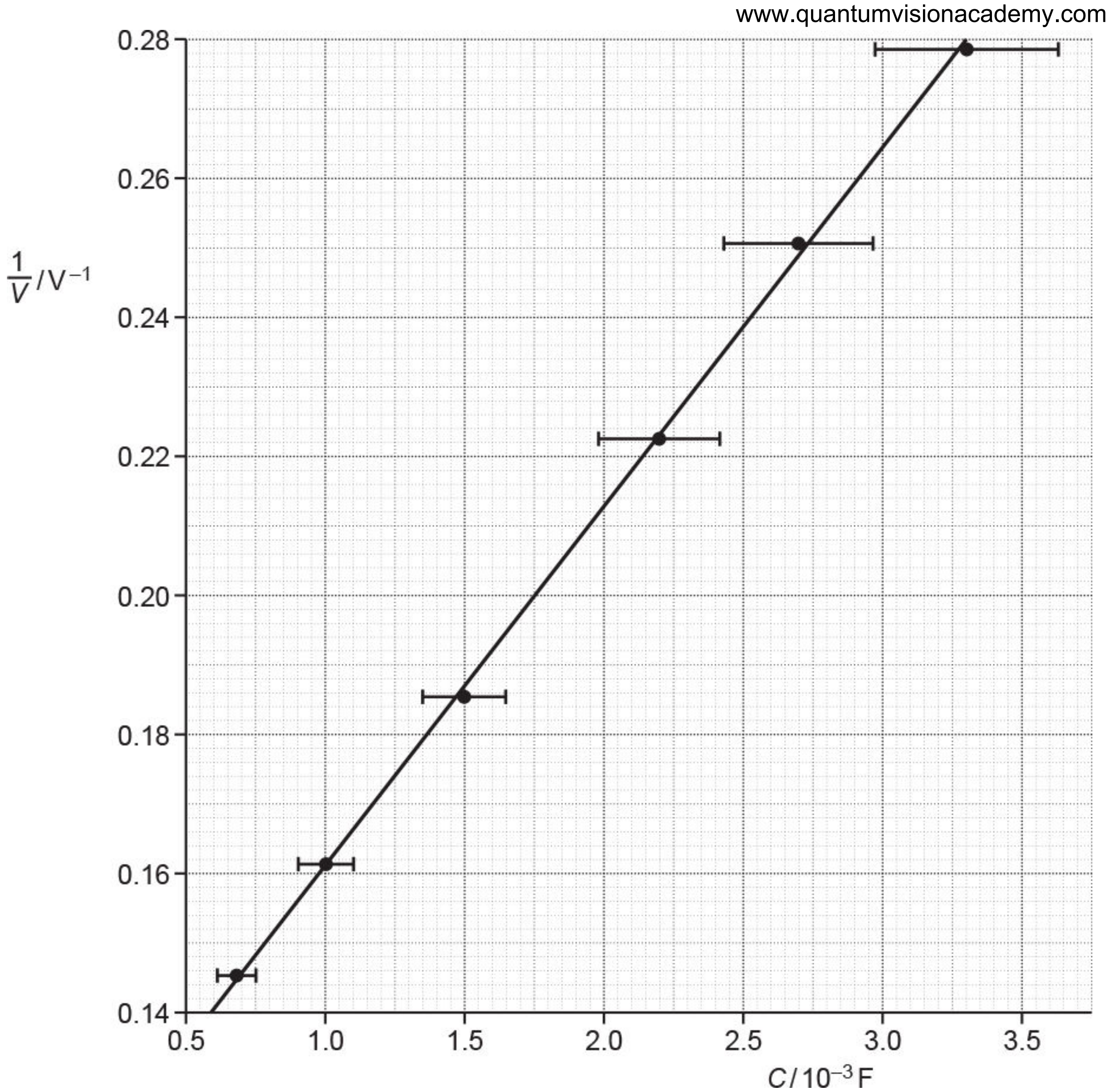
(b) A student wants to determine the values of E and C_0 by repeating the experiment above and measuring the potential difference (p.d.) V for a selection of capacitors of capacitance C.

The student decides to plot a graph of $\frac{1}{V}$ against C.

(i) Use the expression in **(a)** to show that the graph should be a straight line of gradient $\frac{1}{C_0 E}$ and y-intercept $\frac{1}{E}$.

[1]

(ii) The data points, error bars and the line of best fit drawn by the student are shown in the graph below.



The gradient of the line of best fit is 51 V^{-1} F^{-1}. The value of E is 9.1 V.

Determine the value of C_0 in millifarads (mF). Write your answer to 2 significant figures.

C_0 = ... mF **[2]**

(iii) Draw on the graph a straight line of worst fit.

Use this line to determine the absolute uncertainty in your value of C_0. Write your answer to an appropriate number of significant figures.

absolute uncertainty = ... mF **[4]**

(c) The experiment is repeated with a resistor of resistance 10 kΩ placed in series between **S** and the capacitor of capacitance C_0.

State with a reason what effect, if any, this would have on the experiment.

[1]

END OF QUESTION PAPER

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
1	a		Any suitable values with units, eg: 5 MΩ and 1 μF.	B1	**Examiner's Comments** All candidates had to do was to provide suitable values for the resistance and capacitance with appropriate units; this they did with great skill. Only a small number of candidates omitted either one or both units and lost this accessible mark.
	b	i	$R = \dfrac{4.9\times10^{-7}\times5.0}{\pi\times(0.06\times10^{-3})^2}$ or R = 217 (Ω)	C1	**Note** : An incorrect equation here for A prevents this and any subsequent marks.
		i	time constant = 0.010 × 217	C1	
		i	time constant = 2.2 (s)	A1	**Allow** 2 marks for 0.54 (s) - diameter of 0.12 mm used instead of radius 0.06 mm. **Examiner's Comments** Most candidates picked up two or more marks in this synoptic question. Most candidates correctly used the resistivity equation to first determine the resistance of the bundle of wire and then the time constant of 2.2 s for the circuit. A very small number of candidates used ρ = 8900 for the resistivity of the metal instead of ρ = 4.9 ×10^{-7} Ωm. This was taken as a monumental error of physics and prevented the candidates from picking up any marks in this question.
		ii	Electrons are removed from **X** or electrons are deposited on **Y**.	B1	**Allow** electrons move anticlockwise (in the circuit).
		ii	**X** becomes positive or **Y** becomes negative	B1	There is no ecf from the previous B1 mark.

Question			Answer/Indicative content	Marks	Guidance
		ii	(The size of charge is the same because) an equal number of electrons are removed and deposited (on the plates).	B1	**Examiner's Comments** There was a good spread of marks, with many candidates scoring two or more marks. Most candidates did explain the charging of the two plates in terms of the flow of electrons in the circuit. Most candidates realised that the electrons would gather at plate **Y** giving it a negative charge. However, many could not adequately explain why the plates acquired equal but opposite charges. A significant number of candidates, mainly at the top-end, had no problems and gave superb answers in terms of equal number of electrons deposited and removed from the two plates.
		iii	$E = ½ \times 0.010 \times 12^2$ or E = 0.72 (J)	C1	
		iii	$m = 8900 \times [\pi \times (0.06 \times 10^{-3})^2 \times 5.0]$ or $5.0(3) \times 10^{-4}$(kg)	C1	**Note** : An incorrect equation here for m or V prevents this and any subsequent marks.
		iii	$5.03 \times 10^{-4} \times 420 \times \Delta\theta = 0.72$	C1	Correct substitution into $mc\Delta\theta = 0.72$; **allow** any subject.
		iii	increase in temperature = 3.4 (°C)	A1	**Note** : Do not penalise using diameter here again if already penalised in **(i)**. **Examiner's Comments** The majority of candidates scored full marks. Answers were well-structured and showed excellent synoptic knowledge of specific heat capacity. A significant number of candidates struggled when calculating the volume and hence the mass of the bundle of wire. Some candidates used $V = \frac{4}{3}\pi r^3$ to determine the volume of the wire. Such elementary errors are unjustifiable at this level.
		iv	Energy or V^2 increases by a factor of 4.	B1	**Allow** the label E or W for energy.

Question			Answer/Indicative content	Marks	Guidance
		iv	The (change in temperature) increases by a factor of 4 (because $\Delta\theta \propto E$).	B1	**Allow** $\Delta\theta$ = 13.6 (°C) for this B1 mark - possible ecf from **(iii)**. **Examiner's Comments** This question discriminated well with the majority of the candidates realising that the increase in the temperature would be four times greater. The explanations were often correct and elegantly presented in terms of energy $\propto$ p.d^2 for the energy stored in the capacitor. A small cohort of candidates gave qualitative answers and took no account of the potential difference doubling.
			Total	13	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
2	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 **Examiner's Comments** Although the majority of the candidates were awarded a mark, the sketch graphs were generally of poor quality. The curves were often thick and levelled off inappropriately.
		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 **Examiner's Comments** A good number of candidates sketched a graph showing a smaller time constant. A significant number of candidates drew a curve assuming the resistance of the thermistor had increased. A very small number of candidates drew straight lines.
		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 **Examiner's Comments** Most candidates either gave a definition for time constant or half-life. About a third of the candidates, mainly in the upper quartile, gave perfect answers in terms of constant ratio of potential difference V for fixed intervals of time t. The most common answer was *'After one half life the p.d. decreases to V/2, then after another half life to V/4, then V/8, and so on....'*

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	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) **Examiner's Comments** Almost all candidates attempted this question, with most gaining a mark for the correct value for the time constant. There were fewer errors with powers of ten. Very few candidates calculated the total capacitance of the capacitors using the reciprocal equation.
		ii	charge = $6.9 \times 10^{-6} \times 1.4$ (= 9.66×10^{-6} C)	C1	Possible ecf from **(b)(i)** for value of total capacitance
		ii	(Δt = 1/120 = 0.0083 s)		
		ii	current = $\dfrac{6.9\times10^{-6}\times1.4}{0.0083}$	C1	
		ii	current = 1.2×10^{-3} (A)	A1	**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 **Examiner's Comments** This was an unfamiliar question and the success hinged on doing exactly what was stated in the second sentence of the question. A good number of candidates correctly calculated the total charge stored by the capacitors. In order to calculate the average current, this charge had to be divided by the time between each throws; 0.0083 s or simply 1/120 s. This is where many candidates slipped. They divided by time constant or half the time between each throws. Some candidates calculated the maximum power dissipated in the resistor or the maximum current in the 240 Ω resistor. About a quarter of the candidates, mainly in the upper quartile, gained full marks.
		iii	The capacitors do not fully discharge (AW)	B1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		iii	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	**Examiner's Comments** Most candidates struggled here. Those who scored one mark did so for stating that the *'capacitors cannot fully discharge'*.
			Total	9	
3	a		Electrons in the circuit move in a clockwise direction **and** electrons are deposited on plate **B.** (An equal number of) electrons are removed from plate **A** giving it a positive charge (of equal magnitude).	B1 B1	**Allow**: conventional current is in anticlockwise direction.
	b		series capacitors: $C = (100^{-1} + 220^{-1})^{-1} =$ 68.75 (μF) total capacitance = 500 + 68.75 = 568.75 (μF) $E = ½ × 12^2 × 568.75 × 10^{-6}$ $E = 4.1 × 10^{-2}$ (J)	C1 C1 C1 A1	
	c		Connect a voltmeter or data-logger or oscilloscope across the resistor (or capacitor) or an ammeter in series with the resistor. A stopwatch is started when the switch is opened and stopped when the p.d. or the current to decreases to 37% of its initial value. The time constant is the time taken for the p.d. or the current to decreases to 37% of its initial value.	B1 B1 B1	
			Total	9	
4			A	1	
			Total	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
5			A	1	
			Total	1	

Question			Answer/Indicative content	Marks	Guidance
6	a		The charge / Q on each capacitor is the same $V \propto C^{-1}$	M1 A1	 **Allow** $Q = VC$ and some explanation **Examiner's Comments** The success in this question relied on knowing that each capacitor in a series circuit stored the same charge. Failure to mention this important idea led to no marks. This question favoured the top-end candidates, who once again gave brief answers such as *'the charge is the same on each capacitor and the p.d. is twice because V ∝ 1/C'*. Some candidates attempted to answer the question in terms of sharing p.d., but without mentioning the charge being the same for each capacitor. Weaker candidates often spoilt their answers by referring to the current being the same in a series capacitor, no doubt confusing the circuit with resistors in series.
	b		(total resistance =) 27 (kΩ) or 27000 (Ω) (total capacitance =) 100 (μF) or 1.0×10^{-4} (F) (time constant =) $27 \times 10^{3} \times 100 \times 10^{-6}$ time constant = 2.7 (s)	C1 C1 A1	 **Allow** 10^{-4} (F) **Note** 2.7×10^{n} with $n \neq 0$ scores 2 marks **Examiner's Comments** The answers to this question were generally well-structured and easy to follow. Most candidates were familiar with the equations to determine the total resistance, total capacitance and time constant. Only a small number of candidates struggled with the prefixes kilo k and micro μ. The two most commons mistakes in the calculations were: • total capacitance = 400 μF • total resistance = $18 + (18^{-1} + 18^{-1}) = 18.1$ kΩ

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	c	i	(V =)1.5 × 10^{-4} × 40 × 10^{3} or 6 (V) (Q =) 6.0 × 1200 × 10^{-6}	C1	**Allow** I in the range 1.50 to 1.55 **Allow** other correct methods
		i	charge = 7.2 × 10^{-3} (C)	A1	Possible POT error **Examiner's Comments** This question proved to be both challenging and discriminating. The majority of the upper quartile candidates scored two marks for calculating the initial charge stored by the capacitor. Many of these candidates derived and used the equation 'initial charge = I_0RC' or 'initial charge = I_0 × time constant'. A significant number of candidates got nowhere by using the exponential decay equation or determining the area under the curve.
		ii	Current starts at 3.0 (× 10^{-4} A)	B1	**Allow** ± 0.05 × 10^{-} (A)
		ii	Graph showing shorter time constant	B1	**Examiner's Comments** Although the modal mark for this question was one, the discharge curves were often poorly drawn. Most candidates did figure out that the time constant of the circuit was halved, but very few realised that the initial discharge current was 3.0 × 10^{-4} A. Candidates do need to improve their graph sketching skills.
			Total	9	
7			C	1	
			Total	1	

Question			Answer/Indicative content	Marks	Guidance
8	a		The charge on each plate remains the same.	B1	**Allow** other correct methods.
			$C = \varepsilon_0 A/d$, hence the capacitance is halved.	B1	
			$E = ½\ Q^2/C$, $E \propto 1/C$ and hence energy stored doubles.	B1	
	b	i	**1** A straight line of best-fit drawn passing through all error bars.	B1	
		i	**2** $V = V_0 e^{-t/CR}$, therefore $½ = e^{-T/CR}$	M1	
		i	$\ln(0.5) = -T/CR$	M1	
		i	$T = -\ln(0.5)CR$	A0	
		i	**3** gradient = (–) $\ln(0.5)C$	C1	
		i	gradient determined using a 'large triangle' and equal to (–) 7.7×10^{-4} (s Ω^{-1})	C1	**Allow** gradient in the range 7.5 to 8.0 × 10^{-4}
		i	C = gradient/$\ln(0.5)$ = (–) $7.7 \times 10^{-4}/\ln(0.5)$ $C = 1.1 \times 10^{-3}$ (F)	A1	Possible ECF from value of gradient
		ii	Draw a worst-fit straight line through the error bars.	M1	
		ii	Correct description of how to determine the % uncertainty in *C*.	A1	**Allow**: $\frac{\text{difference between worst and best - fit gradients}}{\text{value of best gradient from } \textbf{(i)3}} \times 100$
			Total	**11**	
9			Flemings left hand rule / the force on the electron is in the plane of the paper, right angles to the velocity and 'downwards'.	B1	
			Circular path within field in a clockwise direction.	B1	**Note**: If drawn on Fig. 22.1, then judge 'circular' path by eye.
			Total	**2**	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
10	a		gradient = b and *y*-intercept = lg a	B1	
	b	i	1.70;	B1	both values for the mark
		i	0.41 ± 0.03	B1	**allow ecf** to find uncertainty value
		ii	two points plotted correctly;	B1	**ecf** value and error bar of first point
		ii	line of best fit	B1	**allow ecf** from points plotted incorrectly
	c	i	b = gradient = 1.60	B1	**allow** 1.56 to 1.64; **allow** 1.6
		i	y = 0.86 (± 0.01); × = 1.98 so *y*-intercept = 0.86 – 1.6 × 1.98 = –2.3(1)	B1	**ecf** gradient in finding y-intercept
		i	a = $10^{-2.3}$ = 0.005	B1	
		ii	worst acceptable straight line	B1	steepest or shallowest possible line that passes through the error bars; should pass from top of top error bar to bottom of bottom error bar **or** bottom of top error bar to top of bottom error bar **allow** (1.6) ± 0.1 or 0.2 where plausible working is shown
		ii	b = gradient of steepest line = 1.75 giving uncertainty ± 0.15	B1	
			Total	10	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
11	a		Time constant of charging = 10 s maximum current = 10/100k = 100 μA statements about adequate sensitivity of meter and stopwatch	B1 B1 B1 B1	**allow** alternative but equivalent statements **e.g.** current falls to 37 mA in 10 s **e.g.** readings can be taken every 3 to 5 s so can collect at least 8 sets of values before approaching change of less than 2 μA; sensitivity of 0.5 s adequate
	b	i	1 the (total stored) charge is constant	B1	**max** 2 out of 3 marking points
		i	2 capacitors in parallel must come to the same voltage	B1	**allow** mathematical argument, e.g. initial Q = 1 mC final Q on each is 0.5 mC as identical Cs in parallel
		i	3 capacitors are identical so each stores half/same charge so final V is 5 V	A0	so $V = 0.5 \times 10^{-3} \times 1.0 \times 10^{-4} = 5.0$ V **or** total C × total Q gives 5 V
		ii	C_1 curve : exponential decay curve from 10 V to 5 V	B1	
		ii	C_2 curve: 10 – C_1 curve	B1	
		ii	time axis: curves to be horizontal at 5V about 25 s	B1	time constant of 5 s
			Total	9	
12			A	1	
			Total	1	
13			D	1	
			Total	1	
14			D	1	
			Total	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
15	a		$\varepsilon = 7.2 \times 10^{-12} \times 1.2 \times 10^{-3}/4.0 \times 10^{-4}$ permittivity = 2.2×10^{-11} (F m^{-1})	C1 A1	**Allow** any subject **Allow** ε_o instead of ε **Note** answer to 3 sf is 2.16×10^{-11} (F m^{-1}) **Allow** 1 mark for bald 2.4; relative permittivity calculated **Examiner's Comment** Most candidates effortlessly used the equation $C = \varepsilon A / d$ to determine the permittivity *s* of the insulator between the capacitor plates. Once again, most answers were well-structured and showed good calculator skills. The most common errors were: • Taking the prefix pico (p) to be a factor of 10^{-9}. • Confusing permittivity ε and permittivity of free space ε_0. • Calculating relative permittivity (2.4).
	b	i	capacitance of two capacitors in series = 500 (πF) *C* = 1000 + 500 *C* = 1500 (μF)	C1 A1	**Examiner's Comment** The modal score here was two marks, with most scripts showing excellent understanding of capacitors in combination. Many candidates arrived at the final answer of 1500 μF without much calculation. A small number incorrect swapped the equations for series and parallel combinations and arrived at the incorrect answer of 670 μF.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		ii	$V = 1.5 \times e^{-12/15}$ V = 0.67 (V)	C1 A1	Possible ecf from **(i)** **Allow** 1 mark for 0.83 V, $V = 1.5[1 - e^{-12/15}]$ used **Examiner's Comment** Many candidates correctly calculated the time constant of the circuit and then either determined the p.d. across the capacitors (0.83 V) or the resistor (0.67 V) - the latter being the correct answer. The most common mistake was calculating e^{-12115} rather than $1.5 \times e^{-12/15}$. Weaker candidates got nowhere by attempting to use $V = IR$ and $Q = VC$.
			Total	6	

Question			Answer/Indicative content	Marks	Guidance
16	a		Take ln to give ln$V = -(t / C).1/R + \ln V_0$ gradient (m) = (–) t / C where $t = 15$	M1 A1	**allow** ln $(V / V_0) = -(t / C).1/R$ **Examiner's Comments** The whole question produced a full range of marks and discriminated well. About 70% gained more than half marks. In (a) here was some confusion about V_0. Many candidates correctly stated that ln(V / V_0) = $-t / RC$ but some looked again at the question and wrote ln(V / V) instead not realising that V here related to the unit volt. A smaller number correctly stated the expanded form ln $V = -t / RC + \ln V_0$.
	b	i	1.10 ± 0.07	B1	value plus uncertainty required for the mark
		ii	two points plotted correctly to within ½ small square on x-axis; line of best fit	B1 B1	**ignore** accuracy of length of error bar; **ecf bi** value **or both** worst acceptable lines drawn

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		iii	gradient (= 15/C) = 6.6 (× 10^4); C = 15 / 6.6 × 10^4 = 2.3 × 10^{-4} (F) worst acceptable straight line drawn (C) ± 0.3 × 10^{-4} F	C1 A1 B1 B1	**accept** 6.4 to 6.8 **ignore** power of 10 **accept** 2.3 ± 0.1 × 10^{-4} **allow ecf** for the point calculated incorrectly in **b(ii);** steepest or shallowest possible line that passes through all the error bars; should pass from top of top error bar to bottom of bottom error bar **or** bottom of top error bar to top of bottom error bar **allow** e.g. (C) ± 0.2 × 10^{-4}; **allow** value of C to 4 SF **but N.B.** the uncertainty and the value of C **must be** to the same number of decimal places **allow** 230 ± 30 μF etc **allow** equivalent unit including s Ω^{-1}, C V^{-1}, A s V^{-1} **Examiner's Comments** Candidates were given several opportunities to score marks by plotting points, drawing the best and worst lines on a graph and then extracting data from the graph. Many failed to draw the worst straight line losing themselves two possible marks. Many forgot the power of 10^{-6} in the unit on the x-axis. The normal requirement that the final value for the capacitance *C* should to be given to 2 significant figures (SF) and the absolute uncertainty to 1 SF (e.g. 230 ± 0.20 μF) was waived. However the absolute uncertainty had to be stated to the same number of decimal places as the calculated value of *C* to gain the mark.
	c		ln(0.1) = –15/RC **or** R = –15/C ln(0.1) **or** R = 0.65/C R = 0.65/2.3 × 10^{-4} giving R = 28 kΩ	C1 A1	ln(0.1) = –2.30 **ecf (b)(iii)** **Examiner's Comments** About half of the candidates gained full marks here. Some confused 10% and 90% and about a tenth of the candidates did not attempt an answer.
			Total	11	

<table>
<tr><th colspan="3">Question</th><th>Answer/Indicative content</th><th>Marks</th><th>Guidance</th></tr>
<tr><td>17</td><td></td><td></td><td>D</td><td>1</td><td>

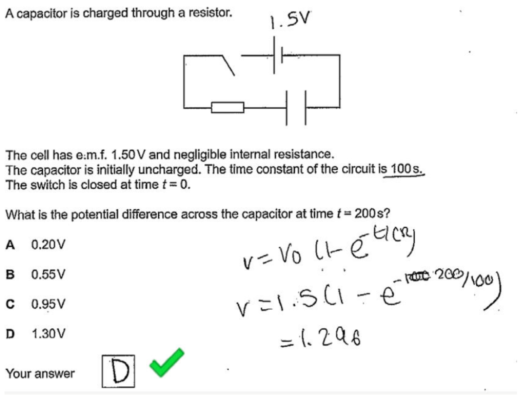
<u>Examiner’s Comments</u>

This question provided good discrimination with most to-end candidates scoring 1 mark for the correct answer **D**. Extracting all the information was the prerequisite for success. The potential difference across the capacitor is required. This could either be done by calculating the potential difference across the resistor (0.20 V), and then subtracting this from the e.m.f. of 1.50 V, or in one step using the equation

$$V = V_0(1 - e_{-t/CR}).$$

It is worth pointing out the answer 0.20 V proved to be the most popular distractor for low-scoring candidates.

Exemplar 2


A capacitor is charged through a resistor.

The cell has e.m.f. 1.50 V and negligible internal resistance.
The capacitor is initially uncharged. The time constant of the circuit is 100 s.
The switch is closed at time t = 0.

What is the potential difference across the capacitor at time t = 200 s?

A 0.20 V
B 0.55 V
C 0.95 V
D 1.30 V

Your answer D

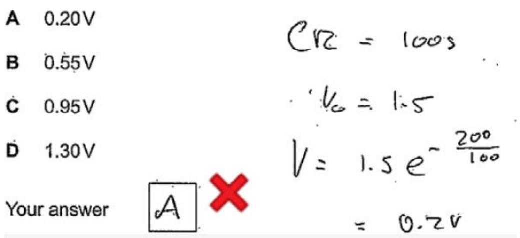
This exemplar illustrates the effortless strategy adopted by this A-grade candidate.

The circuit diagram has been annotated with the e.m.f. of 1.50 V, and the time constant *CR* of 100 s has been underlined. The correct equation has been used to get 1.30 V.

Compare and contrast this answer with the exemplar 3 below from a C-grade candidate.

</td></tr>
</table>

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
					Exemplar 3  A 0.20 V B 0.55 V C 0.95 V D 1.30 V Your answer A $CR = 100s$ $V_0 = 1.5$ $V = 1.5e^{-\frac{200}{100}}$ $= 0.2V$ The answer calculated here of 0.2 V, is the potential difference across the resistor and not the capacitor. This candidate was one step away from getting the correct answer – this value just had to be subtracted from the e.m.f. of 1.50 V. Deciphering the question is vital, as is the analysis that follows.
			Total	1	

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18	a		($V = V_0e^{-t / CR}$) $\ln(V / V_0) = - t / CR$ **or** $\ln V = \ln V_0 - t / CR$	B1	
			$\ln V = \ln V_0 - t / CR$ **and** $y = mx + c$ / gradient = - 1/CR	B1	**Note** the minus sign is necessary <u>Examiner's Comments</u> This question was successfully tackled by the high-scoring candidates, many of whom effortlessly derived the correct expression $\ln V = \ln V_0 - t/CR$ and demonstrated clearly how the equation of a straight line made the gradient equal to $-1/CR$.  The most common errors made by candidates were: • Using the wrong expression $V = V_0(1 - e^{-t/CR})$ • Writing the equation as $\ln(V/V_0) = -t/CR$ and comparing this with $y = mx$, with $y = \ln(V/V_0)$ and $x = t$. • Calculating the gradient of the line to be about -85; which proved to be helpful in the LoR question **22(b)**.

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Question			Answer/Indicative content	Marks	Guidance
	b		**Level 3 (5–6 marks)** Clear description **and** correct value of *C* *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3–4 marks)** Clear description **and** some correct working **OR** Some description **and** correct value for *C* *There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.* **Level 1 (1–2 marks)** Some description **OR** Some working *There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.* **0 marks** No response or no response worthy of credit	B1 × 6	**Indicative scientific points may include:** **Description** • $C = \varepsilon A/d$ • *A* = area (of overlap) and *d* = separation. • Use ruler to measure the side / radius / diameter (andhence the area *A*) • Ensure total overlap of plates. • Measure the thickness / *d* of paper using micrometer /(vernier) caliper. • Take several readings of thickness and determine anaverage value for *d* **Calculation of capacitance** • gradient ≈ 85 • $C \approx 1.2 \times 10^{-8}$ (F) <u>Examiner's Comments</u> This was the second of the two LoR questions in this paper. It required application of practical skills from module 1.1 (Development of practical skills), knowledge of parallel plate capacitor and permittivity. As with the other LoR question 17, examiners expect varied responses for the criteria for the three levels to be met. Unlike some of the analytical questions, there is no one perfect model answer for a specific question. For Level 3, correct value of the capacitance *C* was required together with a clear description of how to do the additional measurements that led to the determination of the permittivity of the paper. For Level 2, it was either clear description with some correct working or some description with the correct value for *C*. Level 1 required some description or some working. As expected, there were diverse answers which demonstrated adequate experimental and practical skills. The

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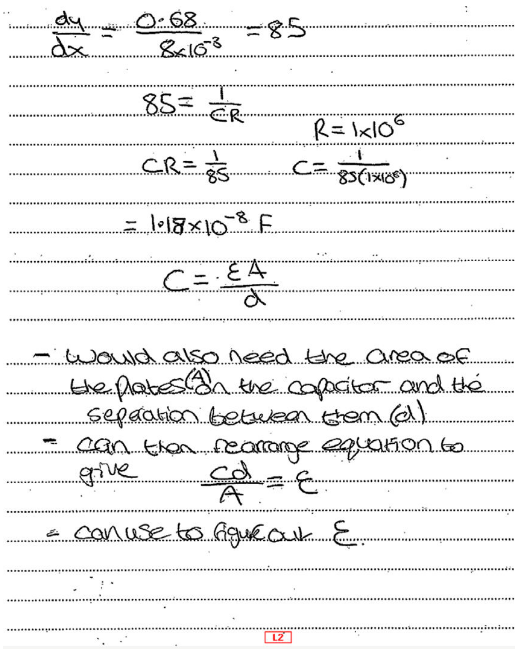
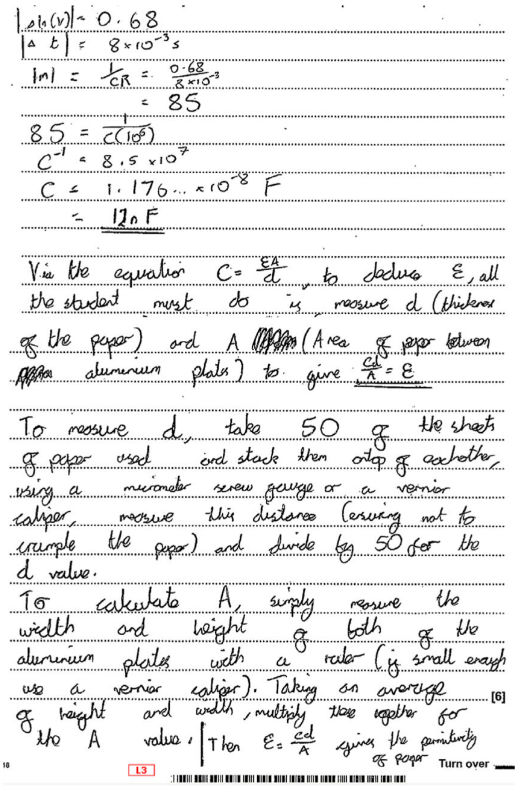
					thickness of the paper was invariably measured using a micrometer, but some candidates decided to measure the total thickness of a large number of sheets using a ruler and then calculating the thickness of each sheet. This technique was as good as using a micrometer or using Vernier calipers. Diverse answers are the characteristic of LoR questions.  The most common errors made were: • Confusing permittivity with either relative permittivity or the permittivity of free space ε_0. • Using $C = 4\pi\varepsilon R$ instead of $C = {}_{\varepsilon}A/d$. • Issues with powers of ten when determining the gradient – mainly because of the milli prefix on the time axis. Exemplar 10 

Question			Answer/Indicative content	Marks	Guidance
					This exemplar illustrates a Level 2 performance from this top-end candidate. The analysis is perfect, but the description is basic and there are no details of the instruments needed to make the measurement. It would have taken a couple more lines to elevate this answer to Level 3. Compare and contrast this with the exemplar below for a Level 3 response. **Exemplar 11**  $\lvert \Delta \ln(V) \rvert = 0.68$ $\lvert \Delta t \rvert = 8 \times 10^{-3}$ s $\lvert m \rvert = \frac{1}{CR} = \frac{0.68}{8 \times 10^{-3}}$ $= 85$ $85 = \frac{1}{C(10^6)}$ $C^{-1} = 8.5 \times 10^7$ $C = 1.176... \times 10^{-8}$ F $\approx$ 12 nF Via the equation $C = \frac{\varepsilon A}{d}$, to deduce ε, all the student must do is measure d (thickness of the paper) and A (Area of paper between aluminium plates) to give $\frac{Cd}{A} = \varepsilon$ To measure d, take 50 of the sheets of paper used and stack them atop of eachother, using a micrometer screw gauge or a vernier caliper, measure this distance (ensuring not to crumple the paper) and divide by 50 for the d value. To calculate A, simply measure the width and height of both of the aluminium plates with a ruler (if small enough use a vernier caliper). Taking an average of height and width, multiply these together for the A value. Then $\varepsilon = \frac{cd}{A}$ gives the permittivity of paper [6] L3 This above is a typical Level 3 answer. Correct calculation and a description that has all the right ingredients. Notice how the appropriate measuring instruments are being used and how the uncertainty in the measurements is reduced.
			Total	8	

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19		i	Q = 9.0 x 10-3 x 2 x 80 = 1.44 (C) $W = (Q^2/2C =) 1.44^2/2 \times 0.12$ W = 8.6(4) (J)	C1 C1 A1	**ECF** for incorrect Q e.g. 2/3 for use of Q = 0.72(C) giving W = 2.2(J) Examiner's Comments The strongest answers were those where candidates set out their response in steps; first calculating the total charge and then using a correct formula to calculate the total energy stored. Many candidates performed the steps of their calculation randomly across the answer space, making it hard to determine their method.
		ii	($W = Pt$ so 8.6 = 0.050t) t = 8.6/0.050 = 170 (s)	A1	**ECF (b)(i)** for incorrect W Examiner's Comments Almost all candidates gained the mark for 3(b)(ii), as any incorrect answer to 3(b)(i) was accepted with error carried forward (ECF).
			Total	4	
20			A	1	Examiner's Comments All the key equations for capacitor-resistor circuits are in the Data, Formulae and Relationship Booklet. As the capacitor charges, the potential difference V across the resistor will fall exponentially with respect to time. The time constant of the circuit CR is 10 s. Therefore, according to the equation $V = V_0e^{-t/CR}$, the correct expression after substitution will be $0.60 = 1.50e^{-0.10t}$. The correct answer is **A**. Just on the knowledge of time constant, neither **C** nor **D** can be the correct answers because of the '10' in the expression. The choice then is between **A** and **B**; as demonstrated above, **A** is the answer. All the distractors were equally popular.
			Total	1	

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Question			Answer/Indicative content	Marks	Guidance
21			B	1	
			Total	1	

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Question			Answer/Indicative content	Marks	Guidance
22		i	*Qd* = constant	C1	**Allow** straight-line graph of *Q* against 1/*d* passes through the origin **Allow** as *d* increases by a given factor (e.g. doubles) then *Q* decreases by the same factor (e.g. halves)
			At least **two** pairs of values substituted to show that *Qd* = constant	A1	**Allow** numbers that show when *d* doubles then *Q* halves **Ignore** prefixes and POT errors <u>Examiner's Comments</u> The question was not carefully examined by most candidates, because the reference to use **Fig. 22.2** was totally ignored. A significant number of candidates focused either on superfluous practical details or the proof of the relationship between *Q* and *d* – which was required in the next question. About a third of the candidates used at least two points on the graph to show that *Qd* = constant. The powers of ten were overlooked by examiners. A small number of candidates, mainly at the lower-end, calculated the gradient of the curve at arbitrary points to provide support for their incorrect reasoning.
		ii	$Q = VC$ and $C = \frac{\varepsilon_0 A}{d}$	C1	**Allow** ε
			Hence $Q = \frac{V\varepsilon_0 A}{d}$ (and $Q \propto \frac{1}{d}$)	A1	**Note** *Q*, or *Q/V* must be the subject here **Allow** $Q \propto C$ and $C \propto \frac{1}{d}$ <u>Examiner's Comments</u> Most candidates successfully, and elegantly, provided the proof for the relationship. Correct answers ranged from the whole space filled with algebra to a couple of succinct lines. A small number of candidates finished off their working by writing $Q = \frac{1}{d}$ instead $Q \propto \frac{1}{d}$ the 'equal' and the 'proportionality' symbols are not equivalent.
			Total	4	

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Question			Answer/Indicative content	Marks	Guidance
23			D	1	
			Total	1	
24			B	1	
			Total	1	

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Question			Answer/Indicative content	Marks	Guidance
25	a		(initial charge) $Q = EC_0$ **or** (Q conserved so final) $Q = V(C + C_0)$ (as capacitors are in parallel) so $EC_0 = V(C + C_0)$ (and hence $V = C_0 E / (C + C_0)$)	M1 A1	At least one correct expression for Q for first mark The two correct expressions equated for the second mark Examiner's Comments Some candidates obtained $Q = EC_0$ by applying the definition of capacitance at A, but then did not realise that charge would be conserved on switching from A to B. Some chose the wrong formula for capacitors in parallel or attempted to use the potential divider equation.
	b	i	$1/V = 1/E + C/EC_0$ (and compare to $y = c + mx$)	B1	Mark is for rearrangement into linear equation Examiner's Comments Some candidates correctly took the reciprocal of both sides of the given equation but were then unable to show a rearrangement into the standard linear form. A common difficulty was an inability to expand the bracket in $\frac{1}{E} \times \frac{(C + C_0)}{C_0}$ to give $\frac{C}{EC_0} + \frac{C_0}{EC_0}$

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		ii	$1/EC_0 = 51 = 1/(9.1\ C_0)$ giving $C_0 = 1/(51 \times 9.1)$ F $C_0 = 2.2$ (mF)	B1 B1	$C_0 = 2.1547 \times 10^{-3}$ F Answer must be correct, rounded correctly and given in mF Candidate's answer must be given to 2 SF <u>Examiner's Comments</u> Some candidates gave their response to 2 d.p. instead of to 2 s.f. as required.

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		iii	(at least) one correct worst fit line drawn gradient calculated correctly using a large triangle uncertainty = C_0 – 1/(wfl gradient x 9.1) uncertainty given is to the same number of decimal places as C_0	B1 B1 B1 B1	Top and bottom points chosen must be from opposite extremes of uncertainty limits, accurate to within half a small square $\Delta x \geq 1.5 \times 10^{-3}$; **expect** 59±1 or 44±1 (**or** 0.059 **or** 0.044); **allow ECF** from poorly drawn line; readings must be accurate to within half a small square **ECF** from **b(ii)**; **expect** uncertainty of up to 0.4(mF) **ECF** from **b(ii)** **If** no value for C_0 given in b(ii), **allow** any answer given to 1dp Examiner's Comments Most candidates gained the mark for using a large triangle (spanning more than 1.5 on the x–axis) to determine the gradient of the worst-fit line. Lower ability candidates were unable to gain credit for finding the gradient of their line because they read the scales on the axes incorrectly. Candidates should take a ruler into the examination and be careful about the positioning of the ruler for drawing a worst-fit straight line. A worst-fit line should join opposite extremes of uncertainty limits and pass between all the uncertainty limits. The Practical Skills Handbook is helpful on this topic. Several candidates performed the unnecessary step of calculating the fractional (or percentage) uncertainty instead of using $\Delta C_0 = \pm \lvert C_{0\ best} - C_{0\ worst} \rvert$ directly.
	c		Only effect is to slow the charging and / or discharging (of capacitor(s)) and so the final charges are unchanged / the values for *V* are unchanged / the graph is unchanged / the gradient is unchanged / there is no effect on the experiment (results)	B1	**Allow** and so the experiment takes longer
			Total	10	