

1

The figure below shows a capacitor of capacitance 370 pF. It consists of two parallel metal plates of area 250 cm². A sheet of polythene that has a relative permittivity 2.3 completely fills the gap between the plates.



not to scale

- (a) Calculate the thickness of the polythene sheet.

thickness = _____ m

(2)

- (b) The capacitor is charged so that there is a potential difference of 35 V between the plates. The charge on the capacitor is then 13 nC and the energy stored is 0.23 μJ.

The supply is now disconnected and the polythene sheet is pulled out from between the plates without discharging or altering the separation of the plates.

Show that the potential difference between the plates increases to about 80 V.

(2)

- (c) Calculate the energy that is now stored by the capacitor.

energy stored = _____ μJ

(2)

- (d) Explain why there is an increase in the energy stored by the capacitor when the polythene sheet is pulled out from between the plates.

(2)

(Total 8 marks)

2

Which of the following statements about a parallel plate capacitor is **incorrect**?

- A** The capacitance of the capacitor is the amount of charge stored by the capacitor when the pd across the plates is 1 V. ☐
- B** A uniform electric field exists between the plates of the capacitor. ☐
- C** The charge stored on the capacitor is inversely proportional to the pd across the plates. ☐
- D** The energy stored when the capacitor is fully charged is proportional to the square of the pd across the plates. ☐

(Total 1 mark)

3

A variable capacitor has a capacitance which can be varied from 6.0×10^{-12} F to 3.0×10^{-12} F. The capacitor is set to its maximum capacitance and fully charged using a 48 V supply. The capacitor is then disconnected from the supply and isolated. Finally the capacitance is reduced to its minimum value without any charge being lost by the capacitor.

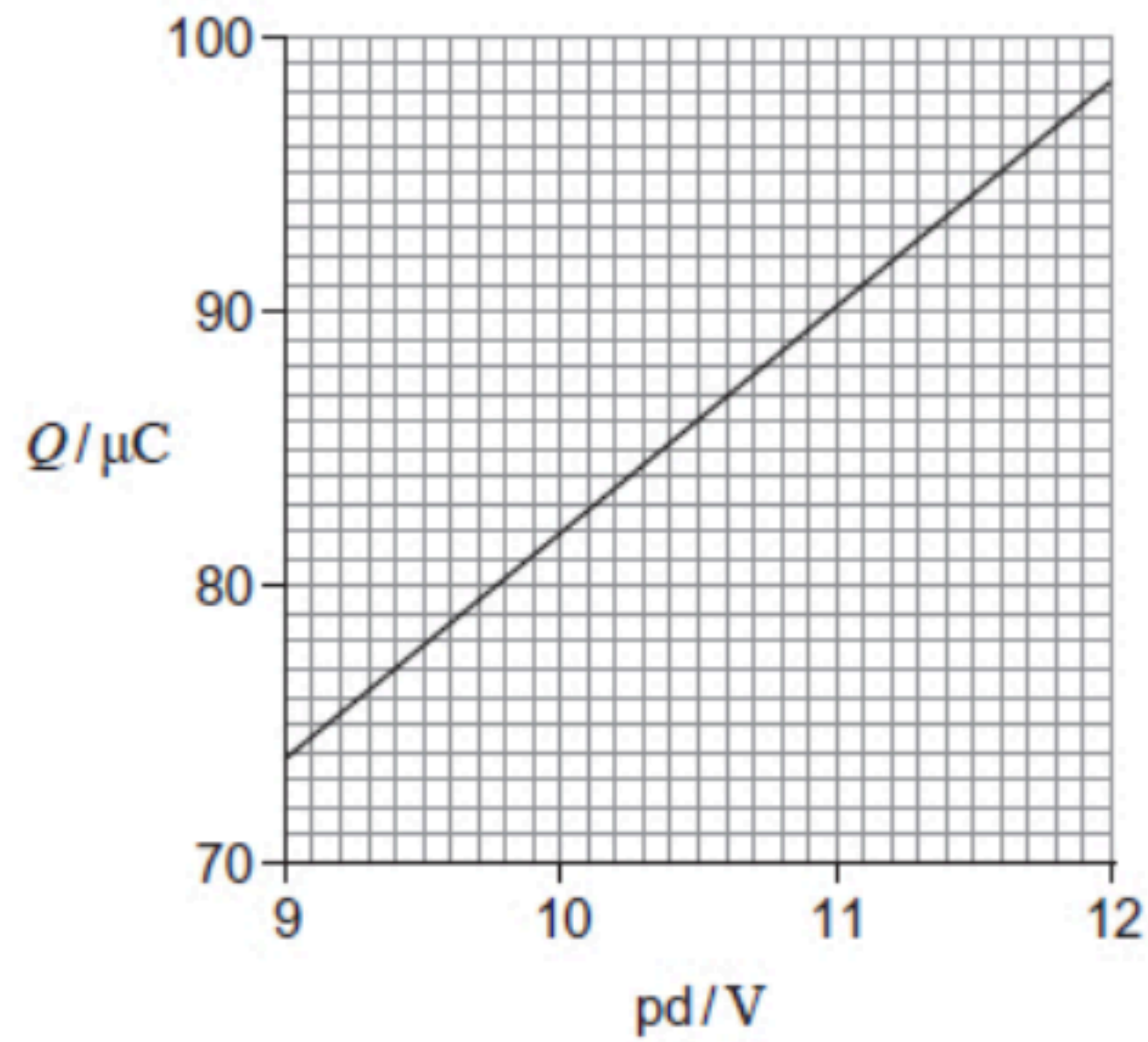
Which line, **A** to **D**, in the table correctly shows the potential difference (pd) across the capacitor and the charge it stores after the capacitance has been reduced?

	pd / V	Charge / C
A	48	2.9×10^{-10}
B	24	2.9×10^{-10}
C	96	2.9×10^{-10}
D	96	1.4×10^{-10}

(Total 1 mark)

4

The graph shows how the charge Q stored by a capacitor varies with the potential difference (pd) V across it as V is increased from 9.0 V to 12.0 V.



- (a) (i) Use the graph to determine an accurate value for the capacitance of the capacitor.

capacitance = _____ μF

(2)

- (ii) Calculate the additional energy stored by the capacitor when V is increased from 9.0 V to 12.0 V.

additional energy = _____ J

(3)

- (b) When a $470\ \mu\text{F}$ capacitor is discharged through a fixed resistor R , the pd across it decreases by 80% in 45 s.

- (i) Calculate the time constant of the capacitor–resistor circuit.

time constant = _____ s

(3)

- (ii) Determine the resistance of R .

resistance = _____ Ω

(2)

- (iii) At which point during the discharging process is the capacitor losing charge at the smallest rate? Tick (✓) the correct answer.

	✓ if correct
when the charge on the capacitor is greatest	
when energy is dissipated at the greatest rate	
when the current in the resistor is greatest	
when the pd across R is least	

(1)

(Total 11 marks)

5

An uncharged 4.7 nF capacitor is connected to a 1.5 V supply and becomes fully charged.

How many electrons are transferred to the negative plate of the capacitor during this charging process?

A 2.2×10^{10}

B 3.3×10^{10}

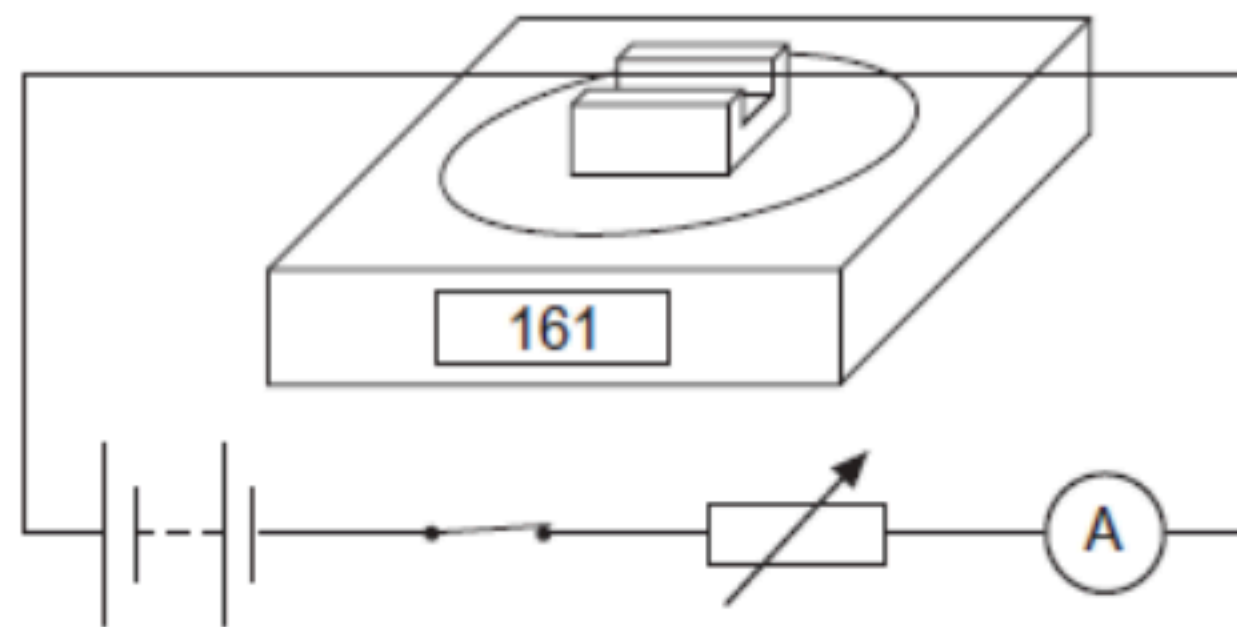
C 4.4×10^{10}

D 8.8×10^{10}

(Total 1 mark)

6

The diagram shows a rigidly-clamped straight horizontal current-carrying wire held mid-way between the poles of a magnet on a top-pan balance. The wire is perpendicular to the magnetic field direction.



The balance, which was zeroed before the switch was closed, read 161 g after the switch was closed. When the current is reversed and doubled, what would be the new reading on the balance?

A -322 g

B -161 g

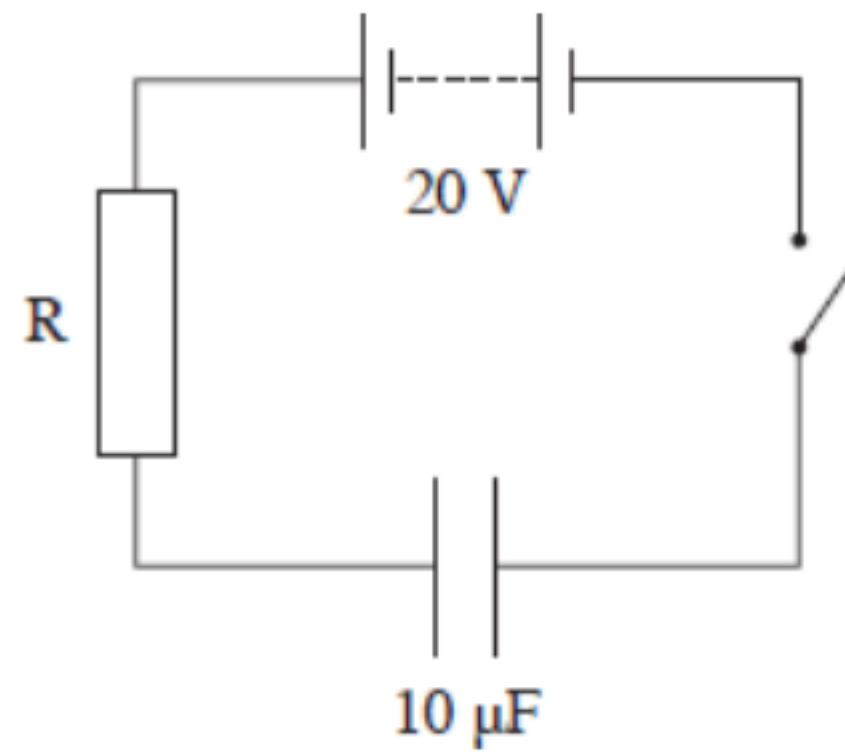
C zero

D 322 g

(Total 1 mark)

7

A capacitor of capacitance $10\ \mu\text{F}$ is charged through a resistor R to a potential difference (pd) of $20\ \text{V}$ using the circuit shown.



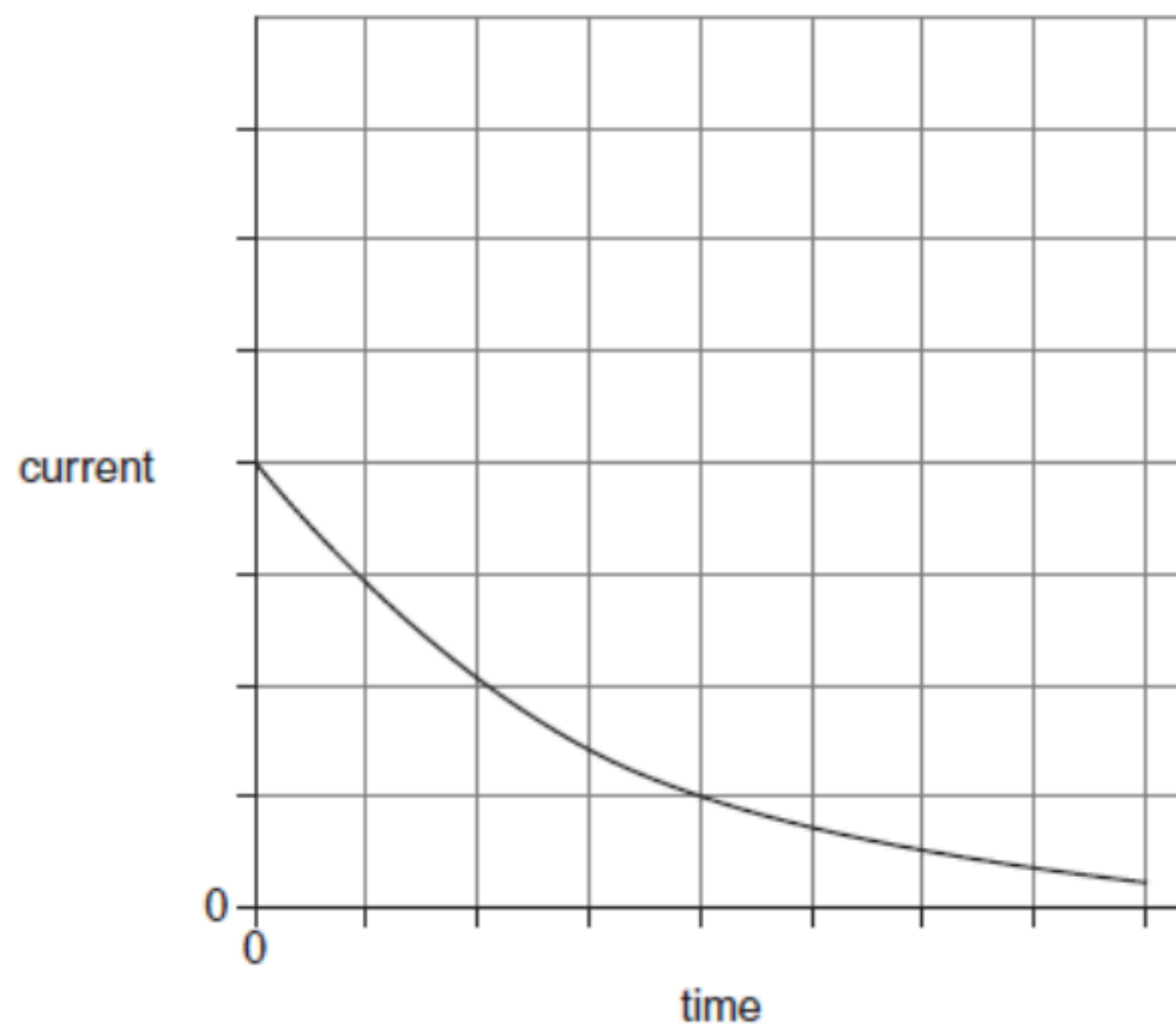
When the capacitor is fully charged which one of the following statements is **incorrect**?

- A** The energy stored by the capacitor is $2\ \text{mJ}$.
- B** The total energy taken from the battery during the charging process is $2\ \text{mJ}$.
- C** The pd across the capacitor is $20\ \text{V}$.
- D** The pd across the resistor is $0\ \text{V}$.

(Total 1 mark)

8

- (a) The graph shows how the current varies with time as a capacitor is discharged through a $150\ \Omega$ resistor.



- (i) Explain how the initial charge on the capacitor could be determined from a graph of current against time.

(1)

- (ii) The same capacitor is charged to the same initial potential difference (pd) and then discharged through a $300\text{ k}\Omega$ resistor. Sketch a second graph on the same axes above to show how the current varies with time in this case.

(3)

- (b) In an experiment to show that a capacitor stores energy, a student charges a capacitor from a battery and then discharges it through a small electric motor. The motor is used to lift a mass vertically.

- (i) The capacitance of the capacitor is 0.12 F and it is charged to a pd of 9.0 V .
The weight of the mass raised is 3.5 N .
Calculate the maximum height to which the mass could be raised.
Give your answer to an appropriate number of significant figures.

maximum height _____ m

(4)

- (ii) Give **two** reasons why the value you have calculated in part (i) would not be achieved in practice.

1. _____

2. _____

(2)

(Total 10 marks)

9

- (a) When an uncharged capacitor is charged by a **constant** current of $4.5 \mu\text{A}$ for 60 s the pd across it becomes 4.4 V.

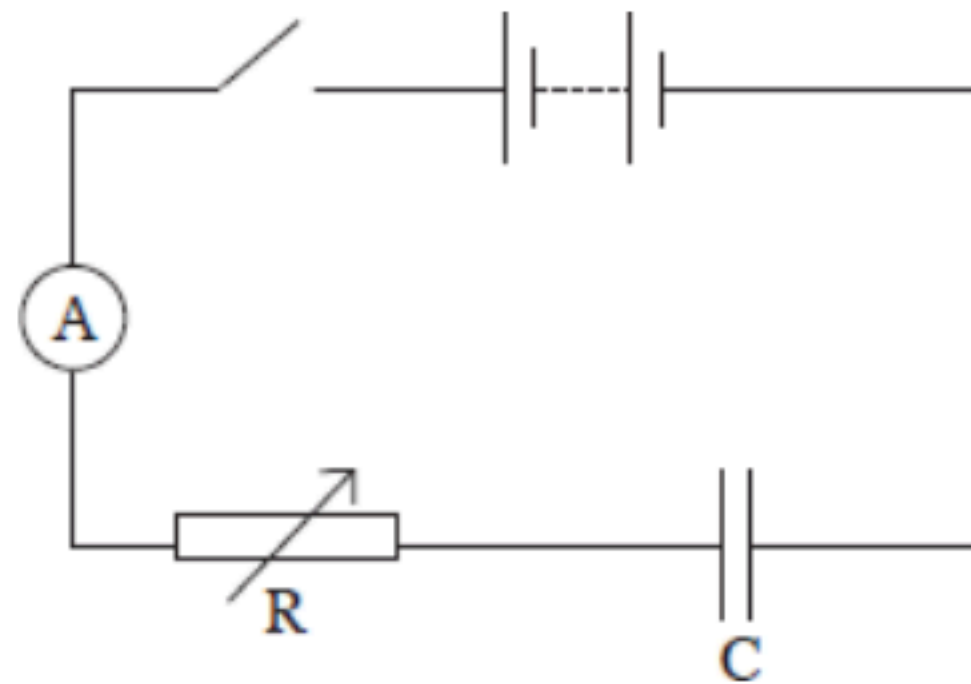
- (i) Calculate the capacitance of the capacitor.

capacitance _____ F

(3)

- (ii) The capacitor is charged using the circuit shown in **Figure 1**. The battery emf is 6.0 V and its internal resistance is negligible. In order to keep the current constant at $4.5\ \mu\text{A}$, the resistance of the variable resistor R is decreased steadily as the charge on the capacitor increases.

Figure 1



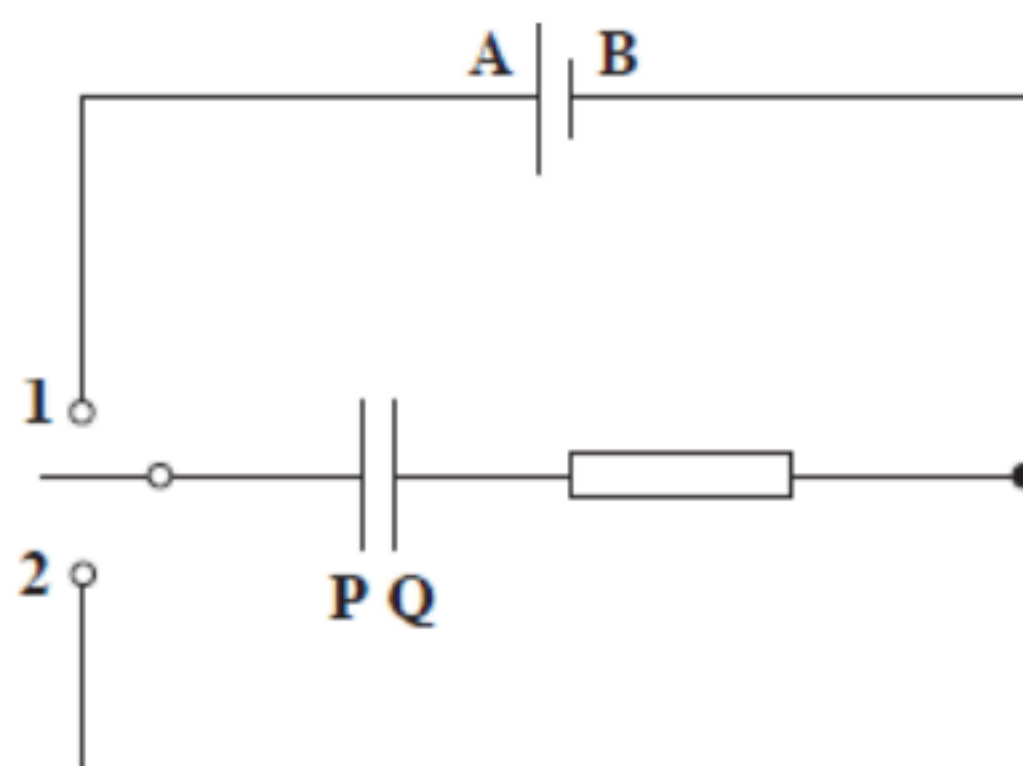
Calculate the resistance of R when the uncharged capacitor has been charging for 30 s.

resistance _____ Ω

(3)

- (b) The circuit in **Figure 2** contains a cell, an uncharged capacitor, a fixed resistor and a two-way switch.

Figure 2



The switch is moved to position **1** until the capacitor is fully charged. The switch is then moved to position **2**.

Describe what happens in this circuit after the switch is moved to position **1**, and after it has been moved to position **2**. In your answer you should refer to:

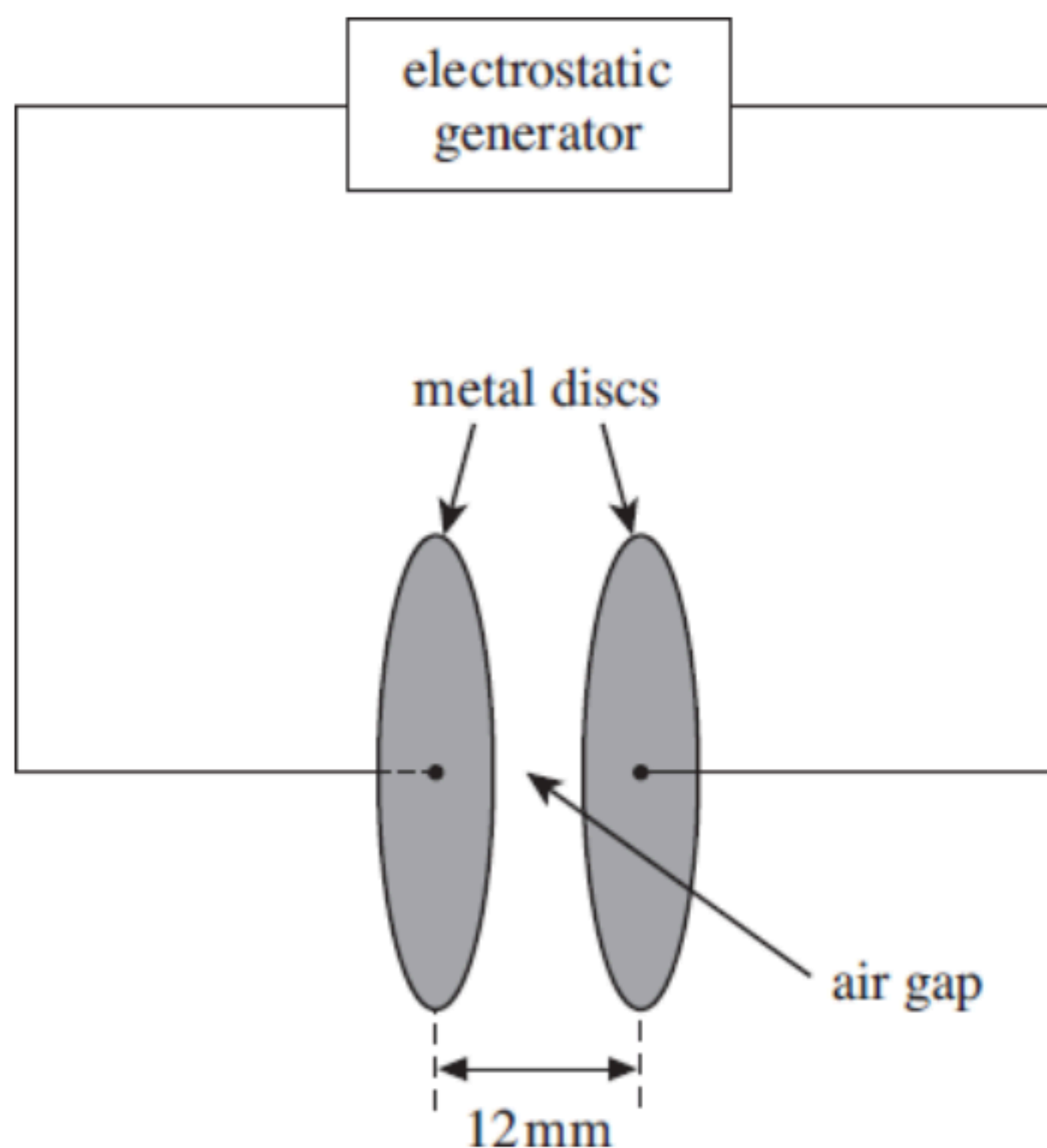
- the direction in which electrons flow in the circuit, and how the flow of electrons changes with time,
- how the potential differences across the resistor and the capacitor change with time,
- the energy changes which take place in the circuit.

The terminals of the cell are labelled **A** and **B** and the capacitor plates are labelled **P** and **Q** so that you can refer to them in your answer.

The quality of your written communication will be assessed in your answer.

10

The diagram below shows an arrangement to demonstrate sparks passing across an air gap between two parallel metal discs. Sparks occur when the electric field in the gap becomes large enough to equal the breakdown field strength of the air. The discs form a capacitor, which is charged at a constant rate by an electrostatic generator until the potential difference (pd) across the discs is large enough for a spark to pass. Sparks are then produced at regular time intervals whilst the generator is switched on.



- (a) The electrostatic generator charges the discs at a constant rate of $3.2 \times 10^{-8} \text{ A}$ on a day when the minimum breakdown field strength of the air is $2.5 \times 10^6 \text{ V m}^{-1}$. The discs have a capacitance of $3.7 \times 10^{-12} \text{ F}$.
- (i) The air gap is 12 mm wide. Calculate the minimum pd required across the discs for a spark to occur. Assume that the electric field in the air gap is uniform.

pd _____ V

(1)

- (ii) Calculate the time taken, from when the electrostatic generator is first switched on, for the pd across the discs to reach the value calculated in part (a)(i).

time _____ s

(2)

- (b) The discs are replaced by ones of larger area placed at the same separation, to give a larger capacitance.

State and explain what effect this increased capacitance will have on:

- (i) the time between consecutive discharges,

(2)

- (ii) the brightness of each spark.

(2)

(Total 7 marks)

11

Which one of the following statements about a parallel plate capacitor is **incorrect**?

- A** The capacitance of the capacitor is the amount of charge stored by the capacitor when the pd across the plates is 1V.
- B** A uniform electric field exists between the plates of the capacitor.
- C** The charge stored on the capacitor is inversely proportional to the pd across the plates.
- D** The energy stored when the capacitor is fully charged is proportional to the square of the pd across the plates.

(Total 1 mark)

12

A 1000 μF capacitor and a 10 μF capacitor are charged so that they store the same energy. The pd across the 1000 μF capacitor is V_1 and the pd across the other capacitor is V_2 .

What is the value of the ratio $\left(\frac{V_1}{V_2}\right)^2$?

- A** $\frac{1}{1000}$
- B** $\frac{1}{100}$
- C** $\frac{1}{10}$
- D** 10

(Total 1 mark)

13

A capacitor stores a charge of 600 μC when charged to a potential difference (pd) of 6.0 V. What will be the pd across the plates if the charge stored increases by 50%?

- A** 3.0 V
- B** 4.5 V
- C** 9.0 V
- D** 12.0 V

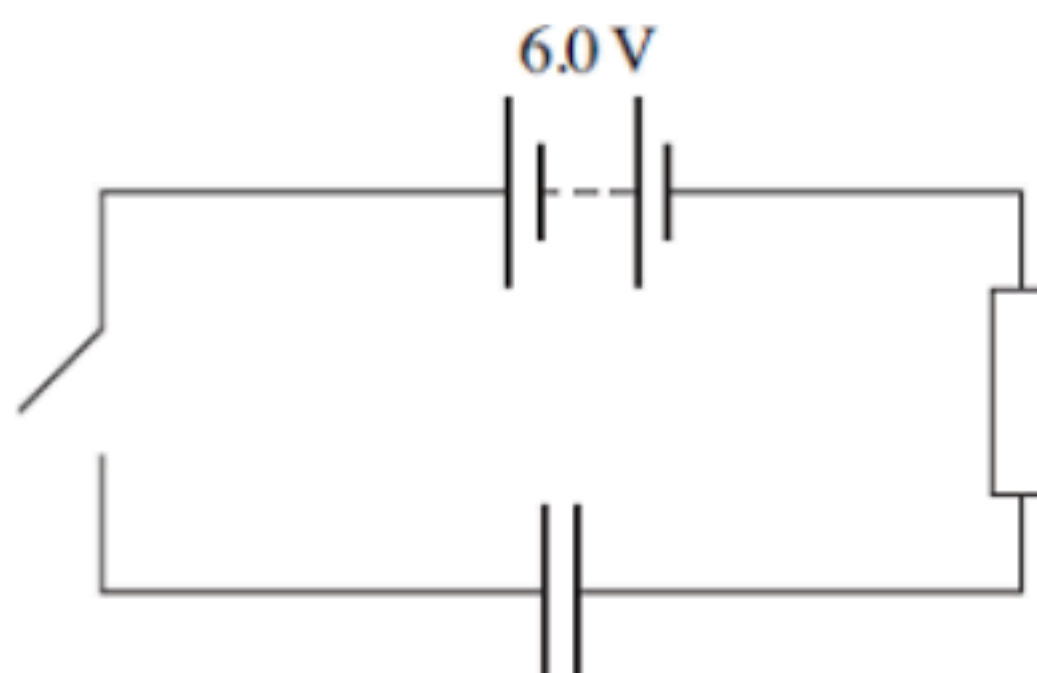
(Total 1 mark)

14

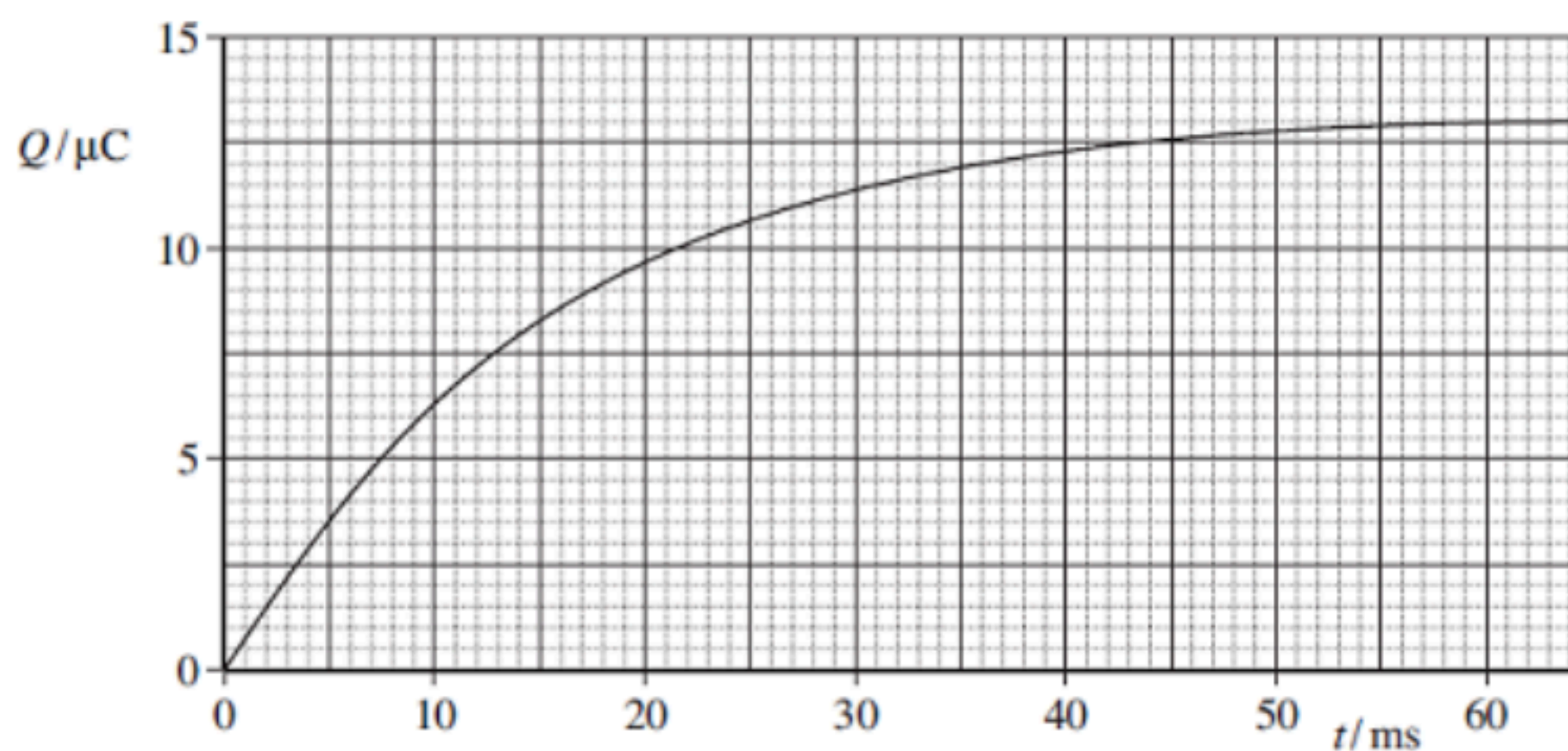
- (a) Define the capacitance of a capacitor.

(2)

- (b) The circuit shown in the figure below contains a battery, a resistor, a capacitor and a switch.



The switch in the circuit is closed at time $t = 0$. The graph shows how the charge Q stored by the capacitor varies with t .



- (b) (i) When the capacitor is fully charged, the charge stored is $13.2 \mu\text{C}$. The electromotive force (emf) of the battery is 6.0 V . Determine the capacitance of the capacitor.

answer = _____ F

(2)

- (ii) The time constant for this circuit is the time taken for the charge stored to increase from 0 to 63% of its final value. Use the graph to find the time constant in milliseconds.

answer = _____ ms

(2)

- (iii) Hence calculate the resistance of the resistor.

answer = _____ Ω

(1)

- (iv) What physical quantity is represented by the gradient of the graph?

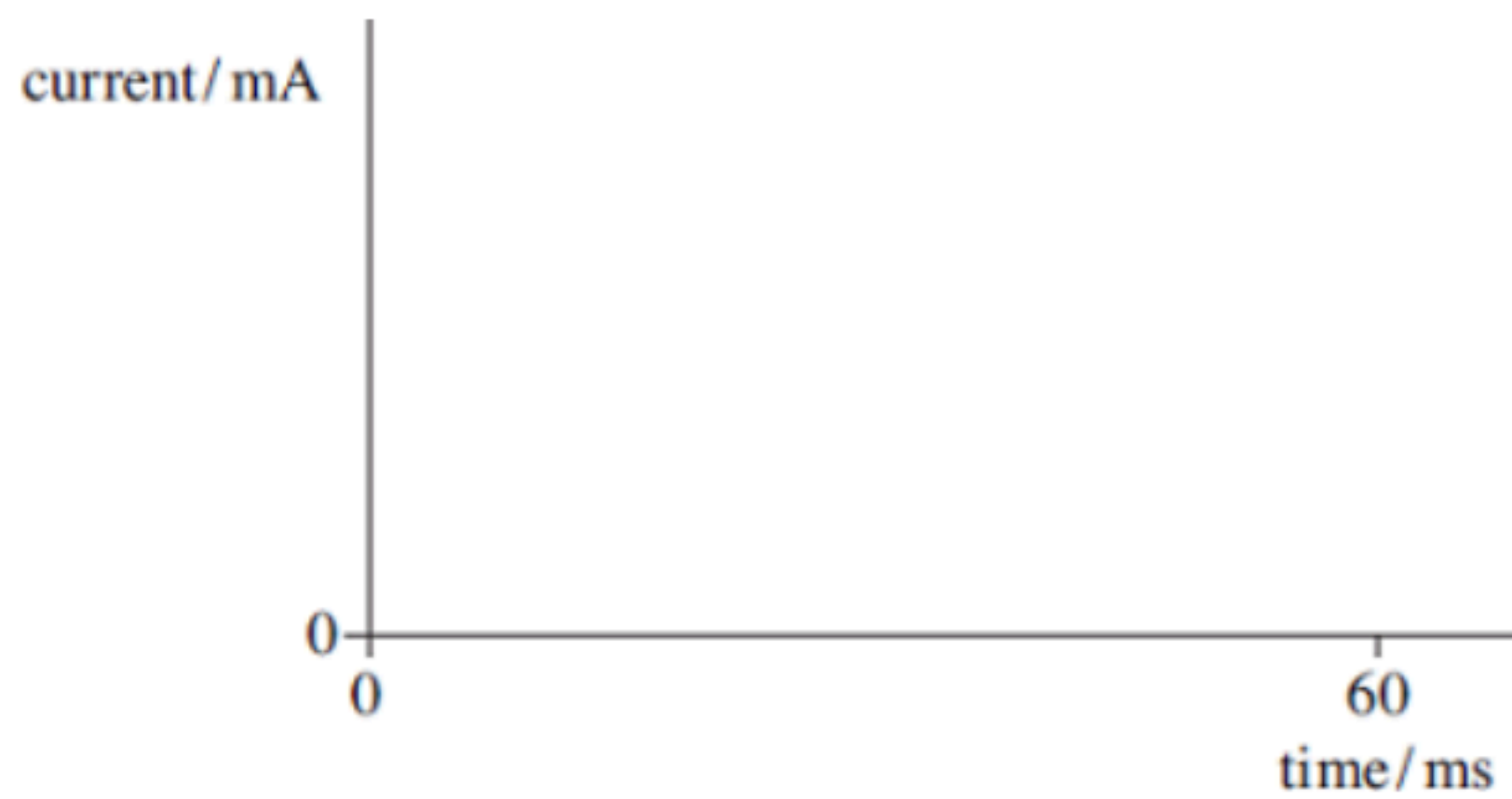
(1)

- (c) (i) Calculate the maximum value of the current, in mA, in this circuit during the charging process.

answer = _____ mA

(1)

- (ii) Sketch a graph on the outline axes to show how the current varies with time as the capacitor is charged. Mark the maximum value of the current on your graph.



(2)

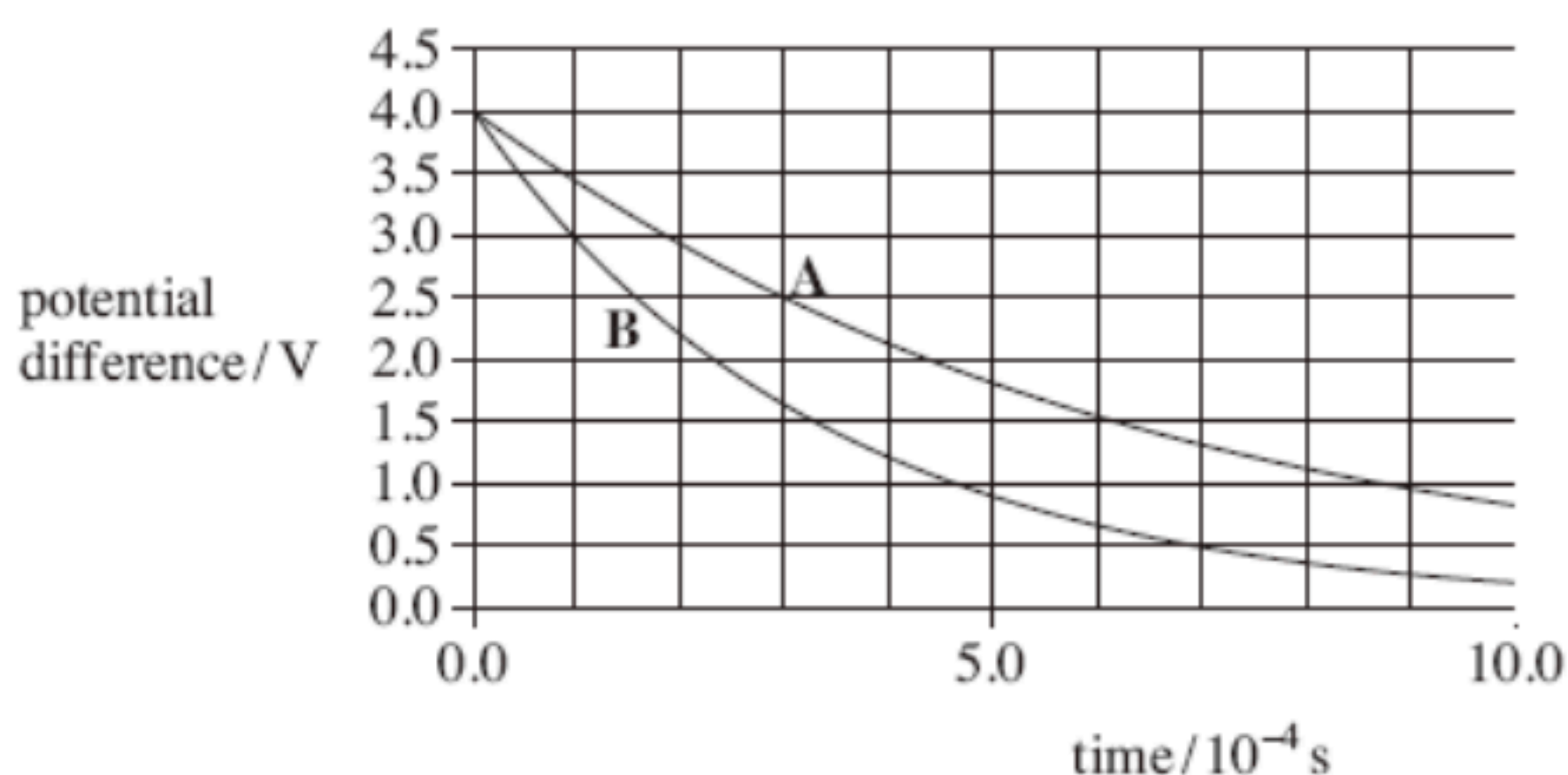
(Total 11 marks)

15

- (a) A particular heart pacemaker uses a capacitor which has a capacitance of $4.2 \mu\text{F}$. Explain what is meant by a *capacitance of $4.2 \mu\text{F}$* .

(2)

- (b) Capacitor **A**, of capacitance $4.2 \mu\text{F}$, is charged to 4.0 V and then discharged through a sample of heart tissue. This capacitor is replaced by capacitor **B** and the charge and discharge process repeated through the same sample of tissue. The discharge curves are shown in the figure below.



- (i) By considering the discharge curve for capacitor **A**, show that the resistance of the sample of heart tissue through which the discharge occurs is approximately 150Ω .

(4)

- (ii) State and explain whether capacitor **B** has a larger or smaller capacitance than that of capacitor **A**.

(2)

- (c) Capacitor **A** was charged to a potential difference of 4.0V before discharging through the sample of heart tissue.
Determine how much energy it passed to the sample of heart tissue in the first 0.90 m s of the discharge.

energy _____ J

(3)

(Total 11 marks)

16

Capacitors and rechargeable batteries are examples of electrical devices that can be used repeatedly to store energy.

- (a) (i) A capacitor of capacitance 70 F is used to provide the emergency back-up in a low voltage power supply.

Calculate the energy stored by this capacitor when fully charged to its maximum operating voltage of 1.2 V. Express your answer to an appropriate number of significant figures.

answer = _____ J

(3)

- (ii) A rechargeable 1.2 V cell used in a cordless telephone can supply a steady current of 55 mA for 10 hours. Show that this cell, when fully charged, stores almost 50 times more energy than the capacitor in part (a)(i).

(2)

- (b) Give **two** reasons why a capacitor is **not** a suitable source for powering a cordless telephone.

Reason 1 _____

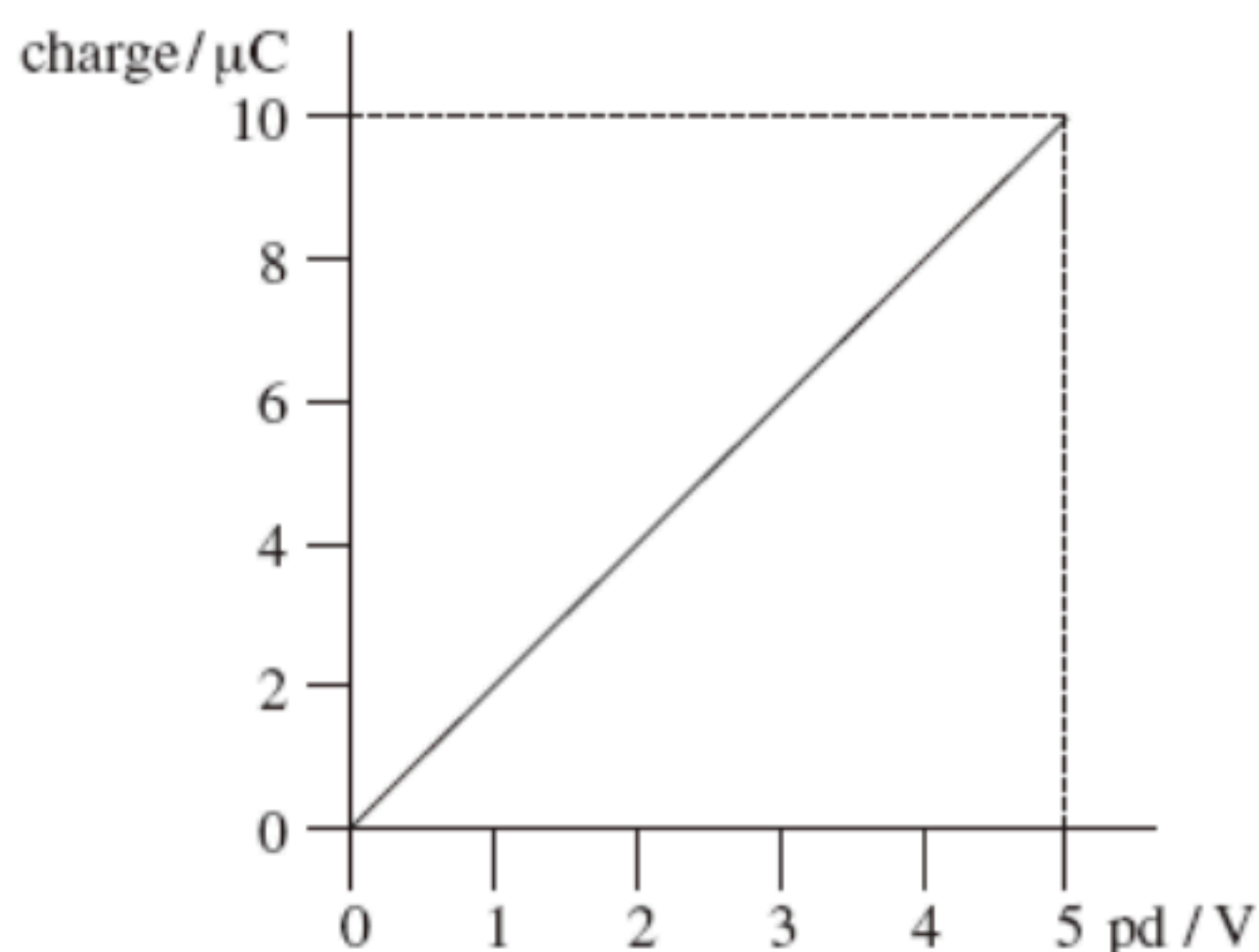
Reason 2 _____

(2)

(Total 7 marks)

17

The graph shows how the charge stored by a capacitor varies with the pd applied across it.



Which line, **A** to **D**, in the table gives the capacitance and the energy stored when the potential difference is 5.0 V?

	capacitance/ μF	energy stored/ μJ
A	2.0	25
B	2.0	50
C	10.0	25
D	10.0	50

(Total 1 mark)

18

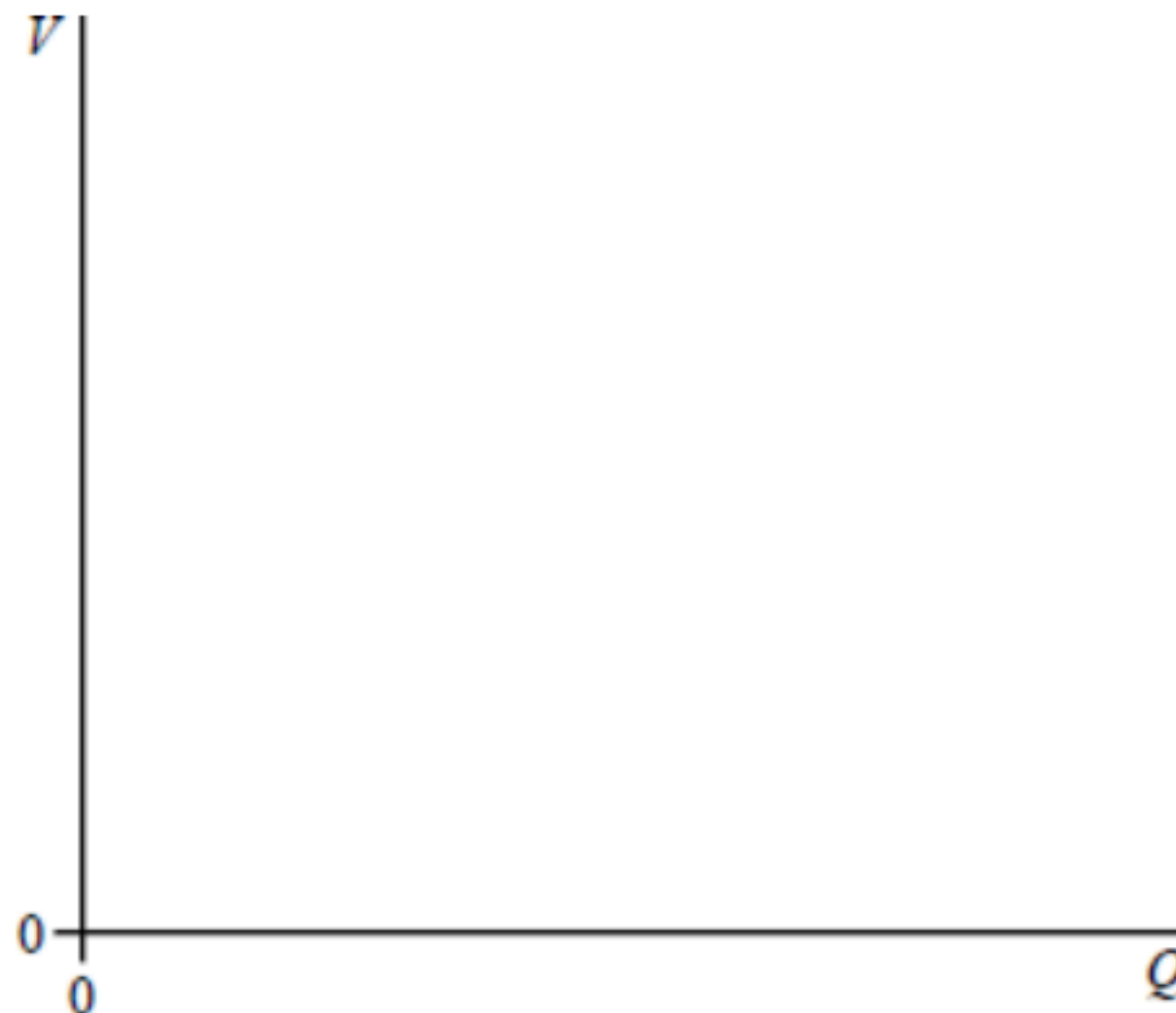
A capacitor of capacitance C stores an amount of energy E when the pd across it is V . Which line, **A** to **D**, in the table gives the correct stored energy and pd when the charge is increased by 50%?

	energy	pd
A	$1.5 E$	$1.5 V$
B	$1.5 E$	$2.25 V$
C	$2.25 E$	$1.5 V$
D	$2.25 E$	$2.25 V$

(Total 1 mark)

19

- (a) A $2.0\ \mu\text{F}$ capacitor is charged through a resistor from a battery of emf $4.5\ \text{V}$. Sketch a graph on the axes below to show how the charge stored, Q , varies with the potential difference, V , across the capacitor during the charging process. Mark appropriate values on the axes of the graph.



(2)

- (b) (i) Show that the energy stored by a charged capacitor is given by $E = \frac{1}{2}QV$.

- (ii) Calculate the energy stored by the capacitor in part (a) when the potential difference across it is $1.5\ \text{V}$.

(5)

(Total 7 marks)

20

- (a) A capacitor is made from two parallel metal plates of the same area, separated by an air gap. It is connected across a battery of constant e.m.f.

The plates are moved further apart, maintaining the same area of overlap, whilst the battery remains connected. State and explain what change, if any, occurs to

- (i) the potential difference across the plates,

- (ii) the capacitance of the capacitor,

- (iii) the charge on each plate of the capacitor,

- (iv) the energy stored by the capacitor.

(4)

- (b) A thunder cloud and the earth beneath it can be considered to form a parallel plate capacitor. The area of the cloud is 8.0 km^2 and it is 0.75 km above the earth.

- (i) Calculate the energy stored if the potential difference between the cloud and the earth is 200 kV .

- (ii) The air suddenly conducts, allowing all the charge to flow to earth in $120 \mu\text{s}$. Calculate the mean current flowing between the cloud and the earth when this happens.

(6)

(Total 10 marks)

21

- (a) For a capacitor of capacitance C , sketch graphs of charge, Q , and energy stored, E , against potential difference, V .



graph A



graph b

What is represented by the slope of graph A?

(3)

(b) A capacitor of capacitance 0.68 F is charged to 6.0 V . Calculate

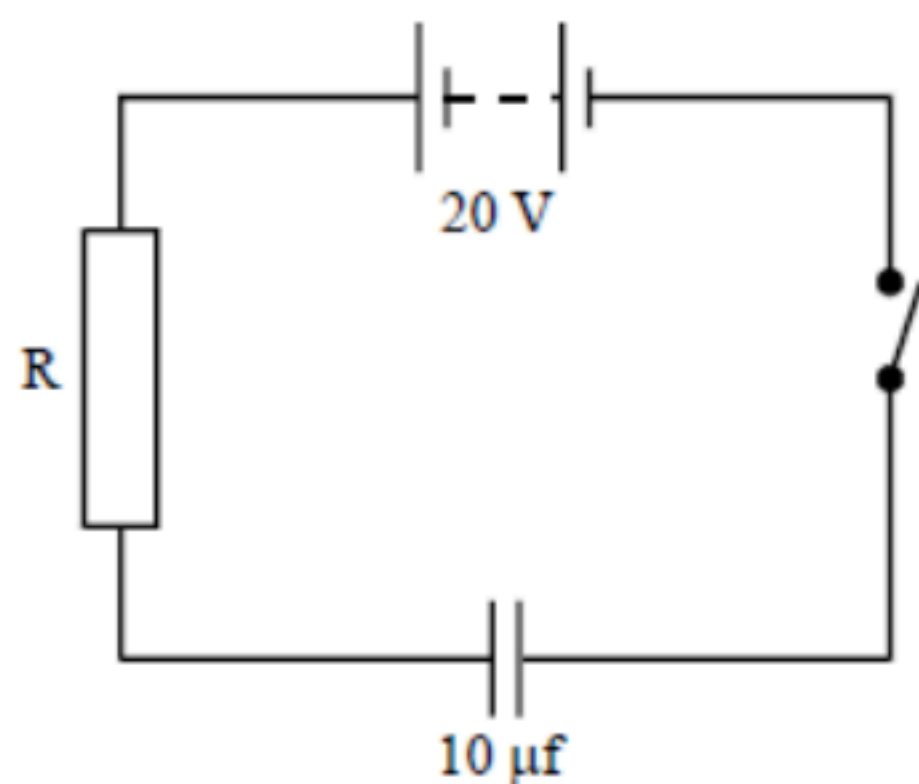
(i) the charge stored by the capacitor,

(ii) the energy stored by the capacitor.

(2)

(Total 5 marks)

22



A capacitor of capacitance $10 \mu\text{F}$ is fully charged through a resistor R to a p.d. of 20 V using the circuit shown. Which one of the following statements is **incorrect**?

- A** The p.d. across the capacitor is 20 V .
- B** The p.d. across the resistor is 0 V .
- C** The energy stored by the capacitor is 2 mJ .
- D** The total energy taken from the battery during the charging process is 2 mJ .

(Total 1 mark)

23

Which of the following does **not** give a value in seconds?

A capacitance $\times$ resistance

B $\frac{1}{\text{frequency}}$

C half-life

D $\frac{\text{power}}{\text{work}}$

(Total 1 mark)

24

(a) Explain what is meant by a capacitance of 1 farad (F).

(1)

(b) A parallel plate capacitor was made from two circular metal plates with air between them. The distance between the plates was 1.8 mm. The capacitance of this capacitor was found to be 2.3×10^{-11} F.

The permittivity of free space $\epsilon_0 = 8.9 \times 10^{-12}$ F m⁻¹

The relative permittivity of air = 1.0

Calculate:

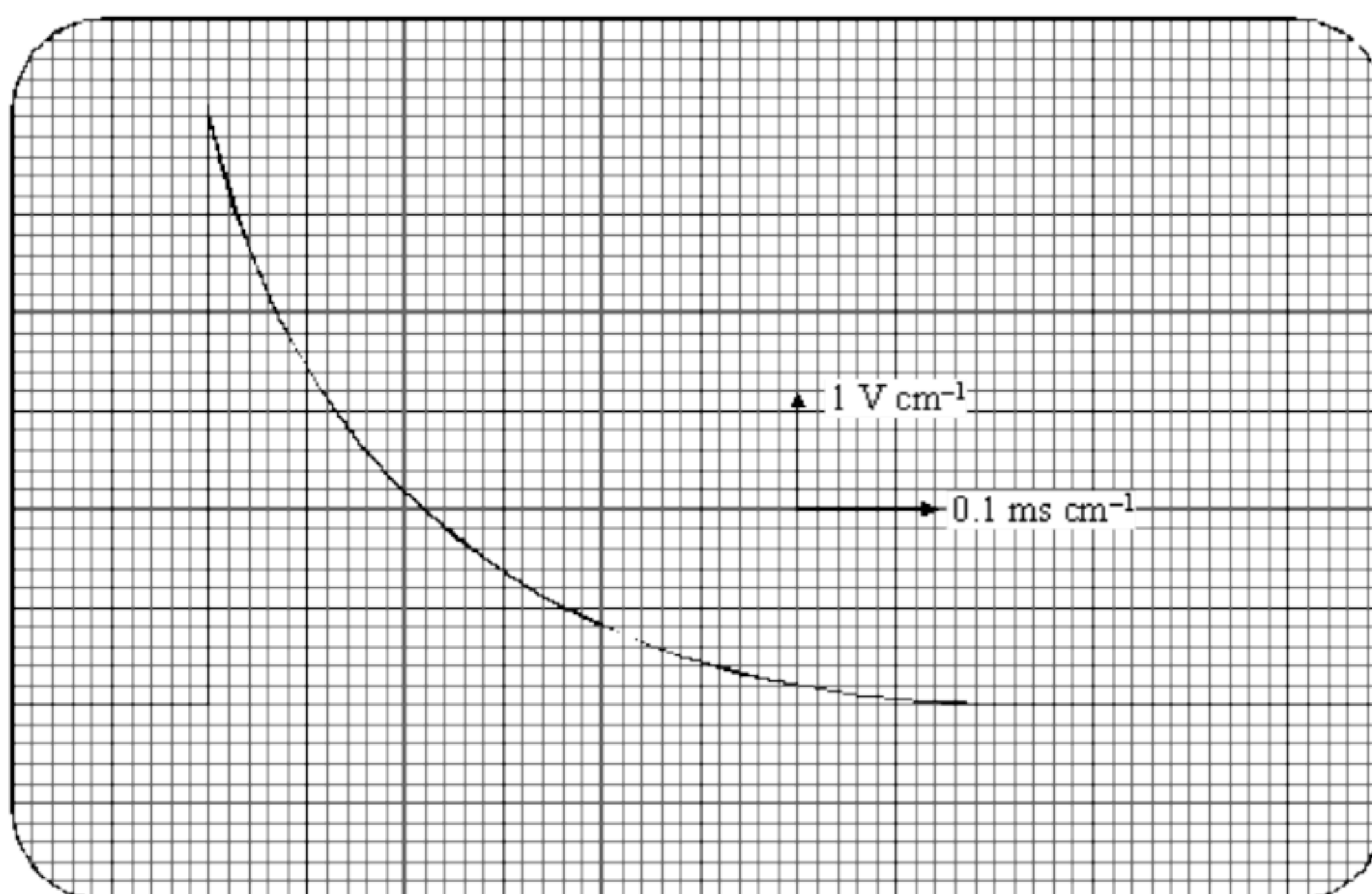
(i) the radius of the plates used in the capacitor;

(3)

- (ii) the energy stored when the potential difference between the capacitor plates is 6.0 V.

(2)

- (c) A student charged the capacitor and then tried to measure the potential difference between the plates using an oscilloscope. The student observed the trace shown in the diagram below and concluded that the capacitor was discharging through the oscilloscope.



Calculate the resistance of the oscilloscope.

(3)

(Total 9 marks)

25

The Earth's surface and the base of a charged cloud can be considered to be two plates of a parallel-plate capacitor.

- (a) Calculate the capacitance of an Earth-cloud system when the base of the cloud has an area of $1.4 \times 10^6 \text{ m}^2$ and is 800 m above the Earth's surface.

$$\epsilon_0 = 8.9 \times 10^{-12} \text{ F m}^{-1}$$

$$\epsilon_r \text{ for air} = 1.0$$

(2)

- (b) A potential difference of $3.0 \times 10^6 \text{ V}$ across each metre of air will cause the air to break down and allow the cloud to discharge to the Earth.

- (i) Show that the average breakdown p.d. for the 800 m layer of air between the Earth and the base of the cloud is about $2.5 \times 10^9 \text{ V}$.

(1)

- (ii) Calculate the maximum energy that the charged Earth – cloud system can store.

(2)

- (iii) Calculate the maximum charge stored by the system before breakdown commences.

(1)

- (c) By considering the cloud discharge to be modelled by a resistor connected across a capacitor, calculate the resistance that would allow a cloud to discharge 99% of its charge to Earth in a time of 0.25 s.

(3)

(Total 9 marks)

Mark schemes

1	(a) $d = \frac{8.9 \times 10^{-12} \times 2.3 \times 250 \times 10^{-4}}{370 \times 10^{-12}} \checkmark$ $1.4 \times 10^{-3} \text{ m (1.4 (1.38) mm)} \checkmark$ <i>Data substitution – condone incorrect powers of 10 for C and A</i> $\checkmark$	2
	(b) New capacitance = 161 pF $\checkmark$ New $V = 0.13 \text{ nC} / 161 \text{ pF} = 81 \text{ V} \checkmark$	2
	(c) Energy stored = $\frac{1}{2} \times 161 \times 10^{-12} \times 81^2 \checkmark$ $0.53 \mu\text{J} \checkmark$	2
	(d) Energy increases because: In the polar dielectric molecules align in the field with positive charged end toward the negative plate (or WTTE). $\checkmark$ Work is done on the capacitor separating the positively charged surface of the dielectric from the negatively charged plate (or vice versa). $\checkmark$	2
		[8]
2	C	[1]
3	C	[1]
4	(a) (i) capacitance = $\left(\frac{Q}{V}\right) = \frac{98.2 - 73.9}{12.0 - 9.0} \checkmark$ $= 8.1 (\mu\text{F}) \checkmark (\pm 0.2 \mu\text{F})$ <i>1 mark only if correct value of C is found from a single point.</i> <i>2 marks if correct value of C is found from at least 2 points and a mean value, or from gradient. (Check graph.)</i> <i>Accept 8 (μF) if from correct working.</i>	

- (ii) additional energy = area between line and Q or V axis ✓
 $= \{ \frac{1}{2} \times (98.2 - 73.9) \times 3.0 \} + \{ (98.2 - 73.9) \times 9.0 \}$ ✓
 $= \{ 36.5 + 218.7 \} = 255 \text{ J or } 2.6 \times 10^{-4} \text{ (J)} \checkmark$

[or, using $\frac{1}{2} QV$:

$$\begin{aligned} \text{additional energy} &= \frac{1}{2} Q_2 V_2 - \frac{1}{2} Q_1 V_1 \checkmark \\ &= \frac{1}{2} \{ (98.2 \times 12) - (73.9 \times 9) \} \checkmark \\ &= 257 \text{ } \mu\text{J or } 2.6 \times 10^{-4} \text{ (J)} \checkmark] \end{aligned}$$

[or, using $\frac{1}{2} CV^2$:

$$\begin{aligned} \text{additional energy} &= \frac{1}{2} CV_2^2 - \frac{1}{2} CV_1^2 \checkmark \\ &= \frac{1}{2} 8.1 \times (12^2 - 9^2) \checkmark \\ &= 255 \text{ } \mu\text{J or } 2.6 \times 10^{-4} \text{ (J)} \checkmark] \end{aligned}$$

[or, using $\frac{1}{2} Q^2/C$:

$$\begin{aligned} \text{additional energy} &= \frac{1}{2} Q_2^2/C - \frac{1}{2} Q_1^2/C \checkmark \\ &= (98.2^2 - 73.9^2) \div (2 \times 8.1) \checkmark \\ &= 258 \text{ } \mu\text{J or } 2.6 \times 10^{-4} \text{ (J)} \checkmark] \end{aligned}$$

First scheme: alternative for 2nd mark

$$= \{ \frac{1}{2} \times (98.2 - 73.9) \times 3.0 \} + \{ 73.9 \times 3.0 \} \checkmark$$

All schemes:

second mark subsumes the first mark.

In all methods, allow tolerance of $\pm 10 \text{ } \mu\text{J}$ in final answer to allow for variation in graph measurements.

Allow ECF for incorrect C value from (a)(i).

3

- (b) (i) ($V = V_0 e^{-t/RC}$ gives) $0.2 V_0 = V_0 e^{-t/RC}$
and $0.2 = e^{-45/RC} \checkmark$

Condone use of 0.8 for 0.2 in first mark only.

$$\ln 0.2 = -\frac{45}{RC} \text{ or } \ln 5 = \frac{45}{RC} \checkmark$$

$$\text{time constant } RC = \frac{45}{\ln 5} \text{ or } \ln 5 = \frac{45}{RC} = 28.0 \text{ (s)} \checkmark$$

3

- (ii) resistance of $R = \left(\frac{\text{time constant}}{C} \right) = \frac{28.0}{470 \times 10^{-6}} \checkmark$
 $= 5.96 \times 10^4 \text{ (}\Omega\text{)} \text{ or } 60 \text{ k}\Omega \checkmark$

Allow ECF for incorrect RC value from (b)(i).

2

- (ii) tick in 4th box **only**

1

[11]

6

A

[1]

7

B

[1]

8

(a)

(i)

determine area under the graph
[or determine area between line and time axis] ✓

1

(ii)

as seen

line starts at very low current (within bottom half of first square) ✓
either line continuing as (almost) horizontal straight line to end ✓✓
or very slight exponential decay curve ✓
which does not meet time axis ✓

OR suitable verbal comment that shows appreciation of difficulty of
representing this line on the scales involved ✓✓✓

*Use this scheme for answers which treat the information in the
question literally.*

3

as intended

line starts at half of original initial current ✓
slower discharging exponential (ie. smaller initial gradient)
than the original curve ✓
correct line that intersects the original curve
(or meets it at the end) ✓

*Use this scheme for answers which assume that both resistance
values should be in Ω or $k\Omega$.*

$\frac{1}{2}$ initial current to be marked within $\pm 2\text{mm}$ of expected value.

3

(b)

(i)

energy stored ($= \frac{1}{2} CV^2$) $= \frac{1}{2} \times 0.12 \times 9.0^2$ ✓ ($= 4.86 \text{ (J)}$)
 $4.86 = 3.5 \Delta h$ ✓
gives $\Delta h = (1.39) = 1.4 \text{ (m)}$ ✓
to 2SF only ✓

SF mark is independent.

*Students who make a PE in the 1st mark may still be awarded the
remaining marks: treat as ECF.*

4

- (ii) energy is lost through heating of wires **or** heating the motor
(as capacitor discharges) ✓

*Allow heating of circuit **or** $I^2 R$ heating.*

energy is lost in overcoming frictional forces in the motor
(or in other rotating parts) ✓

Location of energy loss (wires, or motor, etc) should be indicated in each correct answer.

[**or** any other well-expressed sensible reason that is valid
e.g. capacitor will not drive motor when voltage becomes low ✓]
Don't allow losses due to sound, air resistance or resistance (rather than heating of) wires.

max 2

[10]

9

- (a) (i) $Q (= It) = 4.5 \times 10^{-6} \times 60$ **or** $= 2.70 \times 10^{-4} \text{ (C)}$ ✓

$$C \left(= \frac{Q}{V} \right) = \frac{2.70 \times 10^{-4}}{4.4} \checkmark = 6.1(4) \times 10^{-5} = 61 \text{ (}\mu\text{F)} \checkmark$$

3

- (ii) since V_C was 4.4V after 60s, when $t = 30\text{s}$ $V_C = 2.2 \text{ (V)}$ ✓
[**or** by use of $Q = It$ and $V_C = Q / C$]
 $\therefore$ pd across R is $(6.0 - 2.2) = 3.8 \text{ (V)}$ ✓

$$R \left(= \frac{V}{I} \right) = \frac{3.8}{4.5 \times 10^{-6}} = 8.4(4) \times 10^5 \text{ (}\Omega\text{)} \checkmark (=844 \text{ k}\Omega)$$

In alternative method,

$$Q = 4.5 \times 10^{-6} \times 30 = 1.35 \times 10^{-4} \text{ (C)}$$

$$V_C = 1.35 \times 10^{-4} / 6.14 \times 10^{-5} = 2.2 \text{ (V)}$$

(allow ECF from wrong values in (i)).

3

- (b) **The candidate's writing should be legible and the spelling, punctuation and grammar should be sufficiently accurate for the meaning to be clear.**
The candidate's answer will be assessed holistically. The answer will be assigned to one of three levels according to the following criteria.

High Level (Good to excellent): 5 or 6 marks

The information conveyed by the answer is clearly organised, logical and coherent, using appropriate specialist vocabulary correctly. The form and style of writing is appropriate to answer the question.

The candidate gives a coherent and logical description of the flow of electrons taking place during the charging and discharging processes, indicating the correct directions of flow and the correct time variations. There is clear understanding of how the pds change with time during charging and during discharging. The candidate also gives a coherent account of energy transfers that take place during charging and during discharging, naming the types of energy involved. They recognise that the time constant is the same for both charging and discharging.

*A **High Level** answer must contain correct physical statements about at least **two** of the following for **both** the charging and the discharging positions of the switch:-*

- the direction of electron flow in the circuit*
- how the flow of electrons (or current) changes with time*
- how V_R and / or V_C change with time*
- energy changes in the circuit*

Intermediate Level (Modest to adequate): 3 or 4 marks

The information conveyed by the answer may be less well organised and not fully coherent. There is less use of specialist vocabulary, or specialist vocabulary may be used incorrectly. The form and style of writing is less appropriate.

The candidate has a fair understanding of how the flow of electrons varies with time, but may not be entirely clear about the directions of flow. Description of the variation of pds with time is likely to be only partially correct and may not be complete. The candidate may show reasonable understanding of the energy transfers.

*An **Intermediate Level** answer must contain correct physical statements about at least **two** of the above for **either** the charging or the discharging positions of the switch.*

Low Level (Poor to limited): 1 or 2 marks

The information conveyed by the answer is poorly organised and may not be relevant or coherent. There is little correct use of specialist vocabulary. The form and style of writing may be only partly appropriate.

The candidate is likely to confuse electron flow with current and is therefore unlikely to make effective progress in describing electron flow. Understanding of the variation of pds with time is likely to be quite poor. The candidate may show some understanding of the energy transfers that take place.

*A **Low Level** answer must contain a correct physical statement about at least **one** of the above for **either** the charging or the discharging positions of the switch.*

No answer, or answer refers to unrelated, incorrect or inappropriate physics.

The explanation expected in a competent answer should include a coherent selection of the following points concerning the physical principles involved and their consequences in this case.

Charging

- electrons flow from plate **P** to terminal **A** and from terminal **B** to plate **Q** (ie. from plate **P** to plate **Q** via **A** and **B**)
- electrons flow in the opposite direction to current
- plate **P** becomes + and plate **Q** becomes –
- the rate of flow of electrons is greatest at the start, and decreases to zero when the capacitor is fully charged
- V_R decreases from E to zero whilst V_C increases from zero to E
- at any time $V_R + V_C = E$
- time variations are exponential decrease for V_R and exponential increase for V_C
- chemical energy of the battery is changed into electric potential energy stored in the capacitor, and into thermal energy by the resistor (which passes to the surroundings)
- half of the energy supplied by the battery is converted into thermal energy and half is stored in the capacitor

Discharging

- electrons flow back from plate **Q** via the shorting wire to plate **P**
- at the end of the process the plates are uncharged
- the rate of flow of electrons is greatest at the start, and decreases to zero when the capacitor is fully discharged
- V_C decreases from $-E$ to zero and V_R decreases from E to zero
- at any time $V_C = -V_R$
- both V_C and V_R decrease exponentially with time
- electrical energy stored by the capacitor is all converted to thermal energy by the resistor as the electrons flow through it and this energy passes to the surroundings
- time constant of the circuit is the same for discharging as for charging

Any answer which does not satisfy the requirement for a Low Level answer should be awarded 0 marks.

max 6

[12]

10

- (a) (i) required pd ($= 2.5 \times 10^6 \times 12 \times 10^{-3}$) $= 3.0(0) \times 10^4$ (V) ✓

1

- (ii) charge required $Q (= CV) = 3.7 \times 10^{-12} \times 3.00 \times 10^4$ ✓

$$(\quad = 1.11 \times 10^{-7} \text{ C})$$

Allow ECF from incorrect V from (a)(i).

$$\text{time taken } t \left(= \frac{Q}{I} \right) = \frac{1.11 \times 10^{-7}}{3.2 \times 10^{-8}} = 3.5 \text{ (3.47) (s) } \checkmark$$

2

(b) (i) time increases ✓

(larger C means) more charge required (to reach breakdown pd)

Mark sequentially i.e. no explanation mark if effect is wrong.

or $t = \frac{CV}{I}$ or time $\propto$ capacitance ✓

2

(ii) spark is brighter (or lasts for a longer time) ✓

more energy (or charge) is stored or current is larger

Mark sequentially.

or spark has more energy ✓

2

(Total 7 marks)

11 C [1]

12 B [1]

13 C [1]

14 (a) charge (stored) ✓ per unit potential difference ✓
[or $C = Q/V$ where Q = charge (stored by one plate) ✓ V = pd (across plates) ✓]

2

(b) (i) $C \left(= \frac{Q}{V} \right) = \frac{13.2 \times 10^{-6}}{6.0} \checkmark = 2.2 \times 10^{-6} \text{ (F)} \checkmark$ (or $2.2 \mu\text{F}$)

2

(ii) when t = time constant $Q = 0.63 \times 13.2 = 8.3 \text{ (}\mu\text{C)} \checkmark$

[or $= 0.63 \times 13(.0)$ (from graph) $= 8.2 \text{ (}\mu\text{C)}$]

reading from graph gives time constant $= 15 (\pm 1) \text{ (ms)} \checkmark$

2

(iii) resistance of resistor $= \left(= \frac{\text{time constant}}{C} \right) = \frac{15 \times 10^{-3}}{2.2 \times 10^{-6}} = 6820 \text{ (}\Omega) \checkmark$

1

(iv) gradient = current ✓

1

(c) (i) maximum current = $\left(= \frac{V}{R} \right) = \frac{6.0}{6820} = 0.88 \text{ (mA)} \checkmark$

[**or** value from initial gradient of graph: allow 0.70 – 1.00 mA for this approach]

1

(ii) curve starts at marked I_{max} on I axis and has decreasing negative gradient $\checkmark$

line is asymptotic to t axis and approaches ≈ 0 by $t = 60 \text{ ms} \checkmark$

2

[11]

15

(a) ratio of charge to potential

C1

4.2 μC per volt etc

A1

2

(b) (i) method: time for voltage to half/tangent at origin/use of decay equation/ $1/e$ value

B1

appropriate reading from graph ($T_{1/2} = 440$ or $450 \mu\text{s}$)

B1

substitution into correct equation

B1

R correct for method (151/152/155 Ω)

B1

4

(ii) **B** smaller than **A M0**

B discharges faster/**A** discharges slower

B1

reference to decay equation/calculation for **B**

B1

2

(c) $E = \frac{1}{2} CV^2$ or $\frac{1}{2} QV$ seen

C1

both 4.0 (V) and 0.9 (V)/16.8 (μC) and 3.8 (μC) seen

C1

31.9 (μJ)

A1

3

[11]

16

(a) (i) energy stored by capacitor ($= \frac{1}{2} CV^2$)

$$= \frac{1}{2} \times 70 \times 1.2^2 \checkmark (= 50.4) = 50 \text{ (J)} \checkmark$$

to **2 sf** only $\checkmark$

3

(ii) energy stored by cell ($= I V t$) $= 55 \times 10^{-3} \times 1.2 \times 10 \times 3600 \checkmark$

($= 2380 \text{ J}$)

$$\frac{\text{energy stored by cell}}{\text{energy stored by capacitor}} = \frac{2380}{50} = 48 \text{ (ie about 50)} \checkmark$$

2

(b) capacitor would be impossibly large (to fit in phone) $\checkmark$

capacitor would need recharging very frequently

[**or** capacitor could only power the phone for a short time] $\checkmark$

capacitor voltage [**or** current supplied or charge] would fall continuously while in use $\checkmark$

max 2

[7]

17

A

[1]

18

C

[1]

19

(a) graph to show:
straight line from origin **(1)**
end point at 4.5 (V), 9.0 (μF) **(1)**

2

- (b) (i) $\Delta W = V \Delta Q$ explained (1)
 energy stored or total work done in charging = area under graph or
 charge $\times$ average voltage (1)

energy stored = work done ($= \frac{1}{2} QV$) (1)

- (ii) $Q = 2.0 \times 1.5 = 3.0 \text{ } (\mu\text{C})$ (1)
 $E (= \frac{1}{2} QV) = \frac{1}{2} \times 3.0 \times 10^{-6} \times 1.5 = 2.25 \times 10^{-6} \text{ J}$ (1)
 [or $E = (\frac{1}{2} CV^2 = \frac{1}{2} \times 2.0 \times 10^{-6} \times 1.5^2 = 2.25 \times 10^{-6} \text{ J})$

5

[7]

20

- (a) (i) remains constant since connected to constant p.d. (1)

- (ii) decreases because $C \propto \frac{1}{d}$ (1)

- (iii) decreases because $Q = CV$ and C has decreased (1)

- (iv) decreases because $E = \frac{1}{2} CV^2$ and C has decreased (1)

4

- (b) (i) $C \left(= \frac{\epsilon_0 A}{d} \right) = \frac{8.85 \times 10^{-12} \times 8.0 \times 10^6}{0.75 \times 10^3}$ (1) ($= 9.44 \times 10^{-8} \text{ F}$)

$E (= \frac{1}{2} CV^2) = \frac{1}{2} \times 9.44 \times 10^{-8} \times (200 \times 10^3)^2$ (1)
 $= 1890 \text{ J}$ (1)

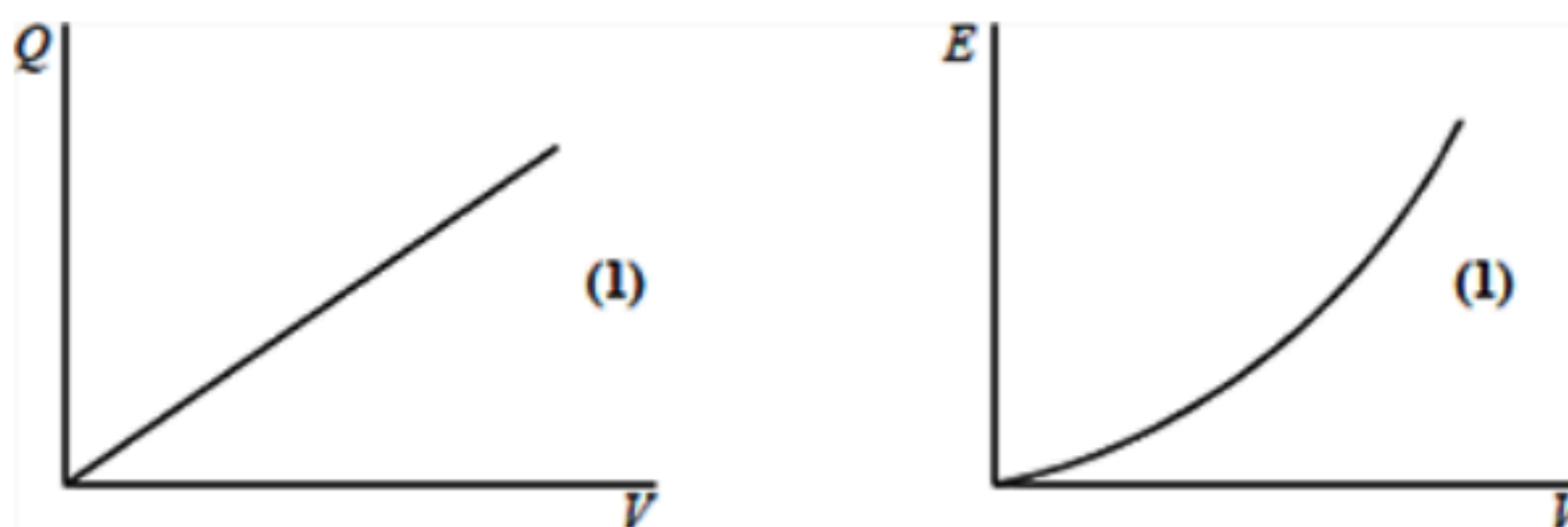
- (ii) $I \left(= \frac{Q}{t} \right) = \frac{9.44 \times 10^{-8} \times 200 \times 10^3}{120 \times 10^{-6}}$ use of $Q = CV$ (1) use of $I = \frac{Q}{t}$ (1)
 $= 157 \text{ A}$ (1)

6

[10]

21

- (a)



capacitance [or charge per volt or Q/V] (1)

(3)

(b) (i) $Q = CV (= 0.68 \times 6.0) = 4.1 \text{ C (1)}$

(ii) $E \left(= \frac{1}{2} QV = \frac{1}{2} \times 4.1 \times 6.0 \right) = 12 \text{ J (1)}$

(2)

[5]

22

D

[1]

23

D

[1]

24

- (a) 1 coulomb of charge is stored for a p.d. of 1 V between the plates
(or equivalent statement) Condone 1 coulomb per volt

B1

1

- (b) (i) Correct substitution in $C = \frac{\epsilon_0 \epsilon_r A}{d}$ (ignore powers of 10)

C1

Plate area = $4.65 \times 10^{-3} \text{ m}^2$ or $C = \frac{\epsilon_0 \epsilon_r \pi r^2}{d}$ with correct data

A1

Radius = (their area / 3.14)^{1/2}; 0.038(4 or 5) m if correct

B1

3

- (ii) $E = \frac{1}{2} CV^2$ or correct numerical substitution or
 $E = \frac{1}{2} QV$ & $Q = VC$

C1

$4.1(4) \times 10^{-10} \text{ J}$

A1

2

- (c) Time constant = RC or Time to halve = $0.69 RC$
or $V = V_0 e^{-t/RC}$

C1

Time to fall to $1/e$ (0. 19 ms) or time to halve (0. 13 ms)
or $V_0 = 6 \text{ V}$ and correct coordinates of point on line
(0.6 ms max)

C1

8.1 - 8.6 $M\Omega$

A1

3

[9]

25

- (a) $C = \epsilon_0 \epsilon_r A/d$

C1

15.6 nF or 16 nF

A1

2

- (b) (i) $2.4 \times 10^9 \text{ (V)}$

B1

1

- (ii) $\frac{1}{2} CV^2$ (or $\frac{1}{2} QV$ if attempt to calculate Q made)

C1

4.3–5.0 $\times 10^{10} \text{ J}$

A1

2

- (iii) 36–40 C

B1

1

(c) recognition that 1% of charge or voltage remains

C1

any appropriate form of decay equation (either exponential or logarithmic)

C1

$3.48 \times 10^6 \, \Omega$ **cao** (but do not allow if physics error)

A1

3

[9]