

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)

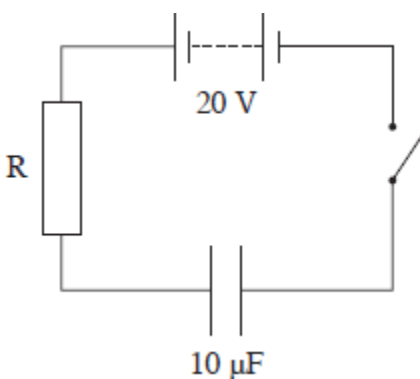
(Total 8 marks)

- 2** When fully charged the 2.0 mF capacitor used as a backup for a memory unit has a potential difference of 5.0 V across it. The capacitor is required to supply a constant current of $1.0 \text{ }\mu\text{A}$ and can be used until the potential difference across it falls by 10%. For how long can the capacitor be used before it must be recharged?

- A** 10 s
B 100 s
C 200 s
D 1000 s

(Total 1 mark)

- 3** A capacitor of capacitance $10 \text{ }\mu\text{F}$ is charged through a resistor R to a potential difference (pd) of 20 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 mJ .
B The total energy taken from the battery during the charging process is 2 mJ .
C The pd across the capacitor is 20 V .
D The pd across the resistor is 0 V .

(Total 1 mark)

4

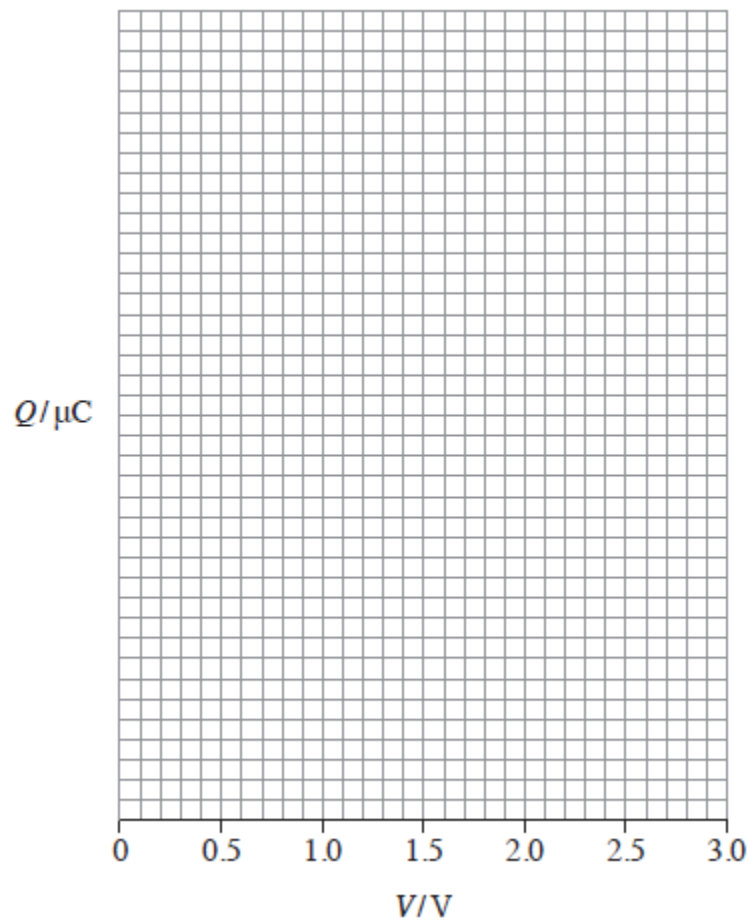
The specification for a pacemaker requires a suitable charge to be delivered in 1.4 ms. A designer uses a circuit with a capacitor of capacitance $3.0 \mu\text{F}$ and a 2.5 V power supply to deliver the charge. The designer calculates that a suitable charge will be delivered to the heart as the capacitor discharges from a potential difference (pd) of 2.5 V to a pd of 1.2 V in 1.4 ms.

- (a) (i) Calculate the charge on the capacitor when it is charged to a pd of 2.5 V.

charge _____ C

(1)

- (ii) Draw a graph showing how the charge, Q , on the capacitor varies with the pd, V , as it discharges through the heart.
Include an appropriate scale on the charge axis.



(3)

- (b) Calculate the energy delivered to the heart in a single pulse from the pacemaker when the capacitor discharges to 1.2 V from 2.5 V.

energy _____ J

(3)

- (c) (i) Calculate the resistance of the heart that has been assumed in the design.

resistance _____ Ω

(3)

- (ii) Explain why the rate of change of pd between the capacitor plates decreases as the capacitor discharges.

(2)

(Total 12 marks)

5

Initially a charged capacitor stores 1600 μJ of energy. When the pd across it decreases by 2.0 V, the energy stored by it becomes 400 μJ .

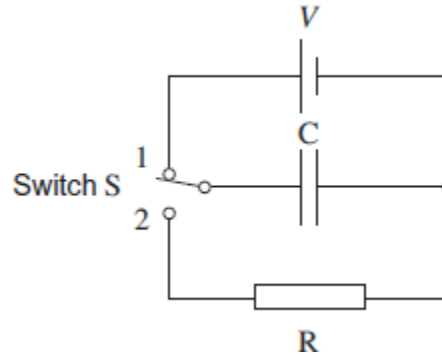
What is the capacitance of this capacitor?

- A 100 μF
B 200 μF
C 400 μF
D 600 μF

(Total 1 mark)

6

Switch S in the circuit is held in position 1, so that the capacitor C becomes fully charged to a pd V and stores energy E .



The switch is then moved quickly to position 2, allowing C to discharge through the fixed resistor R. It takes 36 ms for the pd across C to fall to $\frac{V}{2}$. What period of time must elapse, after the switch has moved to position 2, before the energy stored by C has fallen to $\frac{E}{16}$?

- A 51 ms
- B 72 ms
- C 432 ms
- D 576 ms

(Total 1 mark)

7

A nuclear fusion device is required to deliver at least 1 MJ of energy using capacitors. If the largest workable potential difference is 10 kV, what is the minimum capacitance of the capacitors that should be used?

- A 0.01 F
- B 0.02 F
- C 2 F
- D 100 F

(Total 1 mark)

8

An initially uncharged capacitor of capacitance $20\ \mu\text{F}$ is charged by a constant current of $80\ \mu\text{A}$. Which line, **A** to **D**, in the table gives the potential difference across, and the energy stored in, the capacitor after $50\ \text{s}$?

	potential difference / V	energy stored / J
A	4.0×10^{-3}	2.0×10^{-3}
B	4.0×10^{-3}	4.0×10^{-1}
C	2.0×10^2	2.0×10^{-3}
D	2.0×10^2	4.0×10^{-1}

(Total 1 mark)

9

A $10\ \mu\text{F}$ capacitor is fully charged to a pd of $3.0\ \text{kV}$. The energy stored in the capacitor can be used to lift a load of $5.0\ \text{kg}$ through a vertical height h . What is the approximate value of h ?

- A** $0.03\ \text{mm}$
- B** $0.9\ \text{mm}$
- C** $0.3\ \text{m}$
- D** $0.9\ \text{m}$

(Total 1 mark)

10

A $10\ \text{mF}$ capacitor is charged to $10\ \text{V}$ and then discharged completely through a small motor. During the process, the motor lifts a weight of mass $0.10\ \text{kg}$. If 10% of the energy stored in the capacitor is used to lift the weight, through what approximate height will the weight be lifted?

- A** $0.05\ \text{m}$
- B** $0.10\ \text{m}$
- C** $0.50\ \text{m}$
- D** $1.00\ \text{m}$

(Total 1 mark)

11

A $1\ \mu\text{F}$ capacitor is charged using a **constant** current of $10\ \mu\text{A}$ for $20\ \text{s}$. What is the energy finally stored by the capacitor?

- A** $2 \times 10^{-3}\ \text{J}$
- B** $2 \times 10^{-2}\ \text{J}$
- C** $4 \times 10^{-2}\ \text{J}$
- D** $4 \times 10^{-1}\ \text{J}$

(Total 1 mark)

12

In experiments to pass a very high current through a gas, a bank of capacitors of total capacitance $50\ \mu\text{F}$ is charged to $30\ \text{kV}$. If the bank of capacitors could be discharged completely in $5.0\ \text{ms}$ what would be the mean power delivered?

- A $22\ \text{kW}$
- B $110\ \text{kW}$
- C $4.5\ \text{MW}$
- D $9.0\ \text{MW}$

(Total 1 mark)

13

A $680\ \mu\text{F}$ capacitor is charged fully from a $12\ \text{V}$ battery. At time $t = 0$ the capacitor begins to discharge through a resistor. When $t = 25\ \text{s}$ the energy remaining in the capacitor is one quarter of the energy it stored at $12\ \text{V}$.

- (a) Determine the pd across the capacitor when $t = 25\text{s}$.

(2)

- (b) (i) Show that the time constant of the discharge circuit is $36\ \text{s}$.

- (ii) Calculate the resistance of the resistor.

(4)

(Total 6 marks)

14

A capacitor of capacitance $330\ \mu\text{F}$ is charged to a potential difference of $9.0\ \text{V}$. It is then discharged through a resistor of resistance $470\ \text{k}\Omega$.

Calculate

- (a) the energy stored by the capacitor when it is fully charged,

(2)

- (b) the time constant of the discharging circuit,

(1)

- (c) the p.d. across the capacitor $60\ \text{s}$ after the discharge has begun.

(3)

(Total 6 marks)

15

A $1.0\ \mu\text{F}$ capacitor is charged by means of a **constant** current of $10\ \mu\text{A}$ for $20\ \text{s}$. What is the energy finally stored in the capacitor?

- A $4.0 \times 10^{-4}\ \text{J}$
- B $2.0 \times 10^{-3}\ \text{J}$
- C $2.0 \times 10^{-2}\ \text{J}$
- D $4.0 \times 10^{-2}\ \text{J}$

(Total 1 mark)

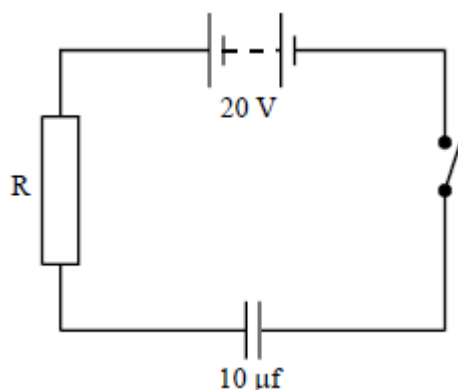
16

A $1\ \mu\text{F}$ capacitor is charged using a constant current of $10\ \mu\text{A}$ for $20\ \text{s}$. What is the energy finally stored by the capacitor?

- A $2 \times 10^{-3}\ \text{J}$
- B $2 \times 10^{-2}\ \text{J}$
- C $4 \times 10^{-2}\ \text{J}$
- D $4 \times 10^{-1}\ \text{J}$

(Total 1 mark)

17



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

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

(Total 1 mark)

18

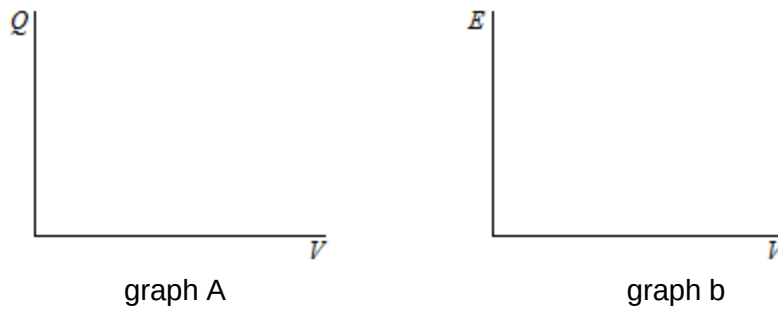
A capacitor of capacitance C stores an amount of energy E when the pd across it is V . Which line, **A** to **D**, gives the correct stored energy and pd when the charge is increased by 50% ?

	energy	p.d.
A	$1.5E$	$1.5V$
B	$2.25E$	$1.5V$
C	$1.5E$	$2.25V$
D	$2.25E$	$2.25V$

(Total 1 mark)

19

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



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,

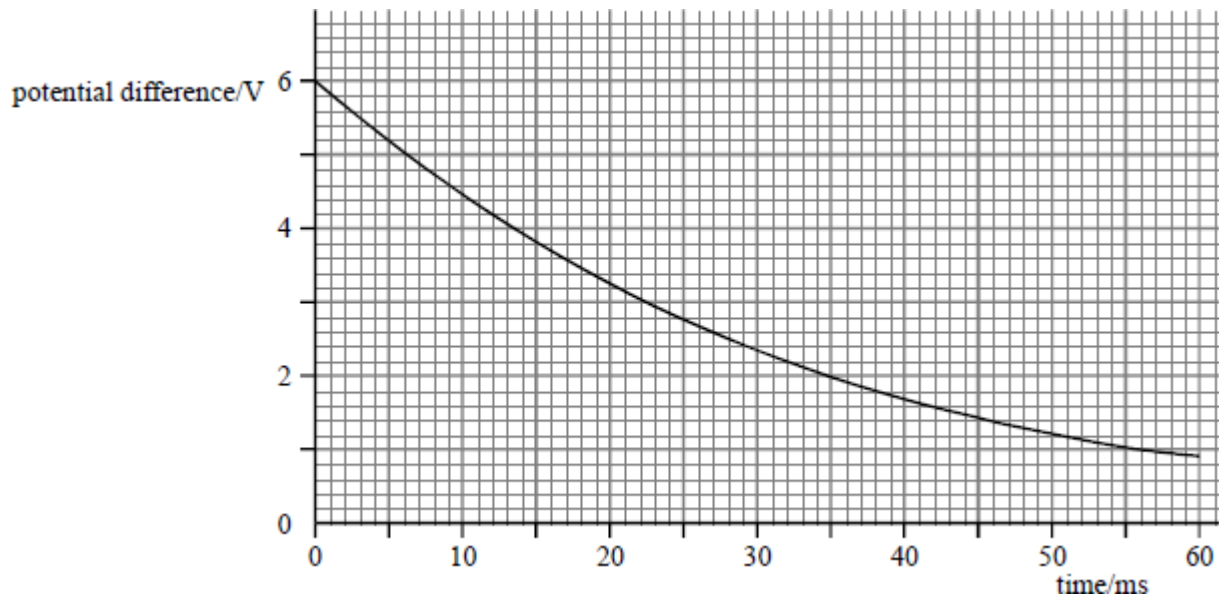
(ii) the energy stored by the capacitor.

(2)

(Total 5 marks)

20

A student used a voltage sensor connected to a datalogger to plot the discharge curve for a $4.7 \mu\text{F}$ capacitor. She obtained the following graph.



Use data from the graph to calculate

- (a) the initial charge stored,

(2)

- (b) the energy stored when the capacitor had been discharging for 35 ms,

(3)

- (c) the time constant for the circuit,

(3)

- (d) the resistance of the circuit through which the capacitor was discharging.

(2)

(Total 10 marks)

21

- (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)

22

A $10 \mu\text{F}$ capacitor is connected across the terminals of a 100 V d.c. power supply and allowed to charge fully.

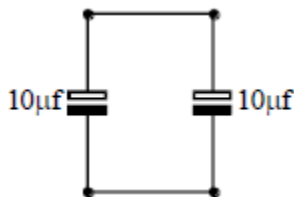
(a) Calculate

(i) the charge on the capacitor,

(ii) the energy stored by the capacitor.

(2)

- (b) The fully-charged capacitor is disconnected from the power supply and connected via two wires across the terminals of an uncharged $10\ \mu\text{F}$ capacitor as shown.



The charge on the original $10\ \mu\text{F}$ capacitor is shared equally between the capacitors in the parallel combination.

- (i) Calculate the potential difference across the terminals of each capacitor.

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

- (iii) Account for the difference between the energy stored by the two capacitors in parallel and that stored by the original single $10\ \mu\text{F}$ capacitor.

(4)

(Total 6 marks)

23

- (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 $2.3 \times 10^{-11}\ \text{F}$.

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

The relative permittivity of air = 1.0

Calculate:

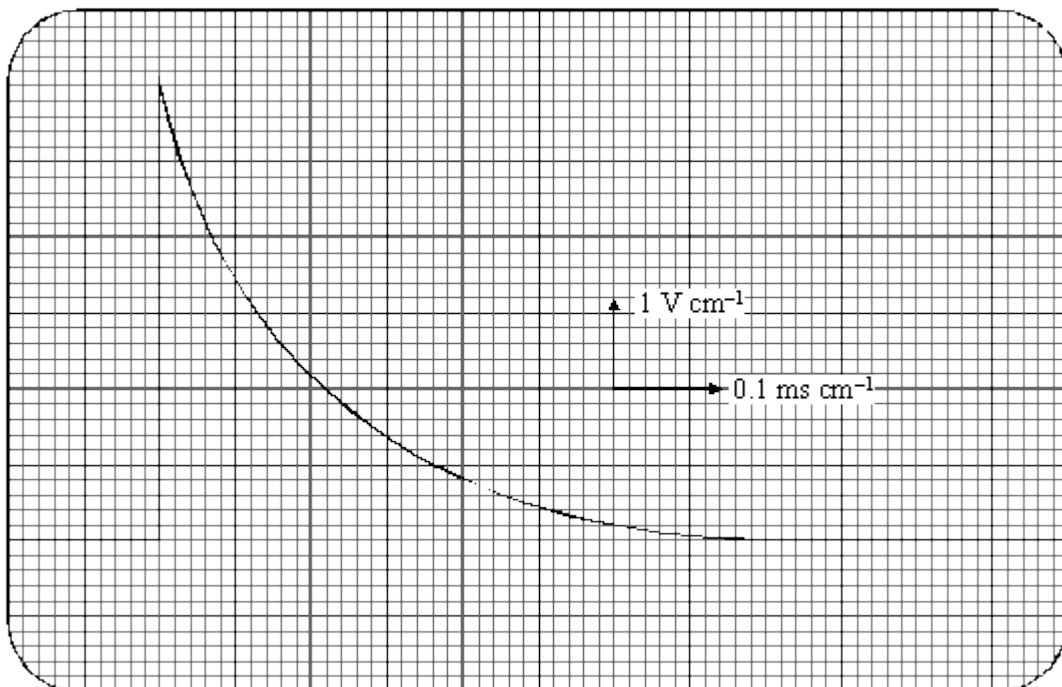
- (i) the radius of the plates used in the capacitor;

(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)

24

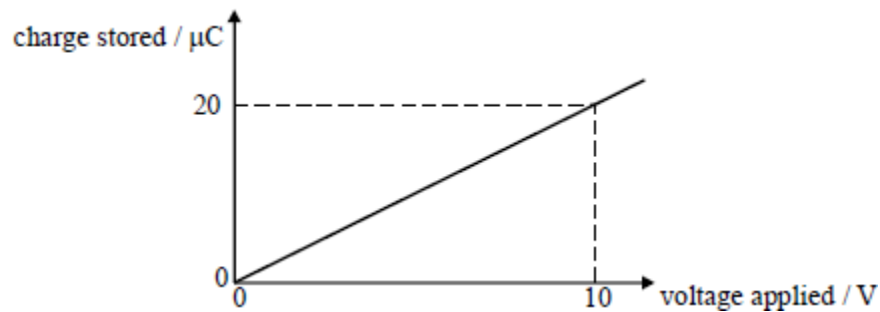
In experiments to pass a very high current through a gas, a bank of capacitors of total capacitance $50\ \mu\text{F}$ is charged to $30\ \text{kV}$. If the bank of capacitors could be discharged completely in $5.0\ \text{ms}$ what would be the mean power delivered?

- A 9.0 MW
- B 4.5 MW
- C 110 kW
- D 22 kW

(Total 1 mark)

25

The graph shows the charge stored in a capacitor as the voltage across it is varied.



The energy stored, in μJ , when the potential difference across the capacitor is $5\ \text{V}$, is

- A 25
- B 50
- C 100
- D 200

(Total 1 mark)

1

2

2

2

2

2

[1]

3

[1]

4

1

2

(b) Attempted use of $E = \frac{1}{2} CV^2$ Or attempted use of $E = \frac{1}{2} QV$

C1

9.38 (μJ) – 2.16 (μJ) seen

or $E = \frac{1}{2} \times 3 \times 10^{-6} \times 2.5^2 - \frac{1}{2} \times 3 \times 10^{-6} \times 1.2^2$ seen

or $E = \frac{1}{2} \times 3 \times 10^{-6} \times (2.5^2 - 1.2^2)$ seen

or $E = \frac{1}{2} \times 7.5 \times 10^{-6} \times 2.5 - \frac{1}{2} \times 3.6 \times 10^{-6} \times 1.2$ seen

C1

7.2×10^{-6} (J) c.a.o

A1

3

(c) (i) Use of $V = V_0 e^{-\frac{t}{RC}}$
or equivalent with

$$Q = Q_0 e^{-\frac{t}{RC}}$$

C1

$$R = - \left(\frac{1.4 \times 10^{-3}}{\ln\left(\frac{1.2}{2.5}\right) \times 3 \times 10^{-8}} \right) \text{ or } R = - \left(\frac{t}{\ln\left(\frac{V_0}{V}\right) \times C} \right) \text{ or } R = \left(\frac{t}{\ln\left(\frac{V_0}{V}\right) \times C} \right)$$

C1

636 or 640 (Ω)

A1

3

(ii) Current decreases ($I = V / R$) / describes rate of flow of electrons decreasing / rate of flow of charge decreases

M1

Charge lost more slowly so pd falls more slowly because
 $V \propto Q$ or $Q = CV$ where C is constant

A1

MAX 2

[12]

5 B

[1]

6 B

[1]

- 7 B [1]
- 8 D [1]
- 9 D [1]
- 10 A [1]
- 11 B [1]
- 12 C [1]
- 13 (a) $E \propto V^2$ (or $E = \frac{1}{2}CV^2$) (1)
pd after 25 s = 6 V (1)

2

- (b) (i) use of $Q = Q_0 e^{-t/RC}$ or $V = V_0 e^{-t/RC}$ (1)
(e.g. $6 = 12e^{-25/RC}$) gives $e^{\frac{25}{RC}} = \frac{12}{6}$ and $\frac{25}{RC} = \ln 2$ (1)
($RC = 36(.1)$ s)
[alternatives for (i):
 $V = 12 e^{-25/36}$ gives $V = 6.0$ V (1) (5.99 V)
or time for pd to halve is $0.69RC$
 $\therefore RC = \frac{25}{0.69}$ (1) = 36(.2) s]

(ii) $R = \frac{36.1}{680 \times 10^{-6}}$ (1) = $5.3(0) \times 10^4 \Omega$ (1)

4

[6]

- 14 (a) $Q (= CV = 330 \times 9.0) = 2970$ (μC) (1)
 $E (= \frac{1}{2}QV) = \frac{1}{2} \times 2.97 \times 10^{-3} \times 9.0 = 1.34 \times 10^{-2} \text{J}$ (1)
[or $E (= \frac{1}{2}CV^2) = \frac{1}{2} \times 300 \times 10^{-6} \times 9.0^2$ (1) = $1.34 \times 10^{-2} \text{J}$ (1)]

2

- (b) time constant ($= RC$) = $470 \times 10^3 \times 330 \times 10^{-6} = 155$ s (1)

1

(c) $Q(=Q_0 e^{-t/RC}) = 2970 \times e^{-60/155}$

$= 2020 \text{ } (\mu\text{C})$

(allow C.E. for time constant from (b))

$V = \left(\frac{Q}{C}\right) = \frac{2020}{330} = 6.11 \text{ V } \textbf{(1)}$

(allow C.E. for Q)

[or $V = V_0 e^{-t/RC} \textbf{(1)} = 9.0 e^{-60/155} \textbf{(1)} = 6.11 \text{ V } \textbf{(1)}$]

3

[6]

15

C

[1]

16

B

[1]

17

D

[1]

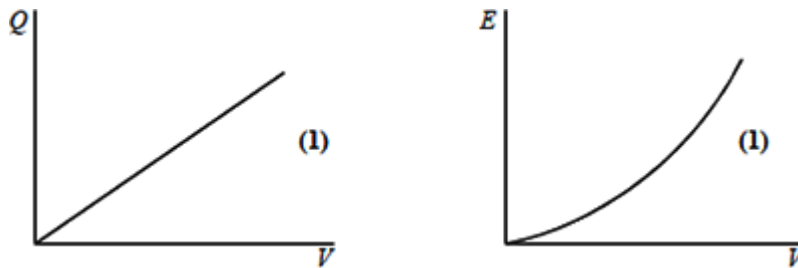
18

B

[1]

19

(a)



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

(3)

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

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

(2)

[5]

20

(a) $Q = CV \textbf{(1)}$

$(= 4.7 \times 10^{-6} \times 6.0) = 28 \times 10^{-6} \text{ C or } 28 \text{ } \mu\text{C } \textbf{(1)}$

2

(b) $E = \frac{1}{2}CV^2$ (1)
 $= \frac{1}{2} \times 4.7 \times 10^{-6} \times 2.0^2$ (1)
 $= 9.4 \times 10^{-6} \text{ J}$ (1)
[or $E = \frac{1}{2}QV$ (1)
 $= \frac{1}{2} \times 9.4 \times 10^{-6} \times 2.0$ (1)
 $= 9.4 \times 10^{-6} \text{ J}$ (1)]

3

(c) time constant is time taken for V to fall to $\frac{V_0}{e}$ (1)
 $\therefore V$ must fall to 2.2 V (1)
time constant = 32 ms (1)
[or draw tangent at $t = 0$ (1)
intercept of tangent on t axis is time constant (1)
accept value 30 - 35 ms (1)]
[or $V = V_0 \exp(-t / RC)$ or $Q = Q_0 \exp(-t / RC)$ (1)
correct substitution (1)
time constant = 32 ms (1)]

3

(d) time constant = RC (1)

$$R = \frac{32 \times 10^{-3}}{4.7 \times 10^{-3}} = 6800 \, \Omega \text{ (1)}$$

(allow C.E. for value of time constant from (c))

2

[10]

21

(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

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

$$E \left(= \frac{1}{2} CV^2 \right) = \frac{1}{2} \times 9.44 \times 10^{-8} \times (200 \times 10^3)^2 \quad (1)$$

$$= 1890 \text{ J} \quad (1)$$

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

$$= 157 \text{ A} \quad (1)$$

6
[10]

22

$$(a) \quad (i) \quad Q = 1.0 \times 10^{-3} \text{ C} \quad (1)$$

$$(ii) \quad E = 5.0 \times 10^{-2} \text{ J} \quad (1)$$

2

$$(b) \quad (i) \quad V = 50 \text{ V} \quad (1)$$

$$(ii) \quad (E_1 = \frac{1}{2} QV = 1.25 \times 10^{-2} \text{ J}) \quad E_2 = 2.5 \times 10^{-2} \text{ J} \quad (1)$$

(iii) current flows (when capacitors connected together) (1)
(energy lost due to) heat in wires (1)

4
[6]

23

(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

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

C1

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

A1

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

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

$$8.1 - 8.6 \text{ M}\Omega$$

A1

3

[9]

24

B

[1]

25

A

[1]