Capacitors

Long Answer Questions

Name: ______________________

Class: ______________________

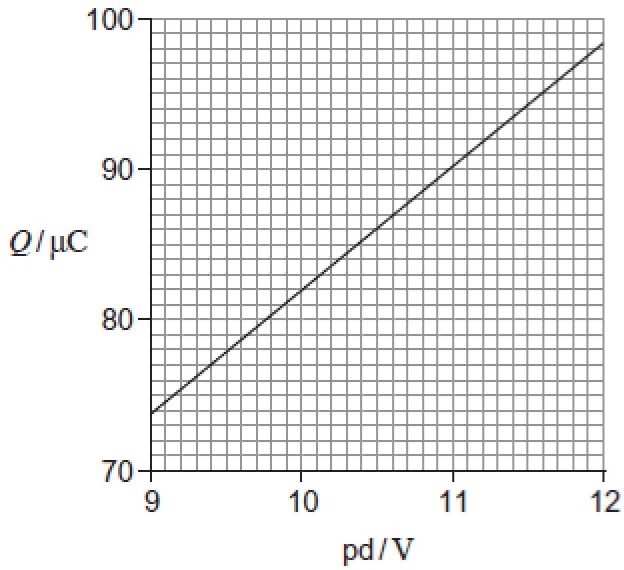
Date: ______________________

Time: **318 minutes**

Marks: **251 marks**

Comments:

1 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 μF 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)

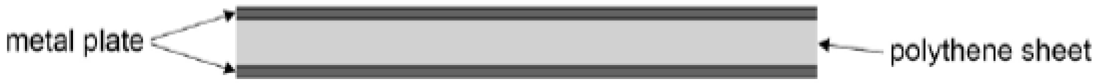
(iii) At which point during the discharging process is the capacitor losing charge at the smallest rate? Tick (✓) the correct answer.

	✓ 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)

2 The figure below shows a capacitor of capacitance 370 pF. It consists of two parallel metal plates of area 250 cm^2. 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

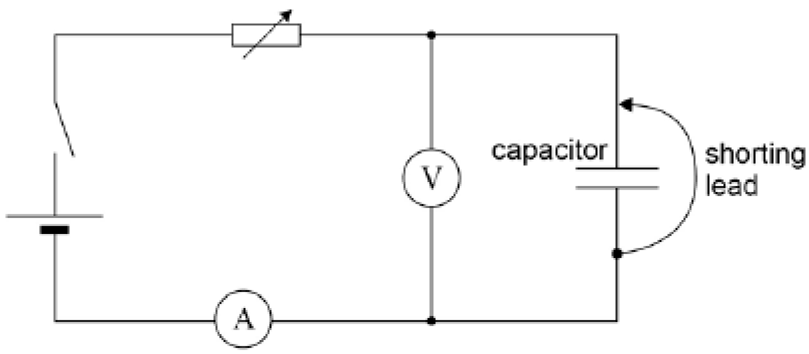
(2)

(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)

3 This question is about capacitor charging and discharging.

A student designs an experiment to charge a capacitor using a constant current. The figure below shows the circuit the student designed to allow charge to flow onto a capacitor that has been initially discharged.



The student begins the experiment with the shorting lead connected across the capacitor as in the figure above. The variable resistor is then adjusted to give a suitable ammeter reading. The shorting lead is removed so that the capacitor begins to charge. At the same instant, the stop clock is started.

The student intends to measure the potential difference (pd) across the capacitor at 10 s intervals while adjusting the variable resistor to keep the charging current constant.

The power supply has an emf of 6.0 V and negligible internal resistance. The capacitor has a capacitance of 680 μF. The variable resistor has a maximum resistance of 100 kΩ.

(a) The student chooses a digital voltmeter for the experiment. A digital voltmeter has a very high resistance.

Explain why it is important to use a voltmeter with very high resistance.

(1)

(b) Suggest **one** advantage of using an analogue ammeter rather than a digital ammeter for this experiment.

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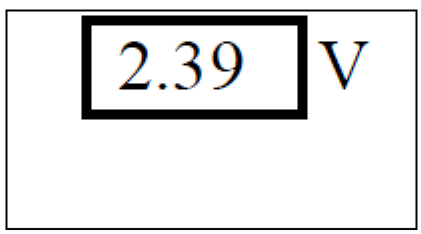
(1)

(c) Suggest a suitable full scale deflection for an analogue ammeter to be used in the experiment.

full scale deflection = ____________________

(2)

(d) The diagram shows the reading on the voltmeter at one instant during the experiment. The manufacturer gives the uncertainty in the meter reading as 2%.



Calculate the absolute uncertainty in this reading.

uncertainty = ____________________V

(1)

(e) Determine the number of different readings the student will be able to take before the capacitor becomes fully charged.

number = ____________________

(3)

(f) The experiment is performed with a capacitor of nominal value 680 μF and a manufacturing tolerance of ± 5 %. In this experiment the charging current is maintained at 65 μA. The data from the experiment produces a straight-line graph for the variation of pd with time. This shows that the pd across the capacitor increases at a rate of 98 mV s^{-1}.

Calculate the capacitance of the capacitor.

capacitance = ____________________ μF

(2)

(g) Deduce whether the capacitor is within the manufacturer's tolerance.

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(1)

(h) The student decides to confirm the value of the capacitance by first determining the time constant of the circuit when the capacitor **discharges** through a **fixed** resistor.

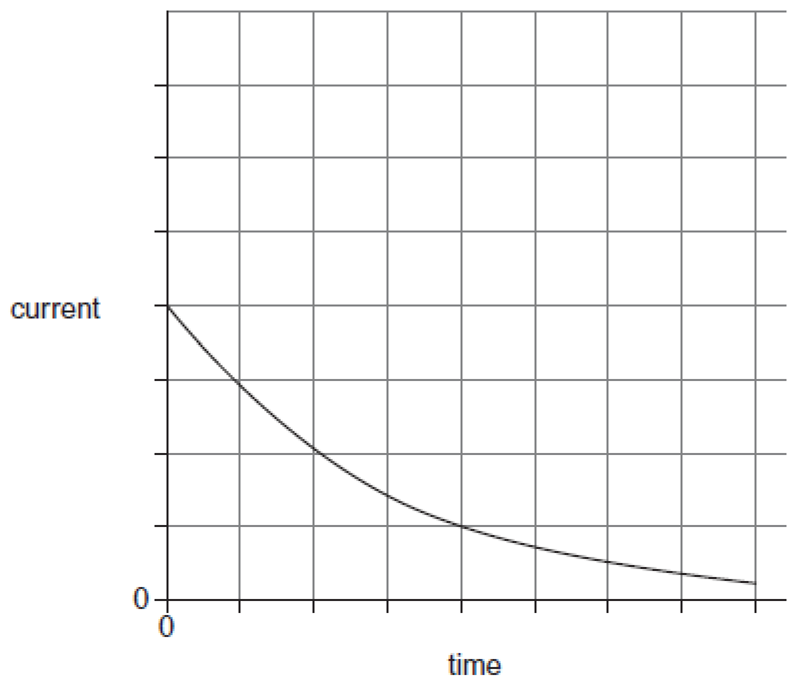
Describe an experiment to do this. Include in your answer:

- a circuit diagram
- an outline of a procedure
- an explanation of how you would use the data to determine the time constant.

(4)

(Total 15 marks)

4 (a) The graph shows how the current varies with time as a capacitor is discharged through a 150 Ω resistor.



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

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(1)

(ii) The same capacitor is charged to the same initial potential difference (pd) and then discharged through a 300 kΩ 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. ____

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2. ____

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(2)

(Total 10 marks)

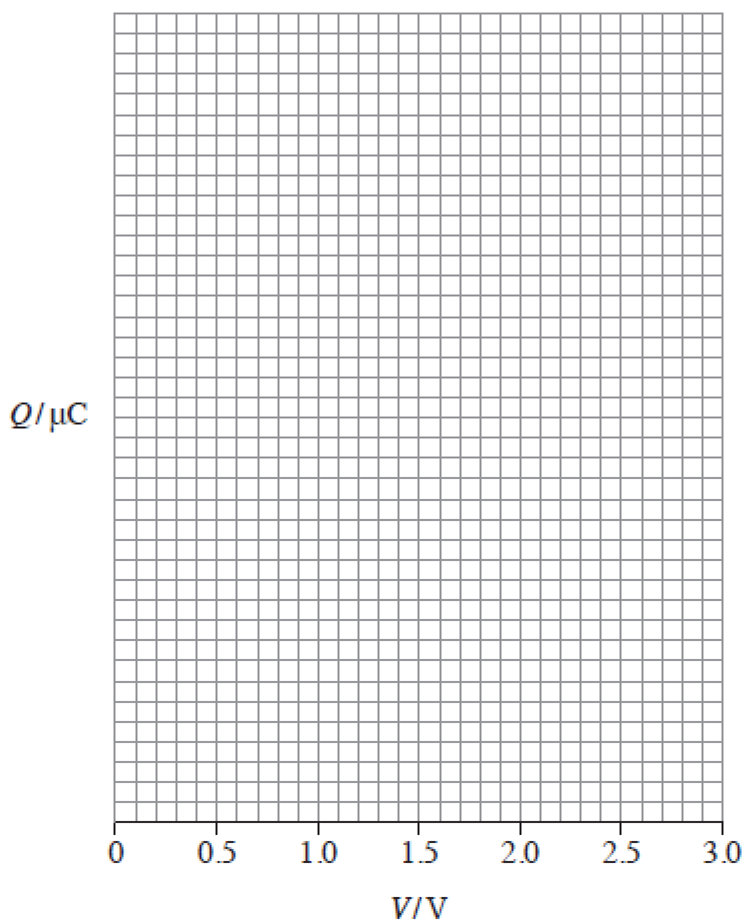
5 The specification for a pacemaker requires a suitable charge to be delivered in 1.4 ms. A designer uses a circuit with a capacitor of capacitance 3.0 μF and a 2.5 V power supply to deliver the charge. The designer calculates that a suitable charge will be delivered to the heart as the capacitor discharges 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.

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(2)

(Total 12 marks)

6 (a) When an uncharged capacitor is charged by a **constant** current of 4.5 μA for 60 s the pd across it becomes 4.4 V.

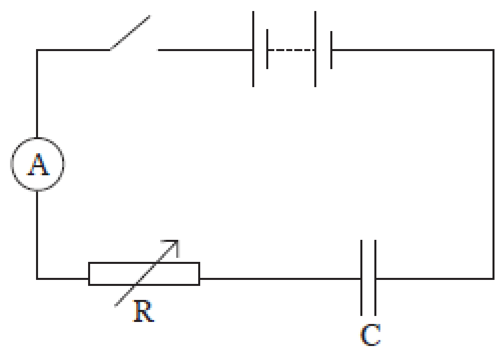
(i) Calculate the capacitance of the capacitor.

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 μA, the resistance of the variable resistor R is decreased steadily as the charge on the capacitor increases.

Figure 1



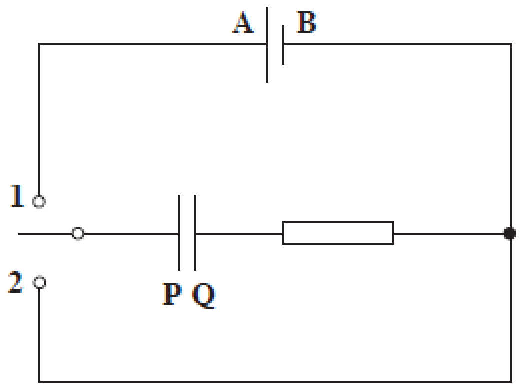
Calculate the resistance of R when the uncharged capacitor has been charging for 30 s.

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.

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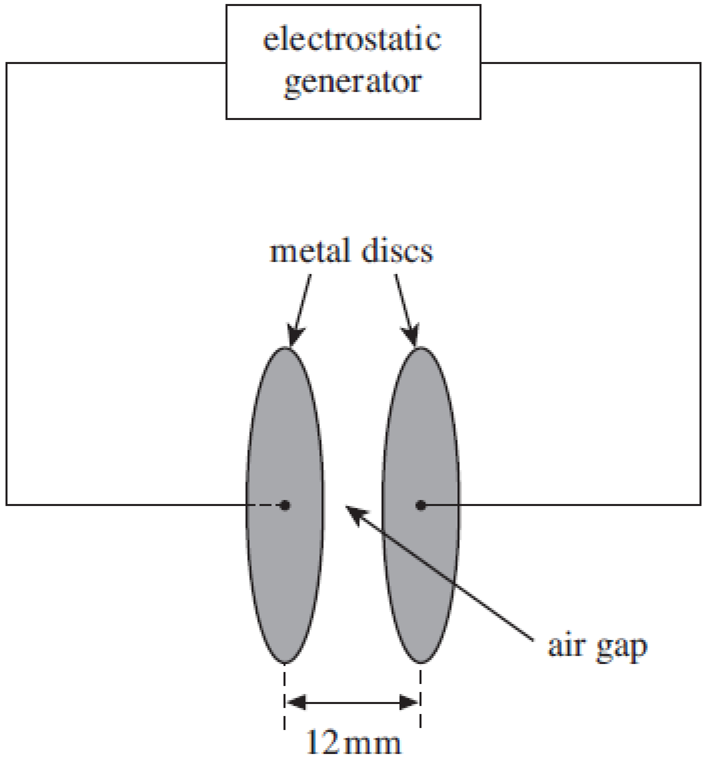
(6)

(Total 12 marks)

7 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 3.2×10^{-8} A on a day when the minimum breakdown field strength of the air is 2.5×10^{6} V m^{-1}. The discs have a capacitance of 3.7×10^{-12} 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,

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(2)

(ii) the brightness of each spark.

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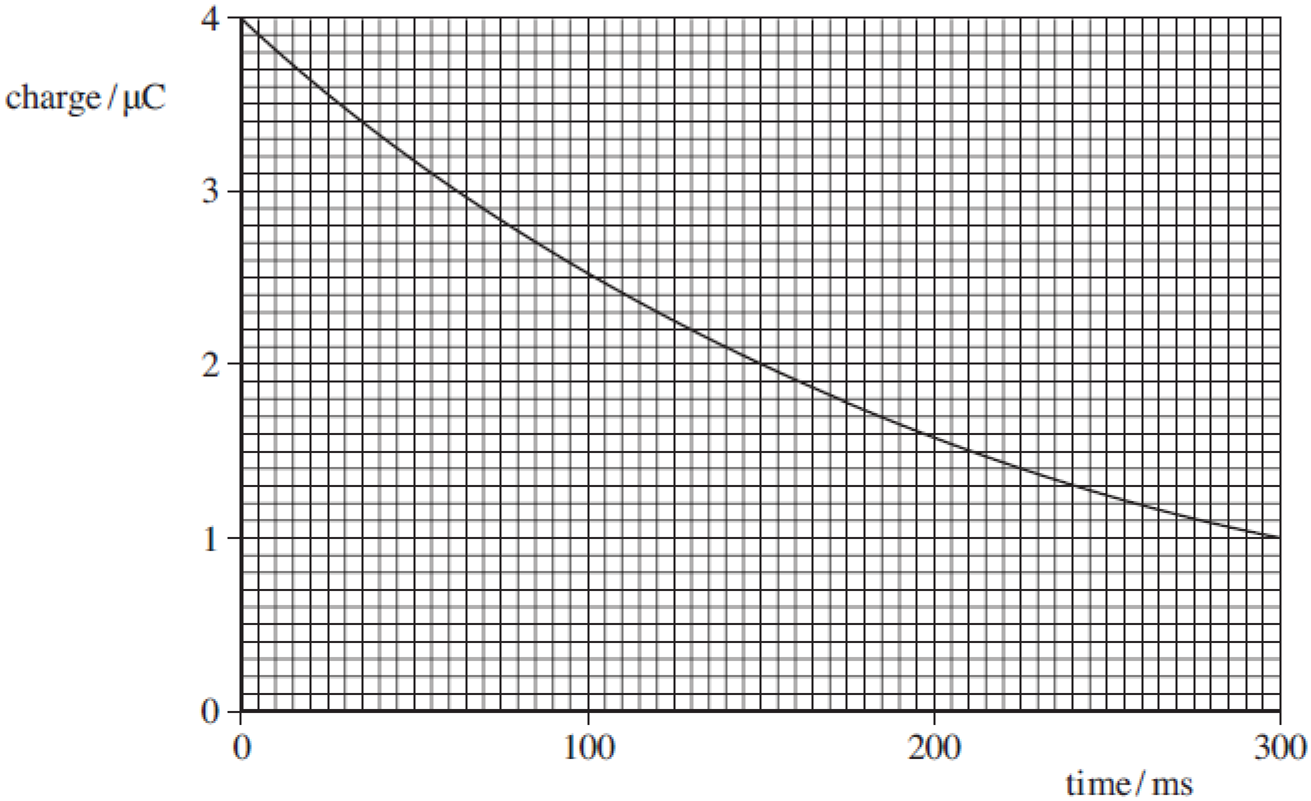
(2)

(Total 7 marks)

8 The graph below shows how the charge stored by a capacitor varies with time when it is discharged through a fixed resistor.



(a) Determine the time constant, in ms, of the discharge circuit.

time constant ____________________ ms

(3)

(b) Explain why the rate of discharge will be greater if the fixed resistor has a smaller resistance.

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(2)

(Total 5 marks)

9 (a) Define the capacitance of a capacitor.

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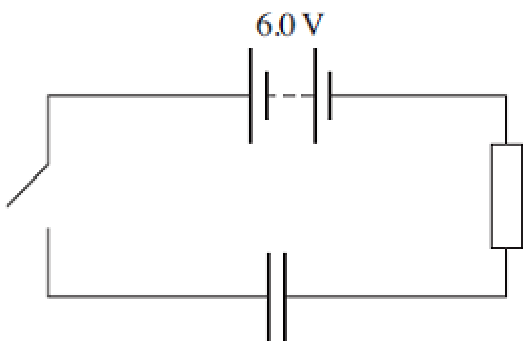
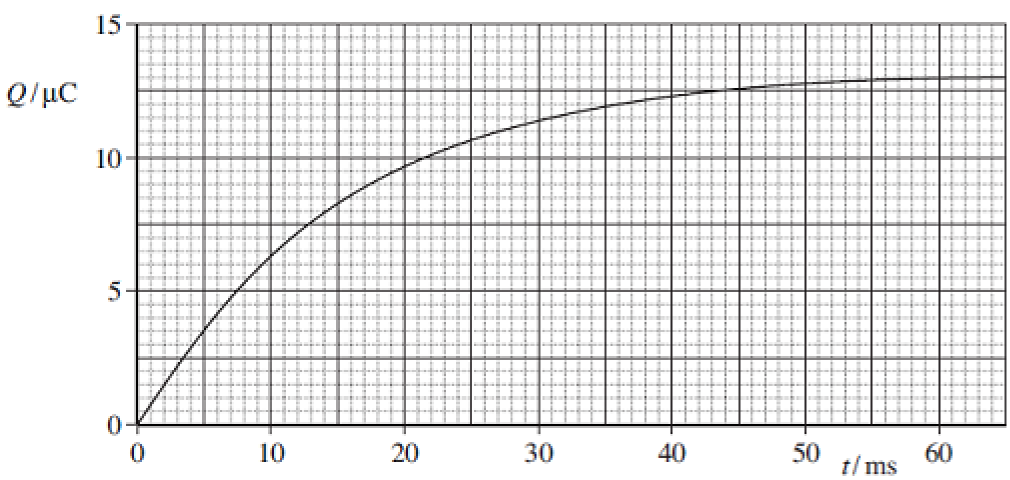
(2)

(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 μC. 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?

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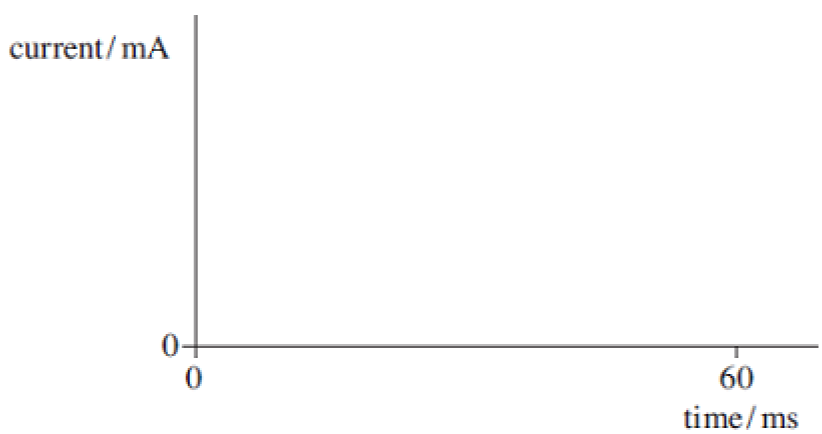
(1)

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

answer = ______________________ mA

(1)

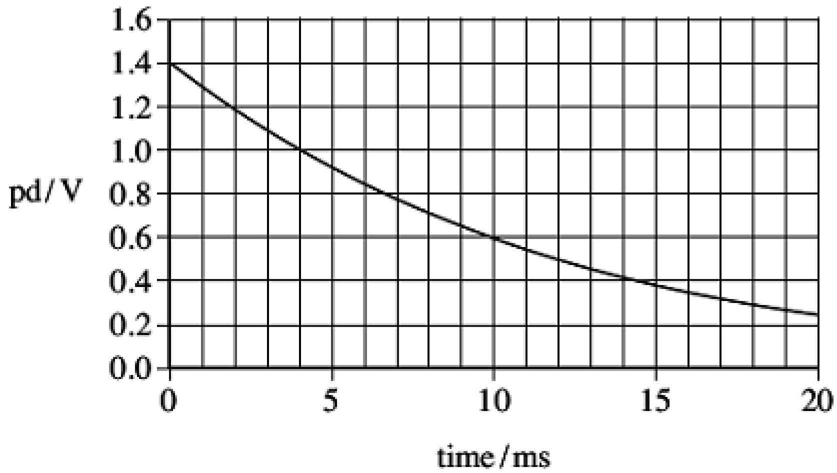
(ii) Sketch a graph on the outline axes to show how the current varies with time as the capacitor is charged. Mark the maximum value of the current on your graph.



(2)

(Total 11 marks)

10 The figure below shows part of the discharge curve for a capacitor that a manufacturer tested for use in a heart pacemaker.



The capacitor was initially charged to a potential difference (pd) of 1.4 V and then discharged through a 150 Ω resistor.

(a) Show that the capacitance of the capacitor used is about 80 μF.

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(3)

(b) Explain why the rate of change of the potential difference decreases as the capacitor discharges.

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(3)

(c) Calculate the percentage of the initial energy stored by the capacitor that is lost by the capacitor in the first 0.015 s of the discharge.

energy lost ______________________%

(3)

(d) The charge leaving the capacitor in 0.015 s is the charge used by the pacemaker to provide a single pulse to stimulate the heart.

(i) Calculate the charge delivered to the heart in a single pulse.

charge ______________________C

(1)

(ii) The manufacturer of the pacemaker wants it to operate for a minimum of 5 years working at a constant pulse rate of 60 per minute.
Calculate the minimum charge capacity of the power supply that the manufacturer should specify so that it will operate for this time.
Give your answer in amp-hours (Ah).

minimum capacity ______________________Ah

(2)

(Total 12 marks)

11 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 ____

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Reason 2 ____

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(2)

(Total 7 marks)

12 (a) A particular heart pacemaker uses a capacitor which has a capacitance of 4.2 μF.
Explain what is meant by *a capacitance of 4.2 μF*.

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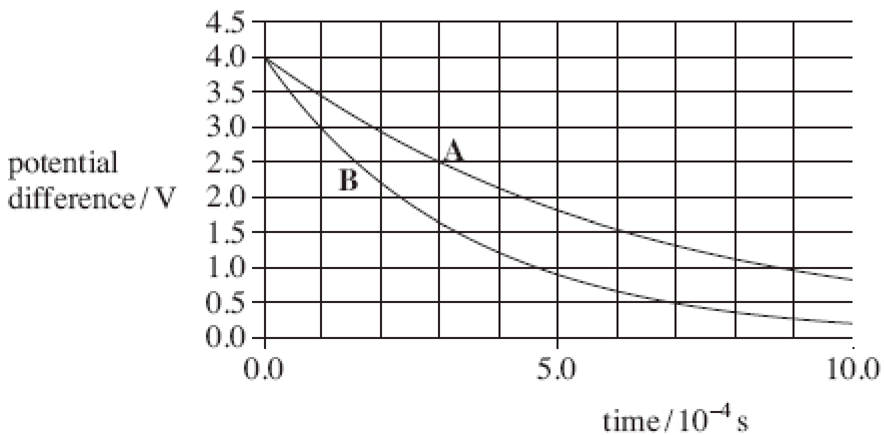
(2)

(b) Capacitor **A**, of capacitance 4.2 μF, 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 150 Ω.

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(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)

13 **Figure 1** shows a circuit that is used in a defibrillator in which a short pulse of charge is used to revive a patient who suffers a cardiac arrest in which their heart stops beating.

Figure 2 shows how the charge on the capacitor varies with time when the capacitor is charging.

Figure 1

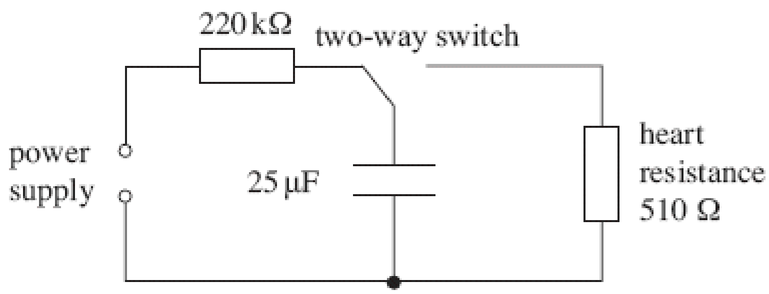
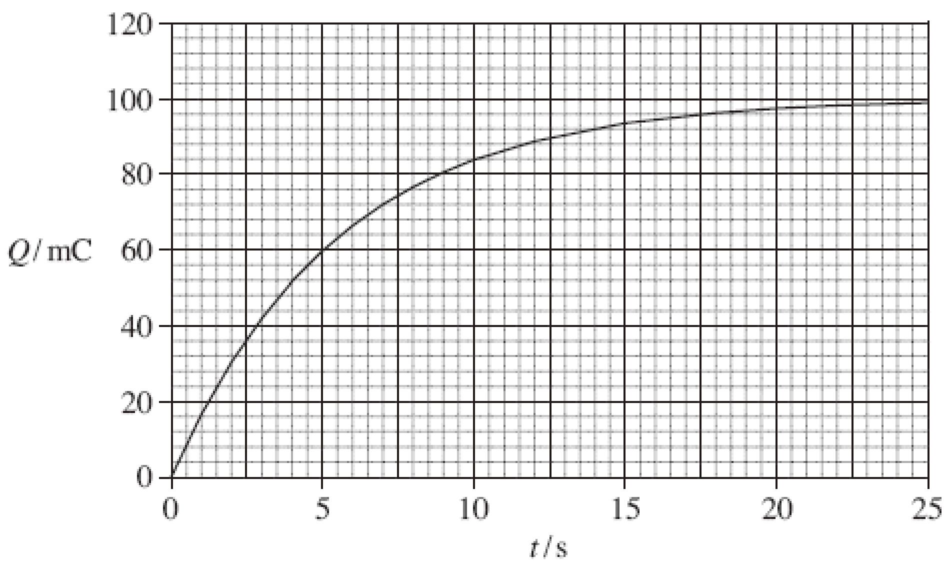


Figure 2



(a) (i) Use **Figure 2** to determine the initial charging current.

initial charging current ____________________ A

(2)

(ii) Calculate the emf of the supply used to charge the capacitor.
Assume that the supply has negligible internal resistance.

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emf of the supply ______________________ V

(2)

(iii) Explain why the current that charges the capacitor falls as the capacitor charges.

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(3)

(b) For the system to work successfully, the capacitor has to deliver 140 J of energy to the heart in a pulse that lasts for 10 ms.

(i) Show that the charge on the capacitor when it is storing this much energy is about 85 mC.

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(2)

(ii) Calculate the average power supplied during the pulse.

average power ______________________ W

(1)

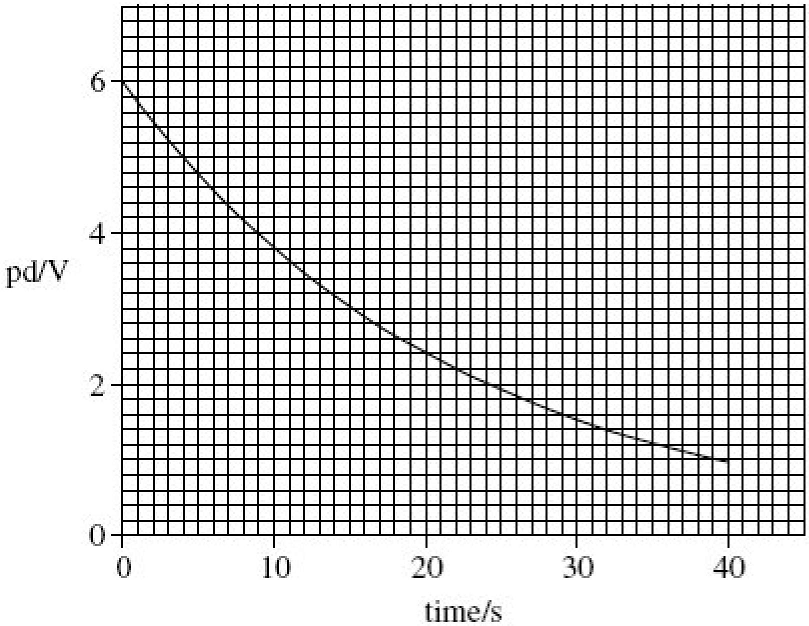
(c) The circuit designer suggests that the capacitor can be used successfully after a charging time equal to 1.5 time constants of the charging circuit shown in **Figure 1**.

Explain with a calculation whether or not the designer's suggestion is valid.

(3)

(Total 13 marks)

14 (a) A capacitor, initially charged to a pd of 6.0V, was discharged through a 100 kΩ resistor. A datalogger was used to record the pd across the capacitor at frequent intervals. The graph shows how the pd varied with time during the first 40 s of discharge.



(i) Calculate the initial discharge current.

answer = ____________________ A

(1)

(ii) Use the graph to determine the time constant of the circuit, giving an appropriate unit.

answer = ____________________

(4)

(iii) Hence calculate the capacitance of the capacitor.

answer = ____________________ μF

(1)

(iv) Show that the capacitor lost 90% of the energy it stored originally after about 25 s.

(3)

(b) In order to produce a time delay, an intruder alarm contains a capacitor identical to the capacitor used in the experiment in part (a). This capacitor is charged from a 12 V supply and then discharges through a 100 kΩ resistor, similar to the one used in the experiment.

(i) State and explain the effect of this higher initial pd on the energy stored by this capacitor initially.

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(2)

(ii) State and explain the effect of this higher initial pd on the time taken for this capacitor to lose 90% of its original energy.

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(1)

(Total 12 marks)

15 (a) (i) Define the capacitance of a capacitor.

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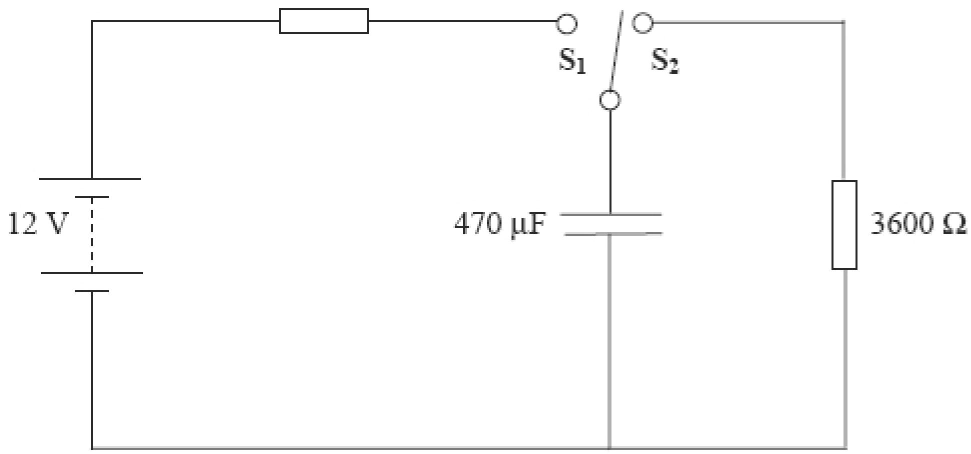
(ii) Calculate the charge, in C, stored on a 470 μF capacitor which has a potential difference of 2.3×10^2 V across it.

(2)

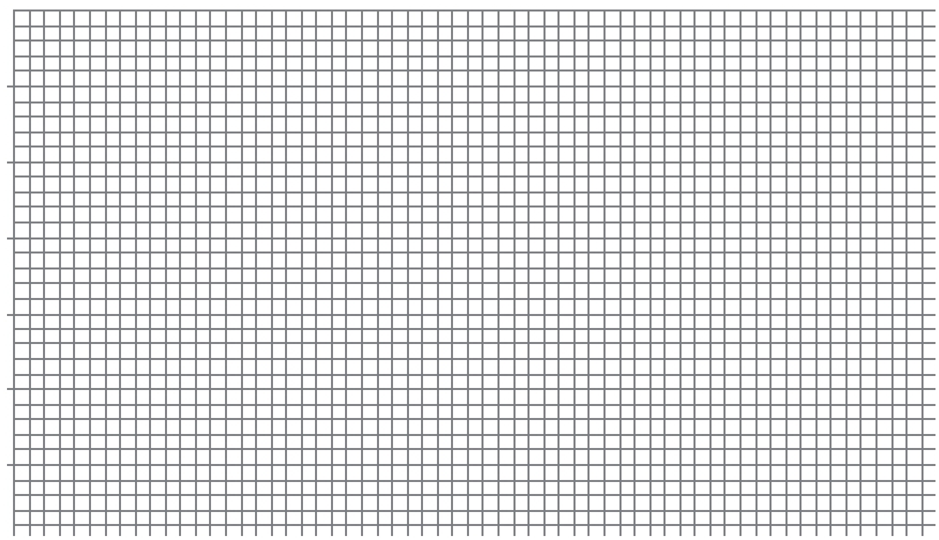
(b) A 470 μF capacitor is connected in a circuit which enables it to charge when the switch is in position **S_1** and discharged when the switch is in position **S_2**. The arrangement is shown in **Figure 1.**

Figure 1



(i) Calculate the time constant of the discharge circuit when the switch is in position **S_2**. Give your answer in s.

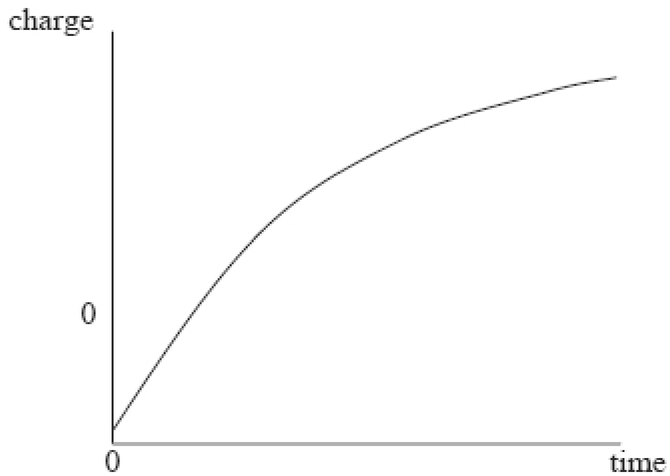
(ii) The capacitor is fully charged and then discharged. On the axes below, mark appropriate scales and draw a graph to show the variation of the potential difference across the capacitor with time for the discharge of the capacitor.



(4)

(c) **Figure 2** shows the variation of charge with time for the charging of the capacitor.

Figure 2



Explain why the charge across the capacitor changes in the way shown by the graph.

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(3)

(Total 9 marks)

16 (a) As a capacitor was charged from a 12 V supply, a student used a coulomb meter and a voltmeter to record the charge stored by the capacitor at a series of values of potential difference across the capacitor. The student then plotted a graph of pd (on the *y*-axis) against charge (on the *x*-axis).

(i) Sketch the graph obtained.

(ii) State what is represented by the gradient of the line.

____

(iii) State what is represented by the area enclosed by the line and the *x*-axis of the graph.

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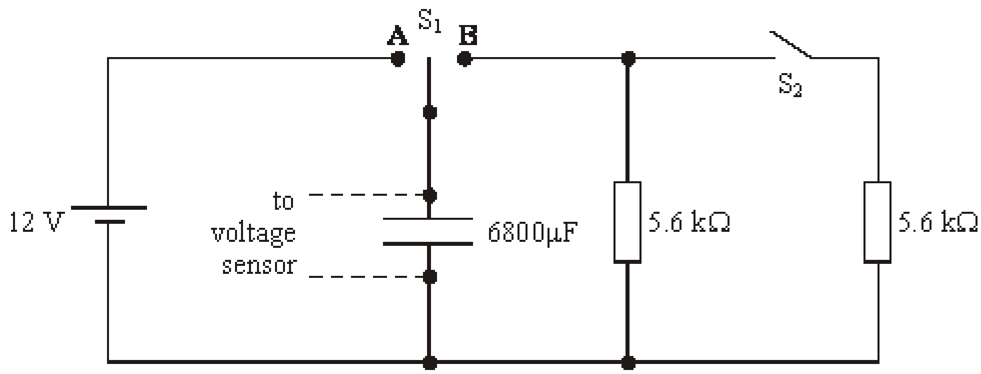
(3)

(b) The student then connected the capacitor as shown in the diagram below to carry out an investigation into the discharge of the capacitor.



The student used a voltage sensor, datalogger and computer to obtain values for the pd across the capacitor at various times during the discharge.

(i) At time t = 0, with switch S_2 open, switch $S_1$was moved from position **A** to position **B**. Calculate the pd across the capacitor when t = 26 s.

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(ii) At time t = 26 s, as the discharge continued, the student closed switch S_2. Calculate the pd across the capacitor 40 s after switch S_1 was moved from position **A** to position **B**.

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(iii) Sketch a graph of pd against time for the student's experiment described in parts (b)(i) and (b)(ii).

(7)

(Total 10 marks)

17 A capacitor of capacitance 330 μF is charged to a potential difference of 9.0 V. It is then discharged through a resistor of resistance 470 kΩ.

Calculate

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

(2)

(b) the time constant of the discharging circuit,

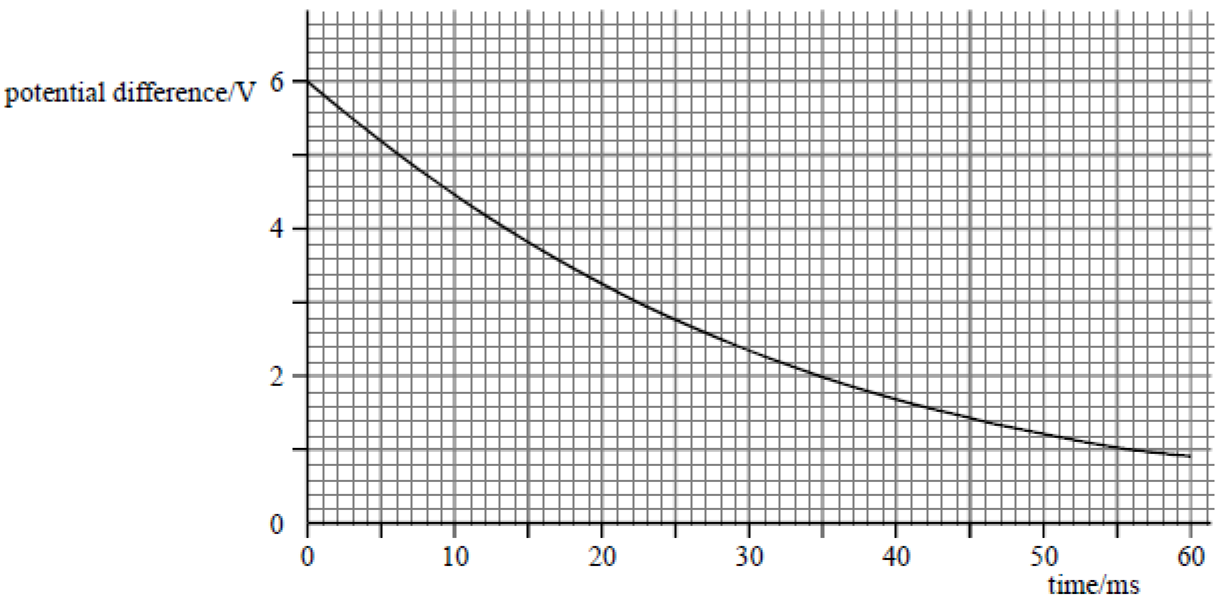
(1)

(c) the p.d. across the capacitor 60 s after the discharge has begun.

(3)

(Total 6 marks)

18 A student used a voltage sensor connected to a datalogger to plot the discharge curve for a 4.7 μF 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)

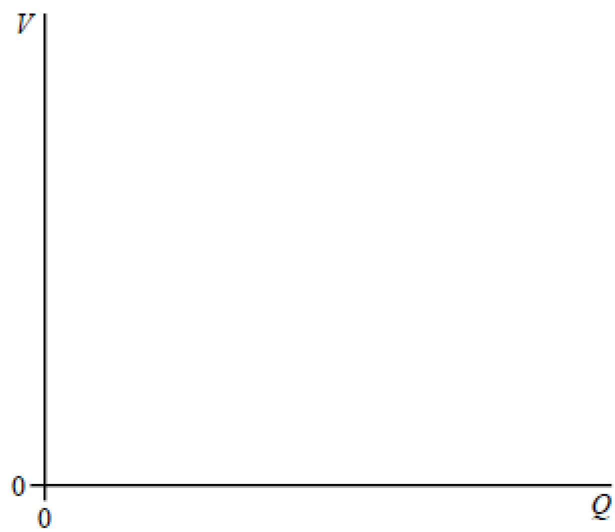
(c) the time constant for the circuit,

(3)

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

(2)
(Total 10 marks)

19 (a) A 2.0 μF capacitor is charged through a resistor from a battery of emf 4.5 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 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 μs. Calculate the mean current flowing between the cloud and the earth when this happens.

___

___

___

___

(6)

(Total 10 marks)

21 (a) State the **three** factors upon which the capacitance of a parallel plate capacitor depends.

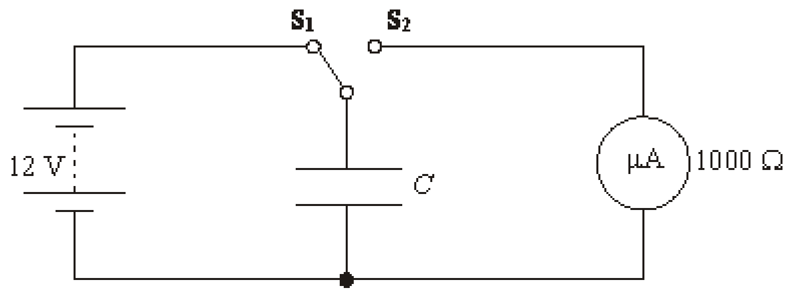
___

___

___

(2)

(b) The figure below shows a circuit for measuring the capacitance of a capacitor.



The switch is driven by a signal generator and oscillates between S_1 and S_2 with frequency *f*.

When the switch is in position S_1 the capacitor charges until the potential difference across it is equal to the supply emf. When the switch moves to position S_2 the capacitor discharges through the microammeter which has a resistance of 1000 Ω.

In one experiment a 0.047 μF capacitor is used with a 12 V supply.

(i) Calculate the charge stored by the capacitor when the switch is in position S_1.

(ii) Calculate the time for which the switch must remain in contact with S_2 in order for the charge on the capacitor to fall to 1% of its initial charge.

(iii) Assuming that the capacitor discharges all the stored charge through the microammeter, calculate the reading on the meter when the switch oscillates at 400 Hz.

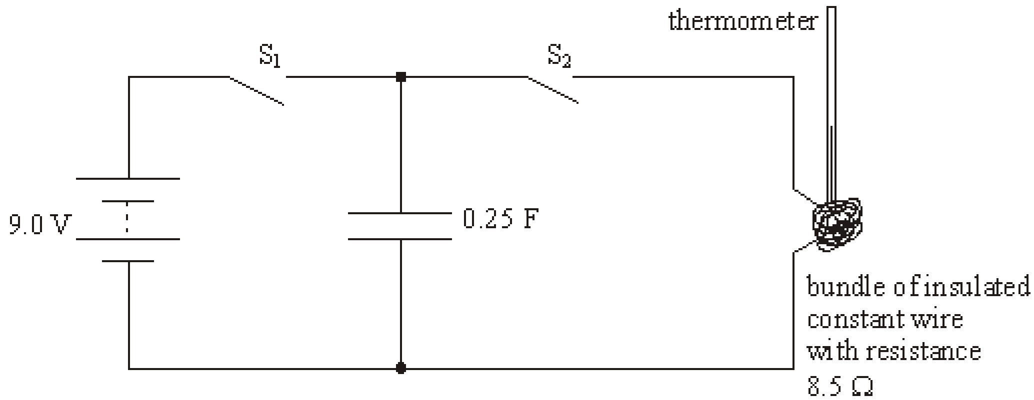
(6)

(Total 8 marks)

22 (a) A 500 μF capacitor and a 1000 μF capacitor are connected in series. Calculate the total capacitance of the combination.

(2)

(b) The figure below shows a diagram of an arrangement used to investigate the energy stored by a capacitor.



The bundle of constantan wire has a resistance of 8.5 Ω. The capacitor is initially charged to a potential difference of 9.0 V by closing $\mathbf{S_1}$.

(i) Calculate the charge stored by the 0.25 F capacitor.

(ii) Calculate the energy stored by the capacitor.

(iii) Switch $\mathbf{S}_1$ is now opened and $\mathbf{S}_2$ is closed so that the capacitor discharges through the constantan wire. Calculate the time taken for the potential difference across the capacitor to fall to 0.10 V.

(7)

(c) The volume of constantan wire in the bundle in the figure above is 2.2×10^{-7} m^3.

density of constantan = 8900 kg m^{-3}

specific heat capacity of constantan = 420 J kg^{-1} K^{-1}

(i) Assume that all the energy stored by the capacitor is used to raise the temperature of the wire. Use your answer to part (b)(ii) to calculate the expected temperature rise when the capacitor is discharged through the constantan wire.

(ii) Give **two** reasons why, in practice, the final temperature will be lower than that calculated in part (c)(i).

____

____

____

(5)

(Total 14 marks)

23 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 × 106 m^2 and is 800 m above the Earth's surface.

$\varepsilon_0 = 8.9 \times 10^{-12}$ F m^{-1}

ε_r for air = 1.0

(2)

(b) A potential difference of 3.0×10^6 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 2.5×10^9 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)

24 (a) (i) A label on a capacitor shows it to have a capacitance of 0.020 F. Explain what this tells you about the capacitor.

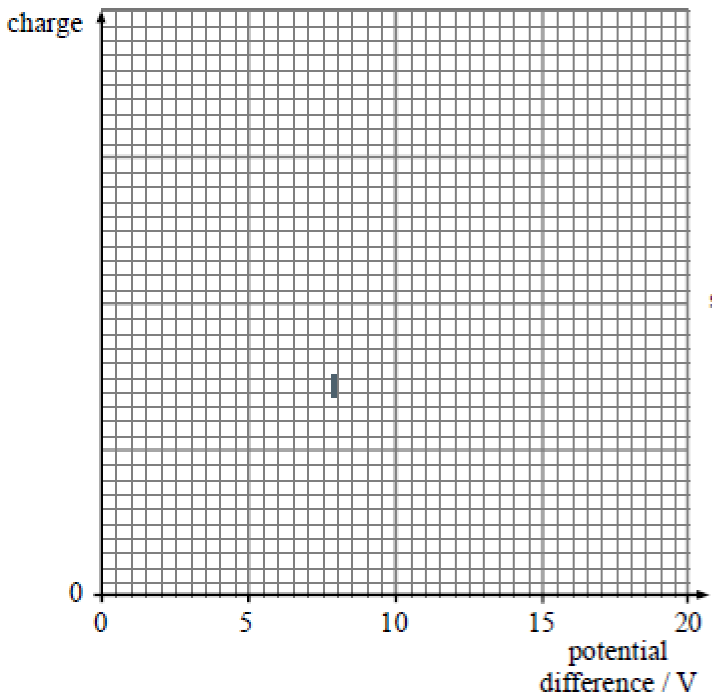
(1)

(ii) Sketch on **Figure 1** the graph that shows how the charge on the 0.020 F capacitor varies with the potential difference across it over the voltage range given. Insert an appropriate scale on the charge axis.

(2)

(iii) Explain how your graph could be used to obtain the energy stored for a given potential difference.

(2)



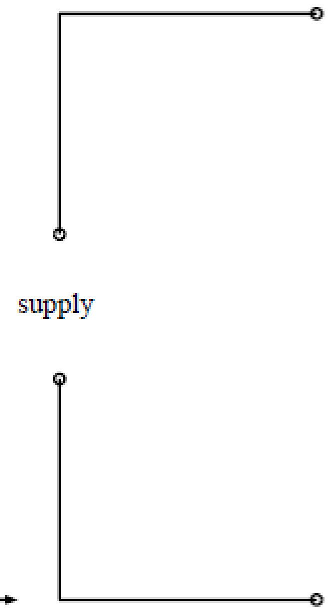


Figure 1 **Figure 2**

(iv) Show on **Figure 2** how **two** similar capacitors could be connected to a supply to store more energy for the same potential difference.

(1)

(b) **Figure 3** shows one 0.020 F capacitor connected to a 20 V supply. By means of the changeover switch **S**, the capacitor is disconnected from the supply and connected to a small motor. The motor lifts an object of mass 0.15 kg through a height of 0.80 m, after which the energy left in the capacitor is negligible.

acceleration of free fall, g = 9.8 m s^{-2}

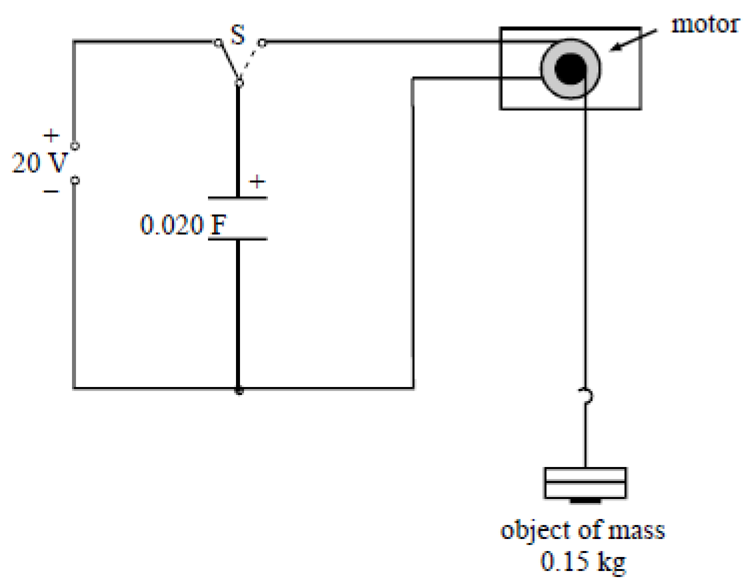


Figure 3

Calculate:

(i) the initial energy stored by the capacitor;

(2)

(ii) the efficiency of the energy conversion.

(3)
(Total 11 marks)

25 (a) A capacitor is marked '2200 μF 15 V'.

(i) Explain what is meant by a capacitance of 2200 μF.

____

____

(2)

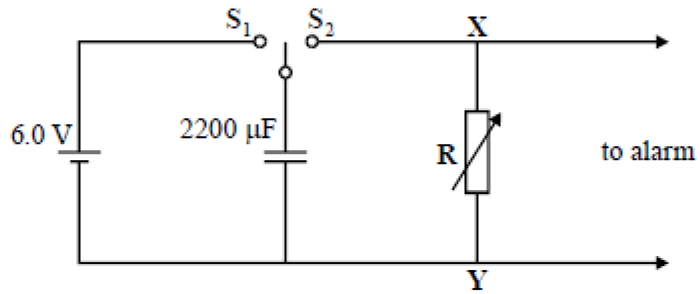
(ii) What is the significance of the 15 V marking?

____

____

(1)

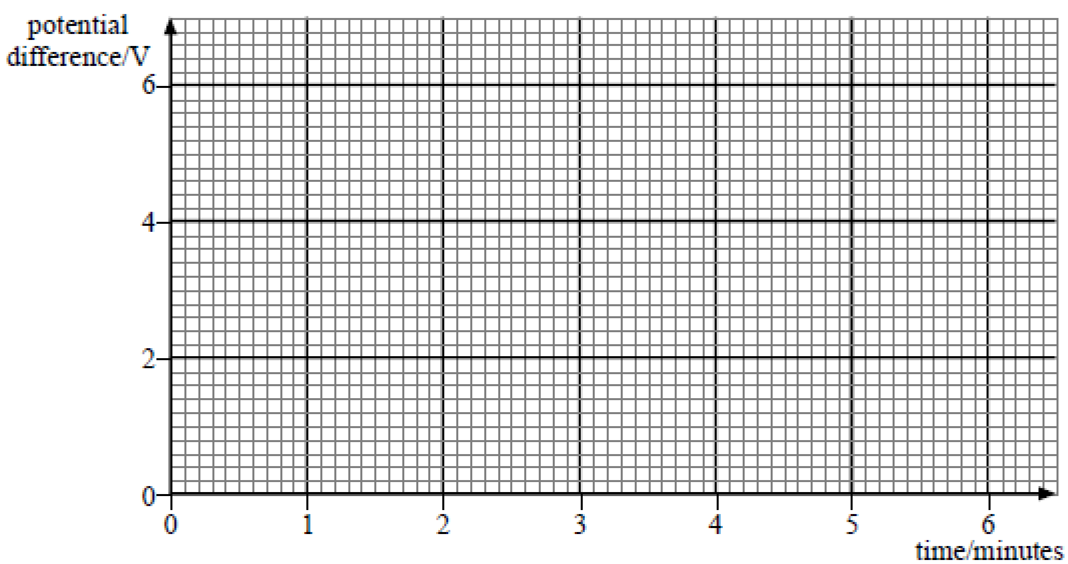
(b) An egg-timer is designed to produce a sound when an egg has been boiled for a sufficient time. The time which elapses before the alarm sounds is controlled by the circuit shown below. The circuit is operated from a 6.0 V cell of negligible internal resistance.



The time is set by means of the variable resistor **R**.

The capacitor is charged by moving the two-way switch to position **S_1** for a short time. The timing is then started automatically when the two-way switch is moved to position **S_2**. An alarm rings when the potential difference between terminals **XY** reaches 2.0 V.

(i) In one setting the time constant of the circuit when the capacitor is discharging is 3.0 minutes. Sketch a graph to show how the potential difference between the terminals **X** and **Y** varies with time for the first 6.0 minutes after the switch moves to the position **S_2**.



(2)

(ii) How long after timing commences will the alarm sound for the setting in part (i)?

___

(1)

(iii) Calculate the resistance of the variable resistor when the time constant is 3.0 minutes.

(2)

(iv) The system is designed to measure cooking times up to 5.0 minutes. Determine the maximum value of the resistance **R** that is needed.

(2)

(v) State how a suitable capacitor would be connected to increase the measurable cooking time.

____

____

(1)

(Total 11 marks)

Mark schemes

1 (a) (i) capacitance $= \left(\frac{Q}{V}\right) = \frac{98.2 - 73.9}{12.0 - 9.0}$ ✓

$= 8.1$ (μF) ✓ (± 0.2 μF)

1 mark only if correct value of C is found from a single point.

2 marks if correct value of C is found from at least 2 points and a mean value, or from gradient. (Check graph.)

Accept 8 (μF) if from correct working.

2

(ii) additional energy = area between line and Q or V axis ✓
= {½ × (98.2 − 73.9) × 3.0} + {(98.2 − 73.9) × 9.0} ✓
= {36.5 + 218.7) = 255 J or 2.6 10^{-4} (J) ✓

[**or**, using ½ QV:
additional energy = ½ Q_2V_2 − ½ Q_1V_1 ✓
= ½ {(98.2 × 12) − (73.9 × 9)} ✓
= 257 μJ or 2.6 × 10^{-4} (J) ✓]

[**or**, using ½ CV^2:
additional energy = ½ CV_2^2 – ½ CV_1^2 ✓
= ½ 8.1 × (12^2 – 9^2) ✓
= 255 μJ or 2.6 × 10^{-4} (J) ✓]

[**or**, using ½ Q^2/C:
additional energy = ½ Q_2^2/C – ½ Q_1^2/C ✓
= (98.2^2 – 73.9^2) ÷ (2 × 8.1) ✓
= 258 μJ or 2.6 × 10^{-4} (J) ✓]

First scheme: alternative for 2nd mark

= {½ × (98.2 − 73.9) × 3.0} + {73.9 × 3.0} ✓

All schemes:

second mark subsumes the first mark.

In all methods, allow tolerance of ± 10 μJ 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) $0.2V_0 = V_0 e^{-t/RC}$
and $0.2 = e^{-45/RC}$ ✓

Condone use of 0.8 for 0.2 in first mark only.

$\ln 0.2 - \frac{45}{RC}$ **or** $\ln 5 = \frac{45}{RC}$ ✓

time constant $RC = \frac{45}{\ln 0.2}$ **or** $\ln 5 = \frac{45}{\ln 5}$ = 28.(0) (s) ✓

3

(ii) resistance of R = $\left(= \frac{\text{time constant}}{C}\right) = \frac{28.0}{470 \times 10^{-6}}$ ✓

= 5.96×10^4 (Ω) or 60 kΩ ✓

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

2

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

1

[11]

2 (a) $d = \frac{8.9\times10^{-12}\times2.3\times250\times10^{-4}}{370\times10^{-12}}$ ✓

1.4×10^{-3} m (1.4 (1.38) mm)✓

Data substitution – condone incorrect powers of 10 for C and A ✓

2

(b) New capacitance = 161 pF✓

New V = 0.13 nC / 161pF = 81 V✓

2

(c) Energy stored = ½ × 161 × 10^{-12} × 81^2 ✓

0.53 μJ✓

2

(d) Energy increases because:

In the polar dielectric molecules align in the field with positive charged end toward the negative plate (or WTTE).✓

Work is done on the capacitor separating the positively charged surface of the dielectric from the negatively charged plate (or vice versa).✓

2

[8]

3 (a) Capacitor must not lose charge through the meter ✓

1

(b) Position on scale can be marked / easier to read quickly etc ✓

1

(c) Initial current = $\frac{6}{100000}$ = 60.0 μA ✓

100 μA or 200 μA ✓ (250 probably gives too low a reading)

Give max 1 mark if 65 μA (from 2.6) used and 100 μA meter chosen

2

(d) 0.05 V ✓

1

(e) Total charge = 6.0 x 680 x 10^{-6} (C) (= 4.08 mC) ✓

Time = 4.08 x 10^{-3} / 60.0 x 10^{-6} = 68 s ✓

Hence 6 readings ✓

3

(f) Recognition that total charge = 65 t μC and final pd = 0.098 t

so C = 65μ / 0.098✓

660 μF ✓

Allow 663 μF

2

(g) (yes) because it could lie within 646 – 714 to be in tolerance ✓

OR

it is 97.5 % of quoted value which is within 5% ✓

1

(h) Suitable circuit drawn ✓

Charge C then discharge through R and record V or I at 5 or 10 s intervals ✓

Plot ln V or ln I versus time ✓

gradient is 1 / RC ✓

OR

Suitable circuit drawn ✓

Charge C then discharge through R and record V or I at 5 or 10 s intervals✓

Use V or I versus time data to deduce half-time to discharge ✓

$1 / RC = \ln 2 / t_{½}$ quoted ✓

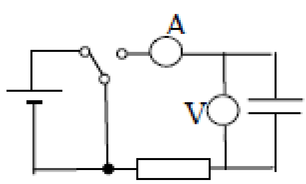
OR

Suitable circuit drawn ✓

Charge C then discharge through R and record V or I at 5 or 10 s intervals ✓

Plot V or I against t and find time T for V or I to fall to 0.37 of initial value ✓

$T = CR$ ✓



Either A or V required

For 2nd mark, credit use of datalogger for recording V or I.

4

[15]

4 (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 kΩ.

½ initial current to be marked within ±2mm of expected value.

3

(b) (i) energy stored (= ½ CV^2) = ½ × 0.12 × 9.0^2 ✓ (= 4.86 (J))

4.86 = 3.5 Δh ✓

gives Δh = (1.39) = 1.4 (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]

5 (a) (i) 7.5×10^{-6} (C) or 7.5 μ(C)

B1

1

(ii) Suitable scale and charge from (i) correctly plotted at 2.5 V

*Large square = 1 or 2 μC **or***
With false origin then large square = 0.5 μC

B1

Only a Straight line drawn through or toward origin

C1

Line must be straight, toward origin **and** only drawn between 2.5 V and 1.2 V (± 1 / 2 square on plotted points)

A1

3

(b) Attempted use of E= ½ CV^2 Or attempted use of E=½ QV

C1

9.38 (μJ) − 2.16 (μJ) seen
or E = ½ × *3 × 10^{-6} × 2.5^2 – ½ × 3 × 10^{-6} × 1.2^2 seen*
or E = ½ × *3 × 10^{-6} × (2.5^2 – 1.2^2) seen*
or E =½ × *7.5 × 10^{-6} × 2.5 – ½ × 3.6 × 10^{-6} × 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

$$R = -\left(\frac{1.4\times10^{-3}}{ln\left(\frac{1.2}{2.5}\right)\times3\times10^{-6}}\right) \text{ or } R = -\left(\frac{t}{ln\left(\frac{V_o}{V}\right)\times C}\right) \text{ or } R = \left(\frac{t}{ln\left(\frac{V_o}{V}\right)\times C}\right)$$

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 <u>so</u> pd falls more slowly <u>because</u> V∝Q or Q=CV where C is constant

A1

MAX 2

[12]

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

$C\left(=\frac{Q}{V}\right)=\frac{2.70\times10^{-4}}{4.4}$ ✓ $= 6.1(4) \times 10^{-5} = 61$ (μF) ✓

3

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

$R\left(=\frac{V}{I}\right)=\frac{3.8}{4.5\times10^{-6}}$ $= 8.4(4) \times 10^{5}$ (Ω) ✓ (=844 kΩ)

In alternative method,
$Q = 4.5 \times 10^{-6} \times 30 = 1.35 \times 10^{-4}$ (C)
$V_C = 1.35 \times 10^{-4} / 6.14 \times 10^{-5} = 2.2$ (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.*

Incorrect, inappropriate or no response: 0 marks

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]

7 (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 $(= CV)$ $= 3.7 \times 10^{-12} \times 3.00 \times 10^4$ ✓

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

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

$$\text{time taken } t\left(=\frac{Q}{I}\right)=\frac{1.11\times10^{-7}}{3.2\times10^{-8}}=3.5\ (3.47)\ (\text{s})\ ✓$$

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 ∝ 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)

8 (a) ($Q = Q_0 e^{-t/RC}$ gives)$1.0 = 4.0e^{-300/RC}$ ✓

from which $\frac{300}{RC} = \ln 4$ ✓ and time constant RC = 220 (216) (ms) ✓

[Alternative answer:

time constant is time for charge to decrease to Q_0 /e [**or** 0.37 Q_0] ✓

4.0/e = 1.47 ✓

reading from graph gives time constant = 216 ± 10 (ms) ✓

In alternative scheme, 4.0/e = 1.47 subsumes 1st mark. Also, accept $T_{½}$ = 0.693 RC (or = ln 2 RC) for 1st mark.

3

(b) current is larger (for given V)(because resistance is lower)

[**or** correct application of $I = V / R$] ✓

current is rate of flow of charge

[**or** correct application of $I = \Delta Q / \Delta t$]

larger rate of flow of charge (implies greater rate of discharge)

[**or** causes larger rate of transfer of electrons from one plate back to the other] ✓

[Alternative answer:

time constant (or RC) is decreased (when R is decreased) ✓

explanation using $Q = Q_0 e^{-t/RC}$ **or** time constant explained ✓]

Use either first or alternative scheme; do not mix and match.

Time constant = RC is insufficient for time constant explained.

max 2

[5]

9 (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) $C\left(=\frac{Q}{V}\right) = \frac{13.2 \times 10^{-6}}{6.0}$ ✓ $= 2.2 \times 10^{-6}$ (F) ✓ (or 2.2 μF)

2

(ii) when t = time constant $Q = 0.63 \times 13.2 = 8.3$ (μC) ✓

[**or** = 0.63 × 13(.0) (from graph) = 8.2 (μC)]

reading from graph gives time constant = 15 (± 1) (ms) ✓

2

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

1

(iv) gradient = current ✓

1

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

[**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 ✓

line is asymptotic to t axis and approaches ≈ 0 by t = 60 ms ✓

2

[11]

10 (a) time to halve = 0.008 s or two coordinates correct

C1

$C = T_{1/2}/(0.69 \times 150)$ or eg $0.4 = 1.4\, e^{-0.015/150C}$

A1

77 μF (consistent with numerical answer)

A1

3

(b) **max 3 from**

as capacitor discharges:

pd decreases

B1

current through resistor decreases (since $I \propto V$)

B1

rate at which charge leaves the capacitor decreases (since $I = \Delta Q/\Delta t$)

B1

rate of change of charge is proportional to rate of change of pd
(since $V \propto Q$)

B1

condone quicker discharge when pd is larger

B1

3

(c) energy stored $\propto V^2$ or use of ½ CV^2
or initial energy = 78.4 (or 75.5) μJ
or final energy using V = 0.38–0.4 0 V
(answer in range 5.6 – 6.4 μJ)

C1

fraction remaining = $(0.4/1.4)^2$ or 0.072 – 0.081
or energy lost = 72 μJ

C1

91.8 to 92.8% lost

A1

3

(d) (i) charge = 77 μC to 82 μC

B1

1

(ii) charge required = $77 \times 10^{-6} \times 5 \times 3.15 \times 10^{7}$ (= 12128 C)
or 1A–h =3600 C

C1

3.36(3.4) Ah

A1

2

[12]

11 (a) (i) energy stored by capacitor (= ½ CV^2)

= ½ × 70 × 1.2^2 ✓ (= 50.4) = 50 (J) ✓

to **2 sf** only ✓

3

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

(= 2380 J)

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

2

(b) capacitor would be impossibly large (to fit in phone) ✓

capacitor would need recharging very frequently
[**or** capacitor could only power the phone for a short time] ✓

capacitor voltage [**or** current supplied or charge] would fall continuously while in use ✓

max 2

[7]

12 (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 ($T_{½}$ = 440 or 450 μs)

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) $E = ½ CV^2$ or $½ QV$ 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]

13 (a) (i) tangent drawn at $t = 0$

M1

coordinates correct and manipulated correctly
0.015 to 0.020 (A) 15 mA – 20 mA
or V = 4000 V as in (ii) then I = 18 mA

A1

2

(ii) V = 220 × their (i) condoning powers of 10

C1

about 4000 V (3300 – 4400 V)

A1

or use of $V = Q/C$; V = 100 mC/25 μF

C1

4000 V

A1

2

(iii) more charge leads to increased potential difference across the capacitor

M1

pd = $V_R + V_C$
or if V_C increases then V_R decreases

M1

(if V_R falls) so I falls

A1

3

(b) (i) use of energy = ½ Q^2/C or use of $C = Q/V$ and ½ QV

C1

0.083(7) or 0.084 C condone 0.083 C

A1

2

(ii) power = 14 kW

B1

1

(c) time constant = 5.5 s

M1

sensible attempt to find the charge after 8.3 s – by calculation or reading from graph

M1

about 78 mC and needs to be 85 mC/has not reached 85 mC so designer’s suggestion is not valid

A1

3

[13]

14 (a) (i) initial discharge current $\left(= \frac{V}{R} = \frac{6.0}{1.0 \times 10^5}\right)$ = 6.0×10^{-5} (A) **(1)**

1

(ii) time constant is time for *V* to fall to (1/e) [or 0.368] of initial value **(1)**

pd falls to (6.0/e) = 2.21 V when *t* = time constant **(1)**

reading from graph gives time constant = 22 (± 1) **(1)**

unit: s **(1)** (ΩF not acceptable)

[**alternatively** accept solutions based on use of $V = V_0 e^{-t/RC}$

eg $1.5 = 6.0\ e^{-30/RC}$ **(1)** gives $RC = \frac{30}{\ln(6.0/1.5)}$ **(1)** = 22 **(1)** s **(1)**]

4

(iii) capacitance of capacitor $C = \left(\frac{\text{time constant}}{R} = \frac{22}{1.0 \times 10^5}\right)$

= 2.2×10^{-4} (F) = 220 (μF) **(1)**

1

(iv) energy $\propto V^2$ (or energy = ½ CV^2) **(1)**

$\therefore \frac{E_2}{E_1}$ = 0.10 gives = $\frac{V_2}{V_1}$ $(0.10)^{1/2}$ **(1)** (= 0.316)

$\therefore V_2$ = 0.316 × 6.0 = 1.90 (V) **(1)**

reading from graph gives V_2 = 1.90 V when t = 25 s **(1)**

[**alternatively** accept reverse argument:

ie when t = 25 s, V_2 = 1.9 V from graph **(1)**

final energy stored = ½ × 2.2 × 10^{-4} × 1.9^2

= 3.97 × 10^{-4} (J) and initial energy stored = 3.96 × 10^{-3} (J) **(1)**

which is 10 × greater, so 90% of initial energy has been lost **(1)**]

[**alternatively**, using exponential decay equation:

use of $V = V_0 e^{-t/R}$ with t = 25 s and RC = 22 s gives V = 1.93 V **(1)**

energy $\propto V^2$ (or energy = ½ CV^2) gives $\frac{E_2}{E_1} = \left(\frac{1.93}{6.0}\right)^2$ = 0.103 **(1)**

$\therefore$ fraction of stored energy that is lost = $\frac{E_2 - E_1}{E_1} = 1 - \frac{E_2}{E_1}$ = 0.90 **(1)**]

3

(b) (i) initial energy stored is 4 × greater **(1)**

because energy $\propto V^2$ (and V is doubled) **(1)**

2

(ii) time to lose 90% of energy is unchanged because time constant is unchanged (or depends only on R and C) **(1)**

1

[12]

15 (a) (i) charge stored per unit volt or equation with terms defined **(1)**

(ii) 0.108 C or 0.11 C c.a.o. **(1)**

2

(b) (i) 1.7 s **(1)**

(ii) correct curvature **(1)**

intercept on V axis, asymptotic to t axis **(1)**

initial voltage, time constant and V after RC seconds shown **(1)**

4

(c) initially no pd across C so rate of charging is high **(1)**

Pd across C increases as the capacitor charges **(1)**

rate of charging reduces **(1)**

3

[9]

16 (a) (i) straight line through origin **(1)**

(ii) $\frac{1}{\text{capacitance}}$ **(1)**

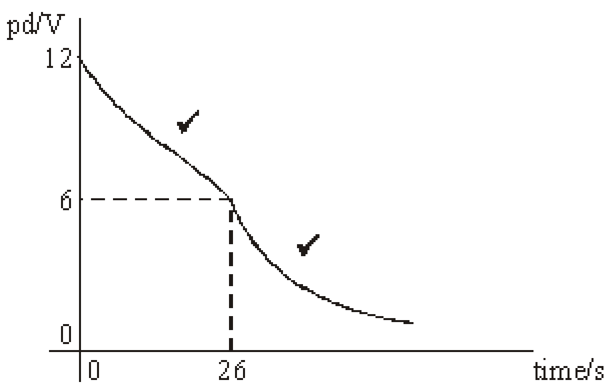
(iii) energy (stored by capacitor) **(1)** (or work done (in charging capacitor))

3

(b) (i) $RC = 5.6 \times 10^3 \times 6.8 \times 10^{-3}$ **(1)** (= 38.1 s)
$V(= V_0\, e^{-t/RC}) = 12\, e^{-26/38.1}$ **(1)**
$= 6.1$ V **(1)** (6.06 V)
[or equivalent using $Q = Q_0 e^{-t/RC}$ and $Q = CV$]

(ii) $(RC)' = 2.8 \times 10^{3} \times 6.8 \times 10^{-3}$ **(1)** (= 19.0 s)
V (= $6.06\, e^{-14/19}$) = 2.9(0) V **(1)**
(use of V = 6.1 V gives V = 2.9(2) V)

(iii)



7

[10]

17 (a) Q (= CV = 330 × 9.0) = 2970 (μC) **(1)**
E (= ½QV) = ½ x $2.97 \times 10^{-3} \times 9.0 = 1.34 \times 10^{-2}$ J **(1)**
[or E (= ½CV^2) = ½ × $300 \times 10^{-6} \times 9.0^2$ **(1)** = 1.34×10^{-2} J **(1)**]

2

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

1

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

$= 2020$ (μC)

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

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

(allow C.E. for Q)

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

3

[6]

18 (a) $Q = CV$ **(1)**
(= $4.7 \times 10^{-6} \times 6.0$) = 28×10^{-6} C or 28 μC **(1)**

2

(b) $E = ½CV^2$ **(1)**
$= ½ \times 4.7 \times 10^{-6} \times 2.0^2$ **(1)**
$= 9.4 \times 10^{-6}$ J **(1)**
[or $E = ½QV$ **(1)**
$= ½ \times 9.4 \times 10^{-6} \times 2.0$ **(1)**
$= 9.4 \times 10^{-6}$ 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)**

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

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

2

[10]

19 (a) graph to show:
straight line from origin **(1)**
<u>end point</u> 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 × average voltage **(1)**

energy stored = work done (= ½QV) **(1)**

(ii) Q = 2.0 × 1.5 = 3.0 (μC) **(1)**
E (=½ QV) = ½ × 3.0 × 10^{-6} × 1.5 = 2.25 × 10^{-6}J **(1)**
[or E = (½CV^2 = ½ × 2.0 × 10^{-6} × 1.5^2 = 2.25 × 10^{-6} 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) $C\left(=\frac{\varepsilon_0 A}{d}\right) = \frac{8.85\times10^{-12}\times8.0\times10^{6}}{0.75\times10^{3}}$ **(1)** (= 9.44 × 10^{-8} F)

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

= 1890J **(1)**

(ii) $I\left(=\frac{Q}{t}\right) = \frac{9.44\times10^{-8}\times200\times10^{3}}{120\times10^{-6}}$ use of $Q = CV$ **(1)** use of $I = \frac{Q}{t}$ **(1)**

= 157 A **(1)**

6

[10]

21 (a) area of overlap of the plates

B1

separation of/distance between the plates

permittivity/dielectric constant of free space/the material/dielectric between the plates (condone of the gap)

B1

2

B1 for 1 factor clearly stated
B1 for other two clearly stated

(b) (i) $Q = VC$ (any form) or 0.047 μF × 12 (ignoring powers of 10)

C1

$5.6(4) \times 10^{-7}$ C (0.56 μC)

A1

(ii) time constant = 4.7×10^{-5} s or $0.01 = e^{-t/RC}$

C1

$0.01 = e^{-t/(0.000047)}$ or $0.01 = e^{-t/47}$ or $= \frac{t}{RC} = 4.605$

C1

$2.2\ (2.16) \times 10^{-4}$ s or 0.22 ms

A1

(iii) their (i) × 400 (230 (226) μA or 2.3×10^{-4} A if correct)

B1

6

[8]

22

(a) $1/C = 1/500 + 1/1000$ or $C = \dfrac{500 \times 1000}{500 + 1000}$

C1

330 (333) μF

A1

2

(b) (i) Q = VC *or* Q = *0.25* × *9*

C1

2.3 or 2.25 C (c.a.o. unit essential)

A1

(ii) *energy* = ½ CV^2 or $0.5 \times 0.25 \times 9^2$ or ½ *QV* used

C1

10(.1) J (allow e.c.f. for *Q*)

A1

(iii) $V = V_0\, e^{-t/RC}$

C1

7

$0.1 = 9\, e^{-t/(8.5 \times 0.25)}$

C1

9.6 (9.56) s

A1

(c) (i) $Q = mc\Delta\theta$ or mass = volume × density

C1

correct substitution $10.1 = (2.2 \times 10^{-7} \times 8900 \times 400 \times \Delta\theta)$

C1

12 (12.3) K or °C ecf for energy from (b) (ii)

A1

5

(ii) some energy raises temperature of the thermometer

B1

energy/heat lost to (raise temperature of) surroundings

B1

[14]

23 (a) $C = \varepsilon_0 \varepsilon_r A/d$

C1

15.6 nF or 16 nF

A1

2

(b) (i) 2.4×10^9 (V)

B1

1

(ii) ½ CV^2 (or ½QV if attempt to calculate Q made)

C1

4.3–5.0 × 10^{10} 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

3.48×10^6 **Ω cao** (but do not allow if physics error)

A1

3

[9]

24 (a) (i) 0.02 C of charge produce a p.d. of 1 V between the two terminals

or 0.02 C of charge per unit p.d.

B1

(2)

(ii) straight line through the origin

M1

correct gradient (possible check point 0.2 C at 10 V)

and graph line up to 20 V

A1

(2)

(iii) area between graph line and charge axis

(allow area under graph)

not area of the graph

not area under graph / 2

M1

from 0 to the required voltage or up to the required voltage

A1

or energy = ½QV or ½CV^2

M1

read corresponding Q from the graph

A1

(only allow second mark if graph is straight line through the origin)

or C determined from gradient of graph and V given

(2)

(iv) sketch showing two capacitors in parallel connected to a supply

B1

(1)

(b) (i) energy stored = 0.5 CV^2

C1

4.0 J (condone 1 sf answer)

A1

(2)

(ii) (useful) energy output = mgh

or

efficiency = useful energy out / energy input(in same time)

or

efficiency = useful power out / power input

C1

energy output = 0.15 × 9.8 × 0.8 = 1.18 J

C1

efficiency = 0.294 or 29.4% e.c.f. from (b)(i)

A1

(allow 29% – 30%)

(3)

[11]

25 (a) (i) 2200 × 10^{-6} farads (C V^{-1}) or 2200 μC V^{-1}
or idea of capacitance measuring charge (or coulomb) per volt
or C = Q / V with terms defined

C1

the capacitor 'stores' 2200 μC of charge for a potential difference of 1 volt

A1

(2)

(ii) 15 V is
the maximum safe voltage between the terminals of the capacitor.
or the maximum voltage that should be used across the capacitor
or the voltage at which the capacitor breaks down / insulator conducts

B1

(1)

(b) (i) correct curvature starting at 6 V at time = 0
points plotted correctly at 3 and 6 minutes with reasonable curve (2.2 V and 0.8 V)

B1

or at 3 V at 2.1 minutes and 1.5 V at 4.2 minutes if 'half life' calculated and used

allow ±0.5 small square

B1

(2)

(ii) time alarm rings read correctly from the graph at 2 V
(about 200 s but use candidate's graph condone any shape graph)

B1

(1)

(iii) time constant = RC or ($R = \frac{180}{2.2 \times 10^{-3}}$) **or** time to halve = 0.69CR

C1

82 kΩ

A1

(2)

(iv) cooking time ∝ $CR \propto R$
or quotes $V = V_0 e^{-t/CR}$ **or** $2 = 6 e^{-300/CR}$

C1

resistance = 120 kΩ (124 kΩ)

A1

(2)

(v) connect it in parallel (with the other capacitor)
or
replace capacitor with one of higher value (not just use a larger capacitor)

B1

(3)

[11]