Capacitance Consolidation

Q1. 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}

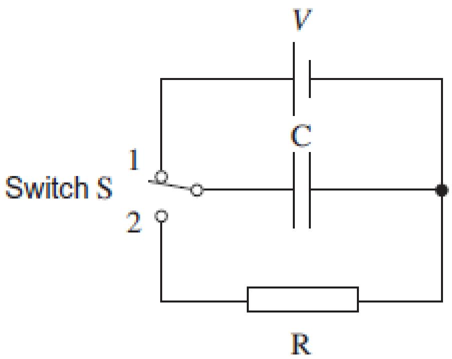
B 3.3×10^{10}

C 4.4×10^{10}

D 8.8×10^{10}

(Total 1 mark)

Q2. 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)

Q3. 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 μA 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

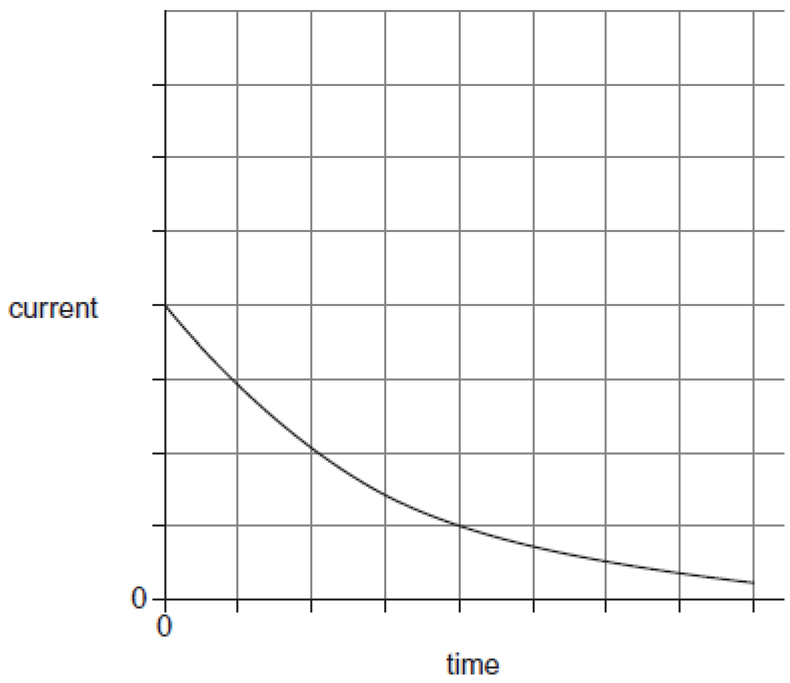
B 100 s

C 200 s

D 1000 s

(Total 1 mark)

Q4. (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)

Q5.(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.

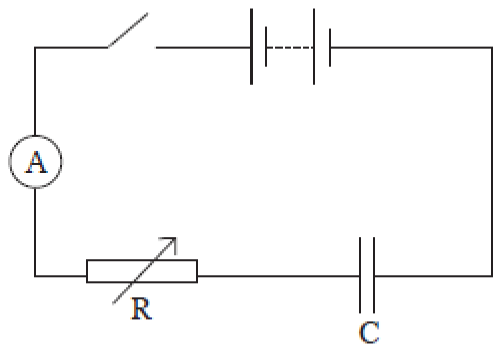
(i) Calculate the capacitance of the capacitor.

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



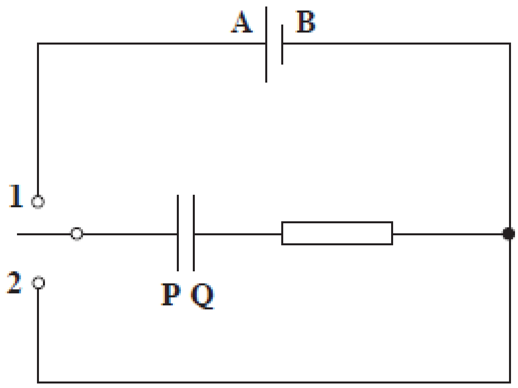
Calculate the resistance of R when the uncharged capacitor has been charging for 30 s.

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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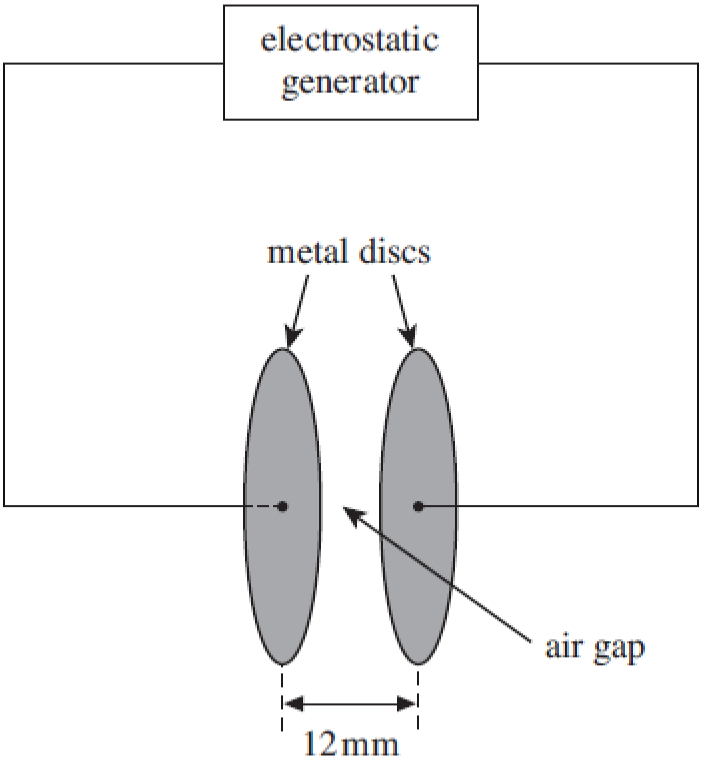
(6)
(Total 12 marks)

Q6. 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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....

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....

....

(2)
(Total 7 marks)

M1.C

[1]

M2.B

[1]

M3.D

[1]

M4.(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 Δ*h* ✓
gives Δ*h* = (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]

M5.(a) (i) $Q(= It)$ 4.5 × 10^{-6} × 60 **or** = 2.70 × 10^{-4} (C) ✓

$$C\left(=\frac{Q}{V}\right)=\frac{2.70\times10^{-4}}{4.4}$$ ✓ = 6.1(4) × 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) × 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]

M6.(a) (i) required pd (= 2.5 × 10^{6} × 12 × 10^{-3}) = 3.0(0) × 10^{4} (V) ✓

1

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

(= 1.11 × 10^{-7} C)

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

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