Mark schemes

1 (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]

2 (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 × $3 \times 10^{-6} \times 2.5^2$ – ½ × $3 \times 10^{-6} \times 1.2^2$ *seen*
or E = ½ × $3 \times 10^{-6} \times (2.5^2 - 1.2^2)$ *seen*
or E =½ × $7.5 \times 10^{-6} \times 2.5$ – ½ × $3.6 \times 10^{-6} \times 1.2$ *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

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

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]

3 (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]

4 (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)

5 (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]

6 (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]

7 **C**

[1]

8 **D**

[1]

9 **A**

[1]

10 C

[1]

Examiner reports

1 AQA apologises for the unfortunate typographical error which crept in to the resistor values in part (a) of this question. Both values ought to have been given in kΩ. The majority of students actually answered the question as it had been intended to appear, and so the mark scheme that would have applied to the intended question in part (ii) was used when marking their work. The students who answered the question as it appeared in the paper were not disadvantaged, because an alternative mark scheme which gave full credit for completely correct responses was adopted for them. The main weaknesses in either approach were a lack of appreciation of the effect of the resistor value on the initial current, and doubt as to whether increasing resistance would speed up the decay or slow it down. In the case of the question as it had been intended, the curve crosses the original curve within the time scale of the graph; this was rarely spotted and so the award of all three marks was quite unusual. The determination of the initial charge on the capacitor from the area under the curve was not as well known as expected. There were many references to the intercept on the current axis, to the initial gradient, and some to "*the initial* area under the curve".

Most students wrote correct and complete answers in part (b)(i). A small number of students mixed up mass and weight, leading to the unnecessary introduction of *g* into the calculation. The more able ones who had done this then realised that *g* was self-cancelling. It was pleasing to see that an appropriate number of significant figures was generally quoted in the final answers. The reasons looked for in the answers to part (b)(ii) were those which cause the greatest energy loss as the weight is raised by an electric motor: losses caused by heating of the connecting wires or the motor and energy lost in overcoming frictional forces as the motor rotates. By comparison, the energy lost in overcoming air resistance (for example) is trivial and was therefore discounted. Examiners expected to see that the locations of the energy losses (wires, motor, circuit, etc) were identified in acceptable answers.

2 (a) (i) This calculation was very well done with over 90% of candidates able to complete it successfully. Mistakes seen were mostly power of ten errors on the value of the capacitor (3×10^{-3} often quoted).

(ii) The majority of candidates were able to achieve at least 2 marks. Of course, many candidates attempted to draw discharge curves instead of the required straight line. Candidates should treat these graphs with caution and be aware of the $Q \propto V$ is always directly proportional irrespective of charging and discharging.

(b) There were lots of mistakes in this calculation. The most common error was the use of $E = \frac{1}{2} CV^2$ where candidates substituted $\Delta V = 1.3\ V$ into this formula, effectively calculating 1.3^2 instead of calculating $2.5^2 \times 1.2^2$. Another common mistake seen was treating Q as a constant in the equation $E = \frac{1}{2} QV$, that is $E = \frac{1}{2} \times 7.2 \times 10^{-6} \times \Delta V$

(c) (i) A common mistake seen here was the use of the wrong formula, a significant number of candidates chose to use $T_{½}$ = 0.69 RC even though the fall in voltage was not quite 50%. Other candidates selected the correct formula but then had difficulty in their rearranging of the formula; many made the mistake of misplacing C in the

rearrangement of the equation: R = $\frac{-t}{\ln(\frac{Q}{Q_0})/C}$ instead of R = $\frac{-t}{C\ln(\frac{Q}{Q_0})}$

(ii) Candidates found this explanation difficult, with only the best candidates able to deliver a detailed, coherent response. Most answers were limited to less charge less potential difference arguments rather than dealing with the rate aspect of the question.

3 The capacitance calculation in part (a)(i) rewarded most students with full marks. Answers to part (a)(ii) made a distinct contrast, because relatively few students were able to progress. Correct answers were rare. The circuit in Figure 1 is one in which the *current is maintained constant* by reducing the resistance as the capacitor is charged. Consequently the large number of attempted solutions that introduced exponential decay equations were totally inappropriate. An understanding of the principle that in a series circuit the sum of the voltages across components is equal to the applied voltage was essential. Many of the efforts progressed as far as establishing that the pd across the capacitor at 30 s would be 2.2V, but then went on to find what is effectively "the resistance of the capacitor" by dividing 2.2V by the current.

The final question in this examination, part (b), concerned a *C-R* circuit is which *R* is constant and charging / discharging *are* exponential processes. Apart from testing this subject content, the question was also used to assess the communications skills of the students. The guidance given in the bullet points helped most students to organise their answers systematically. A very good spread of marks was seen, ranging from students who clearly knew everything that happens during charging and discharging to ones who understood little or nothing about capacitors. A large number of correct statements about the factors listed in the bullet points for both charging and discharging constituted a high level answer (5 / 6 marks). Fewer correct statements about either charging or discharging put answers into the intermediate level (3 / 4 marks) whilst even fewer correct statements put answers into the low level (1 / 2 marks). Contributing also to the overall assessment was examiners' consideration of the incorrect statements made in the answers, and how satisfactorily the answers had been had been written. There were many instances of answers in which it was stated that electrons passed directly from plate **Q** across the gap to plate **P** – these tended to condemn the knowledge of the student concerned. A common misapprehension concerning this circuit was that the reduction in current is caused by an increase in the *resistance of the capacitor* rather than by a decrease in the net potential difference as the capacitor charges or discharges. A large proportion of the students chose to ignore the advice given to refer in their answers to points **A**, **B**, **P** and **Q** in the circuit. This omission usually made their answers somewhat more difficult to assess.

4 Very few candidates experienced any difficulty in (a)(i), where the product of field strength and plate separation readily led to 30,000 V. In the other parts of Question 2 the principal failing of many of the candidates' attempts was to resort to time variations that were exponential. Part (a) puts this question clearly in the context of a charging current that is constant, so any references to exponential changes or time constants showed misunderstanding and were irrelevant. Arithmetical slips sometimes caused the loss of marks in part (a)(ii), but $Q = CV$ and $t = Q / I$ were usually applied correctly to arrive at 3.5 s.

In part (b) it was essential for candidates to realise that both the charging current and the breakdown pd remain constant at their original values when the capacitance is changed. The majority of candidates could see in part (b)(i) that the time between discharges would increase. Many also gave an acceptable explanation, either by stating that the charge stored would have to be larger before the breakdown pd was reached, or by reference to $t = CV / I$, where V and I are both unchanged. A common misconception in part (b)(ii) was to think that the brightness of the spark would be unchanged because the breakdown pd would be the same as it had been originally. It was expected that candidates would know that increased capacitance at the same pd would mean that the energy stored by the capacitor would be greater, so each spark would transfer more energy and would therefore be brighter. Alternatively, explanations in terms of the greater charge stored were also accepted.

5 Part (a) required the evaluation of the time constant of an *RC* circuit from data on a graph of charge against time. This proved to be an easy test, and marks were high. The most economical solution followed from recognising that the charge falls to (1/e) of its initial value in a time equal to the time constant, or from appreciating that Q_0 becomes $Q_0/2$ in a time equal to ln *2 RC*. More extensive answers that relied on a solution of $Q = Q_0 e^{-t / RC}$ were less common; in these it was essential for candidates to show their working correctly for full marks to be accessible. A few candidates knew that the time constant is equal to the time at which the capacitor would have discharged completely had the initial current been maintained. Therefore they drew a tangent to the curve at $t = 0$, continued the line to the time axis and then determined the required value by reading off the time.

Careless use of the language of physical quantities was sometimes an obstacle to progress in part (b). Loose terms such as "the current flows more quickly" (when the resistance is less) should be avoided: the candidate should have stated that the current is greater, or that more charge passes per second. The key to success in this part was to understand the meaning of a rate of change. Those who stated that the current is larger, and that current is the rate of flow of charge, readily scored both marks. Answers which stated that the time constant would be decreased were also accepted but it was then necessary to make reference to the implications, from $Q = Q_0 e^{-t/RC}$, for the second mark to be awarded.

6 Good definitions of capacitance were usually seen in part (a), leading to an easily gained couple of marks. Vague statements such as ‘capacitance is a measure of the ability to store charge’ went unrewarded.

Part (b) caused very few problems, apart from those arising from careless arithmetic or misunderstood powers of 10. In part (b) (iv) it was expected that students would identify the gradient with current; ‘rate of charging’ seemed too obvious for the mark to be given.

The maximum value of the current could be found directly in part (c) (i) by applying $I = V/R$, where V is the emf of the battery and R is the resistance of the resistor. No doubt it was the previous part of this question that directed so many students to base their response on the initial slope of the graph. This was equally acceptable, and a wide tolerance was placed on answers arrived at by this technique. The sketch graphs in part (c) (iii) were often too careless to deserve full credit. This exponential decay curve should start at an intersection with the current axis (with I_{max} marked as required) and should be asymptotic to the time axis. More able students realised that the gradient of this Q-t graph in part (b) was practically zero at t = 60 ms, and that the current should therefore be very close to zero at this time. There were many answers showing a current that increased with time, and many others that had a constant negative gradient.