Mark schemes

1 (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 ∝ 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]

2 (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]

3 (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]

4 (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]

5 (a) (i) initial discharge current $\left(= \frac{V}{R} = \frac{6.0}{1.0 \times 10^5}\right) = 6.0 \times 10^{-5}$ (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 $C = \left(\frac{\text{time constant}}{R} = \frac{22}{1.0 \times 10^5}\right)$

$= 2.2 \times 10^{-4}$ (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)

$\therefore V_2 = 0.316 \times 6.0 = 1.90$ (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]

6 (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]

7 D

[1]

8 B

[1]

9 A

[1]

10 C

[1]

Examiner reports

1 Most students made progress with part (a) and a majority of the students gained full marks.

Part (b) was not done well. Few could provide a complete response and some confused charging and discharging.

Few could cope with all the steps necessary to arrive at the correct answer to part (c).

There were surprisingly few correct responses to part (d) (i) and part (d) (ii) was not done well. The number of seconds in a year is on the *Data and Formulae Booklet* but many tried unsuccessfully to calculate it. Few seemed familiar with the unit Ah (ampere–hour).

2 The data used in this question is realistic. A low voltage 70 F capacitor is available for back-up purposes, and there is a rechargeable cell with the specification quoted. Part (a)(i) was readily answered by the application of ½ CV^2. The choice of an inappropriate number of significant figures, typically three, caused the loss of a mark. Candidates should realise that a final value should only be quoted to two significant figures when the data in the question is given to no more than two significant figures.

Part (a)(ii) was answered poorly, usually because the calculation was approached from the capacitor energy equation (½ *QV*), instead of that giving the energy delivered by a cell (QV). Examiners were ready to penalise the candidates who, having started from the wrong principle, introduced a mysterious factor of two in order to show that the energy stored was 50× greater, rather than 25× greater.

In part (b) candidates' responses were often inadequate because of incompleteness, and/or an inability to express ideas sufficiently clearly. It was expected that satisfactory answers would relate to the use of the capacitor in a cordless telephone. 'A capacitor discharges quickly' is an incomplete answer; 'a capacitor would need recharging frequently' or 'a capacitor would only power the phone for a short time' were much more explicit in the context of the question. Other acceptable answers were that a 70 F capacitor would be too large to fit in the telephone, or that the voltage supplied by it would decrease continuously whilst in use.

3 For part (a), most candidates knew the definition of capacitance, but frequently omitted the 4.2 μC per V aspect.

There was a variety of techniques used in part (b) (i) but most answers were complete.

In part (b) (ii), nearly all candidates recognised that **B** had a smaller capacitance than **A** but most answers only gained a single mark for stating that the discharge happens faster in **B** without explaining why this meant that the capacitance was smaller.

Few candidates correctly calculated the change in energy in part (c) – most used ½ QV but did not calculate the values of *Q* **and** *V* before and afterwards.

4 Candidates were penalised heavily for poor technique in this part (a) (i). It was expected that, at this level candidates, would draw a tangent to the curve and not simply read off coordinates in the first few small squares of the graph to find the initial rate of change of charge. Some who appreciated that a tangent would be useful drew one in the wrong place.

Most candidates used the $V = IR$ approach in part (a) (ii). Some candidates incorporated the 510 Ω heart resistance into the resistance of the charging circuit.

Part (a) (iii) was not done well and very few candidates gave completely convincing arguments and many who seem to have no idea where to start. There were many candidates who wrote about charge build up on the capacitor increasing the resistance of the capacitor. Others appreciating the rise in pd as charge accumulates on the capacitor stated that this reduced the emf of the supply. Appreciation of the reduction in the pd across the resistor as the pd across the capacitor increases was rare. Arguments such as 'charge accumulating repels other charges' gained some credit. There was a significant proportion who wrote that as charge builds up there is less *space* on the capacitor for more charge or that because charge has been added to the capacitor there is less available in the circuit to provide further charge.

A surprising number failed to obtain the correct answer to part (b) (i). Many used ½ QV or ½ CV^2 assuming V to be the value of the emf that had been calculated in (a) (ii).

Those who failed to obtain 14000 W in part (b) (ii) usually failed because of problems with powers of 10.

Only the more able candidates made progress with part (c). Most of these obtained the time constant correctly. Fewer went on to determine the charge after 8.3 s using the graph and to compare this with 85 mC required or to state that the graph showed that about 10.5 s was needed to achieve the 85 mC. There was a small minority of candidates who showed that the energy stored would be insufficient after 8.3 s although this was not necessary.

5 Most candidates were able to calculate the initial discharge current successfully in part (a) (i). The common approaches to finding the time constant in part (a) (ii) were reading from the graph at the point where the pd had fallen to 6.0/e, or solving the exponential equation $V = V_0 e^{-t/RC}$ for corresponding V and t values. It was expected that candidates would know that a time constant is measured in s; the unit ΩF was not accepted. The principal difficulty experienced by some candidates in part (a) (iii) was not spotting that the capacitance value had to be expressed in μF. Answers of 2.2×10^{-4} μF were clearly wrong and caused this mark to be lost.

A wide variety of approaches could be adopted when answering part (a) (iv). Most candidates attempted to answer the question 'in reverse', by showing that after 25 s the energy lost would be 90% of the original; this was acceptable. Some lost the third mark when using this method by failing to link the two energies (calculated correctly) to the 90% value for the loss. A neat and concise solution was seen in a few cases, where candidates reasoned that, since $E \propto V^2$, the percentage loss of energy would be $[1 - (V/V_0)^2] \times 100$.

In part (b) (i) one mark was awarded for a correct consequence of the increased charging pd, and one mark for an explanation. The fact that $E \propto V^2$ was quite well known, and it was expected that candidates would realise that doubling the pd would *quadruple* the energy stored: to state just that the energy stored would ‘increase’ was too simplistic to deserve this mark. Candidates who resorted to $E = \frac{1}{2} QV$ almost invariably reached the wrong conclusion, because they thought that the energy stored would *double*.

In part (b) (ii) the one available mark was given for a correct consequence *together with* an acceptable explanation. Relatively few candidates were able to state that the time taken for 90% of the energy to be lost would be unchanged because the time constant had not altered.