Mark schemes

Q1.

(a) Show attempted use of all three equations:

gradient = $\frac{\Delta V}{\Delta t}$ AND $I = \frac{\Delta Q}{\Delta t}$ AND $Q = CV$ ✓

$I_0 = C \times$ **initial** gradient ✓

mp2 $V = \frac{Q}{C}$ so $\Delta V = \frac{\Delta Q}{C}$

so gradient $\frac{\Delta V}{\Delta t} = \frac{\Delta Q}{C\Delta t} = \frac{I}{C}$

hence I_0 = C × initial gradient

*(Δ)Q = I(Δ)t can be seen via substitution if **both** (Δ)Q and I(Δ)t are seen in equivalent expressions e.g. I(Δ)t = CV is insufficient without (Δ)Q = CV.*

Condone omission of Δ's in MP1.

Condone C or initial gradient as subject for mp2.

*Condone a calculation and an **initial** gradient shown on Figure 2*

mp1 and mp2 are independent.

If no other marks award 1 for I = C × gradient or C or gradient as subject.

2

(b) time constant = 7.5 ± 0.5 (s) ✓

evaluated $R = \frac{\text{their } T}{C}$ correctly ✓

Do NOT allow T = RC for mp1. Value must come from Figure 3 using a valid method.

7.44 s is likely to come from RC and not from the graph.

mp1 Time taken to fall to 1/e or 0.37 of its value = time constant eg 0.45 V to 0.166 V takes 7.5 s

This may be calculated over a larger range or the time to halve the voltage found and this value divided by ln2 eg 0.45 V to 0.225 V takes 5.2 s giving = 7.5 s

Half life 5.2 ± 0.5 (s) and $T = \frac{T_{\frac{1}{2}}}{\ln(2)} = \frac{T_{\frac{1}{2}}}{0.69}$

mp2 T = RC so

$R = \frac{T}{C} = \frac{7.5}{31.0\times10^{-6}} = 2.4(2) \times 10^5\ \Omega$

Condone 2SF for mp2 if working is shown.

2

(c) Supply voltage $V_0 = I_0R$ (expect 8.6 V)✓1

Use of $V = V_0\left(1 - e^{\frac{-t}{RC}}\right)$ ✓2

Allow 9V for mp1 or mp2 but do not allow ecf for rounded value in mp3

Alternative

Use of $V_0 = I_0R$ so $I = \frac{I_0R - 6}{R}$ (expect 1.1 × 10^{-5} A)✓1

Use of $I = I_0 e^{-\frac{t}{RC}}$ ✓2

mp2 allow substitutions OR rearrangements using ln

or

use of $V = \frac{Q}{C}$ *and* $Q = Q_0\left(1 - e^{\frac{-t}{RC}}\right)$

Calculation of the time from correct physics (expect 8.8 to 9.0 s) ✓3

Allow ecf for ✓3 R, T values but not from the wrong equation or mix up of V and I.

3

(d) use of $C = Q/V$ and $C = \varepsilon_r\varepsilon_0 A/d$ ✓

$\frac{V_1}{V_2} = 0.125$ ✓

mp1 $V = \frac{Qd}{\varepsilon_r \varepsilon_0 A}$ *may be seen anywhere in the working, possibly with subscripts or rearranged.*

mp2 $\frac{V_1}{V_2} = \frac{d}{4 \times 2d} = 0.125$

Condone $\frac{1}{8}$ *for mp2*

Award 1 mark for 8 regardless of working

mp2 implies mp1

2

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Q2.

(a) $V = V_0\left(1 - e^{-\frac{t}{RC}}\right)$ with substitution attempted with V_0 being larger than V
✓1

Time to charge to 4.0 V = t_2 = $R_1 C \ln\left(1 - \frac{4}{6}\right)$

OR

Time to charge to 2.0 V = t_1 = $-R_1 C \ln\left(1 - \frac{2}{6}\right)$ ✓2

$t = t_2 - t_1 = -R_1 C \ln\left(\frac{1}{3}\right) - \left\{-R_1 C \ln\left(\frac{2}{3}\right)\right\}$

$$\left(= -R_1 C\left(\ln\frac{1}{3} - \ln\frac{2}{3}\right) = -R_1 C \ln\left(\frac{\frac{1}{3}}{\frac{2}{3}}\right)\right) = -R_1 C \ln\left(\frac{1}{2}\right)$$ $0.69 R_1 C$

OR

= $R_1 C$ (1.10 - 0.41) = 0.69 $R_1 C$✓3

NB The answer can be obtained incorrectly by finding the time to charge to 2V using a 4V supply. This approach may only gain the first mark for an attempted use of the equation.

Award 0 for a solution using the discharge equation.

Condone R for R_1

✓2 If given in an equation then then time must be the subject or be in a form that is used to obtain mp3

can be awarded for t_2 = 1.10 × R_1 C ***OR*** *t_1 = 0.41 × R_1 C*

✓3 Must see 0.69 R_1 C for 3 marks.

Only award MP3 for 0.69 R_1 C if the solution involves a time difference.

3

(b) Attempt to find usable data from **Figure 2** ✓1
Determine scaling factor **OR** Determine R_1 ✓2
Calculate Q the charge stored at 4 V or the charging time constant **from a valid method** ✓3
Determine C to a value that rounds to 1×10^{-4} (F) to 2 or more sf (expect to see 1.0×10^{-4} F) ✓4

Method 1 (from area)

✓1a Attempt at finding area under *I-t* graph by counting boxes

✓2a 1 cm² box corresponds to charge 0.5×10^{-5} C

✓3a Number of 1 cm² boxes = 80 (78 to 82)

$Q = (80 \times 0.5 \times 10^{-5}) = (3.9 \text{ to } 4.1)\ 10^{-4}$ (C)

✓4a $C = \frac{\text{their } Q}{4}$ = a value that rounds to 1×10^{-4} (F) (≥ 2 sf required)

Award **MAX 1** for estimating the average current by sight and using $C = \frac{IT}{V}$

Method 2 (from individual data points)

Possible methods are shown but only final answers requested are needed to gain marks.

✓1b Use of a current and voltage across the resistor, e.g. $I = 2.0 \times 10^{-5}$ A and voltage across resistor = 2 V (when capacitor has 4 V)

OR

$I = 6.0 \times 10^{-5}$ A and voltage across resistor = 6 V (when capacitor has 0 V)

✓2b $R_1 = \frac{V}{I} = \frac{2.0}{2.0 \times 10^{-5}}$

OR $\left(\frac{V}{I} = \frac{6}{6 \times 10^{-5}}\right)$ *= 1.0×10^5 (Ω)*

✓3b Charging time constant = $R_1 C$

Eg using $I = I_0 e^{\frac{-t}{R_1 C}}$ then $R_1 C = \frac{t}{\ln\left(\frac{I_0}{I}\right)}$

Substituting $I = 2 \times 10^{-5}$ A and

$I_0 = 6 \times 10^{-5}$ A and $t = 11$ s.

OR

Graphical method must include evidence from Figure 2

charging time constant ($R_1 C$) = 10.(0) (s)

✓4b $C = \frac{\text{time constant}}{R_1} = \frac{10.0}{1.0 \times 10^5}$

= a value that rounds to 1×10^{-4} (F) (≥ 2 sf required)

4

(c) Reading of relevant discharge data from **Figure 3** provided there is an attempt to use data ✓$_1$

A valid substitution of their data into a relevant equation to find R_1 or R_{Total} ✓$_2$

$R_2 = R_{Total}$ - their = $2.0 \times 10^5\ \Omega$ ✓$_3$

allow **one** ecf from either their R_{Total} **or** their R_1

When R_1 is derived in an earlier question accept this value of R_1 and allow ecf for R_{total}

When R_1 is derived in this question, allow one ecf from either their R_{total} or their R_1

*✓$_1$ From **Figure 3** this can be the time taken for the voltage to fall to half its value.*

*✓$_2$ Finding R_{Total} from **Figure 3***

4.0 V to 2.0 V in (32 - 11) s using

$t_{\frac{1}{2}} = 0.69RC$ *allow* $= 0.7RC$

$R_{Total} = 3.0 \times 10^5\ \Omega$

*Finding R_1 from **Figure 2***

6.0 A to 3.0 A in 6.8 s using

$t_{\frac{1}{2}} = 0.69RC$ *allow* $= 0.7RC$

$R_1 = 1.0 \times 10^5\ \Omega$

OR

Using

$I = I_o e^{\frac{-t}{R_1 C}}$

for example, with $I = 2 \times 10^{-5}$ A and $I_o = 6 \times 10^{-5}$ A and $t = 11$ s

Note R_1 may be taken from (b) and not use the graph information.

3

[10]

Q3.

(a) MAX 2 from: ✓✓

the (excess) electrons move onto/are located on the (outer) surface

the (excess) electrons are equally spaced (conditional on the first point being awarded)

(because) the electrons mutually repel

Condone "like charges repel" in the context of electrons.

2

(b) The triangle used to find the gradient covers more than 50% of the horizontal scale. ✓$_1$

Finding the gradient from their tangent ✓$_2$

$2.0 \pm 0.3 \times 10^6$ ✓$_3$ (correct answer within limits only and to better than 1 sf)

Unit $N\ C^{-1}$ **or** $V\ m^{-1}$ ✓$_4$

✓$_2$ *eg gradient at 0.30 m*

$$E = -\left(\frac{0 - -1.2 \times 10^6}{0.6 - 0}\right)$$

(Ignore minus sign and PoT errors but numerical substitutions must be accurate

Condone answer to more than 3 sf.

Condone 'kg m s^{-3} A^{-1}' for unit.

(Any alternative method that does not use the relationship violates the rubric

e.g. $V = kQ/r$ $E = kQ/r^2$ so $E = V/r$

$E = 060 \times 10^6 \div 0.30$

However, MP3 and MP4 can be awarded)

4

(c) (Alternative A finding the charge held by the sphere)

Use of $V = \frac{Q}{4\pi\varepsilon_0 r}$ for any data point

Or using E from part (b)

Use of $E = \frac{Q}{4\pi\varepsilon_0 r^2}$ with E at 0.3 m ✓$_{1,a}$

Q = 2.0 × 10^{-5} (C) ✓$_{2,a}$

C (= Q/V = 2.0 × 10^{-5} / 1.8 × 10^{6}) = 1.1 × 10^{-11} (F) ✓$_{3.a}$ (2 sf at least)

OR (Alternative B without need to evaluate Q)

Using or referring to both equations $C = Q/V$ and $V = \frac{Q}{4\pi\varepsilon_0 r}$ ✓$_{1.b}$

C(= $4\pi\varepsilon_0 r$) = 4π × 8.85 × 10^{-12} × 0.100 ✓$_{2,b}$

C = 1.1 × 10^{-11} (F) ✓$_{3.b}$ (at least 2 sf needed)

The marks must come from one alternative not a mixed route.

Do not award credit for solutions based on parallel-plate capacitor equation.

✓$_{1,a}$

$Q = 4\pi\varepsilon_o rV$ =

$4\pi \times 8.85 \times 10^{-12} \times 0.100 \times 1.8 \times 10^{6}$

OR

$Q = 4\pi\varepsilon_o r^2 E$ =

$4\pi \times 8.85 \times 10^{-12} \times 0.30^2 \times 2.0 \times 10^{6}$

OR

✓$_{1b}$ *Combining equations to give $C = 4\pi\varepsilon_o r$*

For MP1 condone a starting point of $C = 4\pi\varepsilon_0 r$

3

(d) $\left(E = \frac{CV^2}{2}\right)$

Calculate the energy stored at 1.0 × 10^6 V ✓1

Making use of any one of the energy stored equations

$$E = \frac{QV}{2} = \frac{CV^2}{2} = \frac{Q^2}{2C}$$

to calculate the energy stored when fully charged.

= 18 (J) ✓2

change in electrical energy = 18 – 5.5 = 12.5 (J) ✓3

*✓1 The calculation can use C as an ecf from **(c)** or taken as 1 × 10^{-11}.*

$$E = \frac{1.1\times10^{-11}\times\left(1.0\times10^{6}\right)^2}{2} = 5.5\text{ J}$$

Or 5.0 J when using 1 × 10^{-11} F

*✓2 Allow ecf from **(c)** for example*

$$E = \frac{1\times10^{-11}\times\left(1.8\times10^{6}\right)^2}{2} = 16.2\text{ J}$$

$$E = \frac{\left(2.0\times10^{-5}\right)^2}{2\times1\times10^{-11}} = 20\text{ J}$$

note different values from different forms of the E equation because of rounding and data choice

✓3 Allow ecf from the previous two answers and may be positive or negative

Accept alternative routes based on calculation of two separate energies and a difference

When no other marks awarded, credit one mark for an attempt to calculate an energy difference provided one correct energy equation seen.

3

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