Mark schemes

Q1.

(a) (-)4 J of work done per unit charge ✓

moving from infinity to the point / point to infinity✓

correctly linking direction of movement and sign of charge to gain or loss of energy / sign of energy✓

Do not allow 4V for 4J in mp1 only

Condone answer in terms of eV and electron or proton.

Do not consider the sign of the charge or work in mp1 and mp2

Allow ideas in terms of energy transfer from kinetic to potential (or vice versa).

It is insufficient for mp1 to only refer to potential energy.

Example 3 mark answers

-4 J of work is done in moving (+) 1 C charge from infinity to the point.

4 J of work is done in moving a -1 C charge from infinity to the point.

-4 J of work is done in moving a -1 C charge from the point to infinity.

4 J of work is done in moving (+)1 C charge from the point to infinity.

3

(b) Appreciation that the electric field is the potential gradient OR identify highest electric field occurs in the straight section ✓$_1$

Allow ✓$_1$ for use of $E_{avg} = \frac{\Delta V}{\Delta d}$ *not from a tangent (outside of straight section)*

Just stating $E = \frac{\Delta V}{\Delta r}$ (or $\frac{\Delta V}{\Delta d}$) *is not sufficient for mp1.*

Tangent drawn along the straight section and used for gradient or straight section used with triangle of sufficient size ($\Delta V \geq 1.5V$) ✓$_2$

Straight section of line

x = 110 to 230, 350 to 480, 610 to 730, 850 to 980

No credit for ✓$_1$, ✓$_2$ or ✓$_3$ attempt to find Q from a V, d pair then use of $E = \frac{Q}{4\pi\varepsilon_0 r}$

Value between 1.8 and 2.2 × 10^7 (or 2.0 × 10^7) when rounded to 2 SF✓$_3$

Unit V m^{-1} or N C^{-1} ✓$_4$

Expected value 2.01 × 10^7 V m^{-1}

✓$_4$ is standalone mark with some working

*Do **not** accept a unit given in base units.*

Allow unit consistent with their value in mp3 and mp4.

4

(c) (Loss in) kinetic energy = (Gain in) potential energy

OR use of $W = QV$✓

E_k (= e × (V_{peak} - V_{trough}) = 1.60 × 10^{-19} (-0.20 - -3.40)) = 5.12 × 10^{-19} (J) ✓

mp1 can be from an attempt to calculate potential energy even with a mistake in data values.

2

(d) Initial direction of motion e.g. electron initially moves left/towards x = 0 / x = 300 / **P** ✓$_a$

Explanation for motion in terms of field e.g. electric field is to the right but electron charge is negative ✓$_b$

Linking the gradient of the electrical potential/graph to the magnitude of the acceleration of the electron ✓$_c$

Explanation for motion in terms of potential/energy eg electron moves towards higher potential (due to negative charge) / lower potential energy ✓$_d$

Electrical potential energy is converted into kinetic energy ✓$_e$

Recognition that the electron oscillates (about x = 300 nm) ✓$_f$

Explanation for oscillation in terms of potential / field ✓$_g$

Max 3

Do not accept electron is repelled by negative electrode unless no other marks are awarded.

Allow ✓$_f$ for oscillations about the wrong point or if it is unclear where it oscillates about.

Accept acceleration is 0 at e.g. 300 nm for ✓$_c$

Condone reference to SHM for oscillate. Reject vibration for ✓$_f$

Condone Ep → Ek → Ep → Ek without reference to oscillation in ✓$_f$

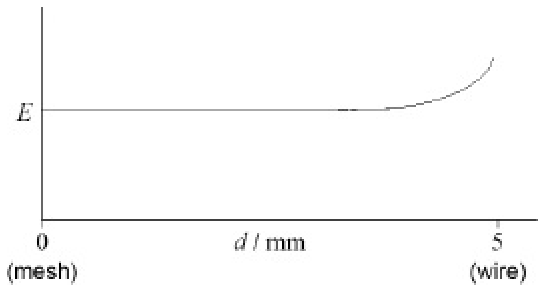
3

[12]

Q2.

(a) Horizontal line above zero for > half the distance ✓

(then) curves upwards ✓



Marks are independent.

2

(b) statement that (kinetic) energy is the same

OR

correct substitution of data into equation/ratio ✓

ratio $\left(= \sqrt{\frac{6.64\times10^{-26}}{9.11\times10^{-31}}} \right)$ = 270 ✓

Some factors (e.g. ½) that cancel may be absent.

2

(c) Due to collisions argon loses more energy / speed / momentum (than electron)

OR

Electron is less ionising (than argon) / Argon is more ionising (than electron)

so ratio is larger. ✓

Mark is for the explanation

Do not allow explanations that suggests the particles have different distances to travel. Do not allow references to air resistance.

Accept idea that "argon has higher probability of collision (than electron)"

Accept reverse arguments

1

(d) Evidence of suitable test for student A suggestion involving 2+ data points ✓1

✓1 test inverse square:

e.g. Nh^2 = constant

Evidence of suitable test for student B suggestion involving 2+ sets of data ✓2

✓2 test exponential:

e.g. N should decrease by half in equal intervals of h

***OR** test $N = k\,e^{-h}$: show that $N\,e^{h}$ is not constant*

Accept log/ln interpretations of the test.

Both tests performed **AND** rejects both suggestions ✓3

✓3

Expect to see for student A $10 \times 1.0^2 = 10$ and $4 \times 1.34^2 = 7.18$ or similar

Expect to see for student B N = 10 to N = 5 changes h by 0.25 and N = 5 to N = 2.5 changes h by 0.31 or similar

reject both students' suggestions with reasons eg Nh^2 is not constant and N does not fall by the same fraction in equal intervals of h

Allow answer accepting B if a reference to experimental error is made and the difference is small.

3

[8]

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 ✓$_{1,a}$

$Q = 2.0 \times 10^{-5}$ (C) ✓$_{2,a}$

C (= Q/V = $2.0 \times 10^{-5} / 1.8 \times 10^{6}$) = 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 $V = \frac{Q}{4\pi\varepsilon_0 r}$ ✓$_{1.b}$

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

$C = 1.1 \times 10^{-11}$ (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.

✓$_{1,a}$

$Q = 4\pi\varepsilon_o r V =$

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

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

[12]