A-Level Physics

Electric Fields

Mark Scheme

Time available: 84 minutes
Marks available: 60 marks

1. (a) Arrow pointing up labelled magnetic force or F_M and arrow pointing down labelled electric force or F_E ✓

As location A is given in the question the base of the arrows do not need to sit exactly on A but arrows, if extended, should pass through A.

Care – in some cases A can look like an arrow head.

1

(b) Statement that electric and magnetic forces balance
OR
$qE = Bqv$
OR
$E = vB$
OR
$1.5 \times 10^5 \times 0.12$ ✓

electric field strength = $E = 1.8 \times 10^4$ (V m^{-1}) ✓

A correct final answer gains both marks

2

(c) (centripetal force or $F_c = \frac{mv^2}{r}$, equals force due to the magnetic field or $F_m = Bqv$)

$\frac{mv^2}{r}$ and hence $\frac{mv}{Bq}$ ✓

Condone use of F to represent both F_c and F_m

Allow an interchange between use of q and Q.

Note F = is required

1

(d) $r \left(= \frac{mv}{Bq} = \frac{1.0\times10^{-26}\times1.5\times10^{5}}{0.12\times1.6\times10^{-19}} \right) = 0.078(1)$ ✓

distance (= 2r) = 0.16 (m) ✓ (0.156 m)

ecf on second mark.

second mark given only if mv/Bq used in a calculation.

2

(e) (using an energy approach)
work done by field equals gain in KE $qV = \frac{1}{2} mv^2$ ✓$_{1a}$

$\left(\text{so } v = \sqrt{\frac{2qV}{m}} = \left(\frac{2\times1.6\times10^{-19}\times\frac{6000}{2}}{1.2\times10^{-26}}\right)^{1/2}\right)$

mark for using the V/2 either in an equation or via a substitution ✓$_{2a}$

= 2.8(3) × 10^5 (m s^{-1}) ✓$_{3a}$
OR
(using a force approach)

Force on ion = $ma = qE$ ✓$_{1b}$

$$a = \frac{6000 \times 1.6 \times 10^{-19}}{1.2 \times 10^{-26} \times d} = 8.0 \times 10^{10}/d$$

Using $v^2 = u^2 + 2as$)
Mark for using equation for E and equation of motion either in symbols or via a substitution ✓$_{2b}$
$v = 2.8 \times 10^5$ (m s^{-1}) ✓$_{3b}$

$_{1a}$ in words or equation which can be awarded even if the ion is not singly charged (candidates can wrongly think it has a charge of 3e)

$_{2a}$ for making use of half the pd ie 3000 V

$_{3a}$ Only allow ecf using 6000V giving

$v = 4.0 \times 10^5$ m s^{-1}

3

(f) A smaller mass gives a smaller time interval ✓$_1$

(The explanation can come from a Force or a Work done approach)
The ions are given the same force ✓$_{2a}$
(so) smaller mass has higher acceleration and smaller time interval ✓$_{3a}$
OR
Work done on ions or kinetic energy gained is the same ✓$_{2b}$
(so) smaller mass is given greater speed and smaller time interval ✓$_{3b}$

Award any two of the three marks

condone use of 'lighter' for 'smaller mass'

3 max 2

[11]

2. (a) Electromagnetic ✓

Reject electrostatic as it is not one of the fundamental forces.

1

(b) Arrow drawn at X in a direction radially away from the centre of the gold nucleus ✓

1

(c) Answer number 5 or 6 plus one consistent justification ✓

First mark must come with at least one justification.

One more consistent justification ✓

List of justifications:
Cannot be 1, 2, or 3 as these s alpha's deflect up. Or must be 5 to 9 as these all alpha's deflect down.

Cannot be 4 as this would backscatter or is scattered at 180°

Cannot be 7, 8 or 9 as the deflection would be too small. Or must be 2, 3, 5, 6 as these have a greater deflection than alpha1.

The second mark is possible to obtain with two consistent justifications even if the first mark is missed.

E.g. if an answer 7 is given then quoting the first two justifications gains a mark.

2

(d) (Using of potential energy = $\frac{Qq}{4\pi\varepsilon_o r}$

Substituting the values of the two charges multiplied together into an equation
$(2 \times 1.6 \times 10^{-19})(79 \times 1.6 \times 10^{-19})$✓$_1$

$$PE = \frac{2\times79\times\left(1.6\times10^{-19}\right)^2}{4\pi\times8.9\times10^{-12}\times5.5\times10^{-14}} \text{ or } 6.58\times10^{-13}\text{ (J)} ✓_2$$

$_2$ The substitution may be inferred at the next stage of the calculation that uses

$KE = \frac{1}{2}mv^2 = PE$

(loss of KE = $\frac{1}{2}mv^2$ = gain in PE}

$$\left(v = \left(\frac{2\times6.58\times10^{-13}}{6.8\times10^{-27}}\right)^{1/2}\right)$$

$v = 1.4 \times 10^7$ (m s^{-1})✓$_3$

3

(e) Using by substitution or rearrangement $R = r_o A^{1/3}$ ✓

R_{Ag} = 5.7 × 10^{-15} (m) ✓

$$\left(R_{Ag} = R_{Au} \times \left(\frac{A_{Au}}{A_{Ag}}\right)^{1/3}\right)$$

$$\left(R_{Ag} = 6.98 \times 10^{-15} \times \left(\frac{107}{197}\right)^{1/3}\right)$$

The use of the equation must involve both nuclei.

2

(f) Nucleons are incompressible / Nucleons have a constant separation / Neutrons and protons have similar masses / Neutrons and protons have similar volumes ✓

A mark can be given for 'nucleons touch' but it must be implied that this is with all 12 neighbours'.

1

[10]

3. (a) C (= $4\pi\varepsilon_O r = 4\pi$ × 8.85 × 10^{-12} × 0.020)
= 2.2(2) × 10^{-12} (F) ✓$_1$

✓$_1$ Mark for substitution or answer. Also it may be seen incorporated into the second mark.

Substitution of

V (= Q/C) = 52 × 10^{-9}/2.22 × 10^{-12} ✓$_2$

✓$_2$ Use of r = 0.04 m in the previous mark is treated as an arithmetic error and the substitution 52 × 10^{-9}/4.44 × 10^{-12} is given a CE mark.

V = 23 000 (V) ✓$_3$ (23 400 V)

✓$_3$

A continuation of the CE gives a mark to the answer 12000 or 11700 (V)

A correct answer gains all 3 marks.

Commonly 23000 V gives 3 marks

11700 V gives 2 marks

Also a power of 10 error in the final answer gives 2 marks.

For any other final answer the only possibility is to get one mark for use of $V = Q/C$ when C is clearly given or $V = \frac{Q}{4\pi\varepsilon_0 r}$ is uses with an incorrect value of r.

3

(b) Labelled arrows on **B**

- Tension or T parallel to thread and upwards
- weight or mg or W starting from sphere centre vertically down
- electrostatic force or repulsion to right and starting from the inside or edge of the sphere ✓✓

2 marks for all 3 arrows and labels
1 mark for 2 arrows and labels
1 mark for 3 arrows, no or incomplete labels

For the electrostatic force label also allow F_{elec} or 'force between charges. F_A etc.

Ignore gravity between spheres.

If a reaction force given – max 1 mark.

2

(c) One mark for stating the problem. ✓$_1$

✓$_1$ The problem must be explicitly stated but not much detail is needed. EG Anything used between the spheres may disrupt the field.

One mark for giving a corresponding solution. ✓$_2$

✓$_2$ The solution must be detailed enough to convey what must happen.

For example
Metallic or conducting instruments placed between the spheres will affect the separation (because of the movement of charge/electrons within the instrument)
(Inside) callipers made from a non-conduction material in conjunction with a ruler could be used
Or
A travelling telescope on a vernier scale could be used (at a distance)
Other examples of problems
Physically touching the spheres may alter the reading.
Difficulty of measuring distance between curved objects.
A measuring instrument can have a dielectric constant/permittivity, which will affect the separation/disrupt the field.
Reading a ruler behind the spheres will give rise to a parallax error.

Other examples of solutions.

Ruler and set square set up parallel to the line joining the centres of the spheres.

Measure (beforehand) the length of thread y and measure the angle with a protractor and calculate distance x using trig'.

2

(d) Using distance = 80 mm (mark given even in a wrong formula)
Or
Stating that the charge can be considered to be in the centre of each sphere ✓$_1$

$F\ (= \frac{Q_1 Q_2}{4\pi\varepsilon_o r^2}) = \frac{(52\times10^{-9})^2}{4\pi\varepsilon_o(0.080)^2}$ ✓$_2$

✓$_2$ Power of 10 errors are condoned and so is the use of the wrong separation (as this was penalized in the previous mark).

$F = 3.8 \times 10^{-3}$ (N) ✓$_3$ (Showing at least 2 sig figs)

✓$_3$ No ecf for this final mark.

3

(e) (As each sphere is in equilibrium then $\tan\theta = \frac{F_{electrostatic}}{mg}$ a mark is given for a reference and substitution into this equation in any configuration. The second mark is for an evaluation that is said to be consistent. Use of 4×10^{-3} N given in part (d) gains full credit.)

$\theta = \tan^{-1}\left\{\frac{3.8\times10^{-3}}{3.2\times10^{-3}\times9.8}\right\}$ ✓= 6.9° which is consistent ✓

or

$F_{electrostatic} = \{3.2 \times 10^{-3} \times 9.8 \times \tan 7°\}$ ✓
= 3.8(5) × 10^{-3} (N) which is consistent ✓

or

$m = \left\{\frac{3.8\times10^{-3}}{9.8\tan 7^o}\right\}$ ✓ = 3.1(6) × 10^{-3} (kg) which is consistent ✓

Alternatively

$T = \frac{3.2\times10^{-3}\times9.8}{\cos 7^o}$ = 0.032 ✓$_{1Alt}$

and $T = \frac{3.8\times10^{-3}}{\sin 7^o}$ = 0.031, the same value so consistent ✓$_{2Alt}$

using 4 × 10^{-3} N gives 7.3°

More circular routes using Pythagoras are possible but they end in the same calculated results.

using 4 × 10^{-3} N gives 3.3(2) × 10^{-3} kg

✓$_{1Alt}$ Any equation that results in the calculation of the tension.

✓$_{2Alt}$ A second calculation of the tension which is stated to be consistent with the first.

2

(f) (In the following calculations condone the use of 1 sig fig for all data)

F_{grav} $(= \frac{GMm}{r^2})$ = 6.67 × 10^{-11} × $\frac{(3.2\times10^{-8})^2}{0.080^2}$ ✓$_{1a}$

F_{grav} = 1.1 × 10^{-13} (N) which is small/negligible compared to F_{elect} (≈ 4 × 10^{-3} N) so statement is valid ✓$_{2a}$

Alternative
(find the ratio between the forces)

$$\left(\frac{F_{elec}}{F_{grav}} = \frac{\frac{Q_1Q_2}{4\pi\varepsilon_o r^2}}{\frac{GMm}{r^2}}\right)$$

$$\frac{F_{elec}}{F_{grav}} = \left(\frac{Q_1Q_2}{Mm}\right)\frac{1}{G4\pi\varepsilon_o}$$

(mark given for this ratio or the substitution below)

$$\frac{F_{elec}}{F_{grav}} = \left(\frac{(52\times10^{-9})^2}{(3.2\times10^{-3})^2}\right)\times\left(\frac{1}{6.67\times10^{-11}\times4\times\pi\times8.85\times10^{-12}}\right)$$ ✓$_{1b}$

F_{elec} is 3.6 × 10^{10} times F_{grav}

OR

or F_{grav} is 2.8 × 10^{-11} times F_{elec} ✓$_{2b}$

✓$_{1a}$ It is the use of the formula that is important for the mark. Giving the equation in symbols followed by an answer gains the mark.

✓$_{2a}$ No ecf for the second mark in order to keep the same level of difficulty as in the alternative.

2

[14]

4. (a) Ionisation is when an atom / molecule loses (or gains) one (or more) electrons ✓

1

(b) Potential energy of ion is transferred to kinetic energy of ion✓

Power supply transfers energy to the ion✓

Decrease in energy stored in supply = increase in (kinetic) energy stored by the ion✓

3

(c) electric force is constant✓

magnetic force increases with speed✓

(magnetic force dominates) direction of force predicted by any consistent named force rule✓

3

(d) Path curves upwards between the plates✓

1

(e) The magnetic force is the same (Bqv) ✓

So r increases / less curvature✓

OR

$Bqv = \frac{mv^2}{r}$ so $r = \frac{mv}{Bq}$ ✓

v, B, q constant so $r \propto m$ and r increases✓

2

(f) Same path in velocity separator ✓

since Bqv=Eq so v independent of q ✓

In mass selector radius is decreased ✓

since $r = \frac{mv}{Bq}$ so $r \propto \frac{1}{q}$ ✓

Both correct with one correct justification would get 3 marks

MAX 3

[13]

5. (a) $t = \sqrt{\frac{2s}{g}}$ or $4.5 = \frac{1}{2} \times 9.81 \times t^2$ ✓

t = 0.96 s✓

2

(b) Field strength = 186000V m^{-1}✓

Acceleration = Eq / m

or $186\,000 \times 1.2 \times 10^{-6}$ ✓

0.22 m s^{-2} ✓

3

(c) 0.10(3)m (allow ecf from (i))✓

1

(d) Force on a particle = mg and

acceleration = F / m so always = g✓

Time to fall (given distance) depends (only) on the distance and acceleration✓

OR:

$g = GM / r^2$ ✓

Time to fall = $\sqrt{2s / g}$

so no m in equations to determine time to fall✓

2

(e) Mass is not constant since particle mass will vary✓

Charge on a particle is not constant✓

Acceleration = Eq / m or $(V / d)(q / m)$ or Vq / dm✓

E or V / d constant but charge and mass are ‘random’ variables so q / m will vary (or unlikely to be the same)✓

4

[12]