1 (a) Define the electric potential at a point in an electric field.

____

____

____

____

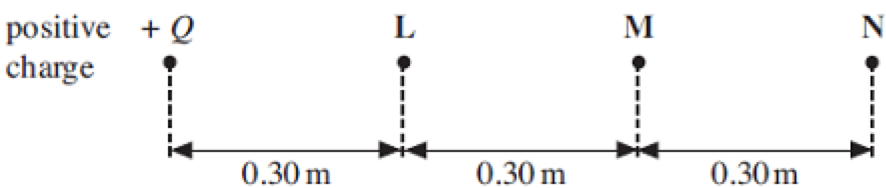
____

____

(3)

(b) **Figure 1** shows part of the region around a small positive charge.

Figure 1



(b) (i) The electric potential at point **L** due to this charge is + 3.0 V. Calculate the magnitude *Q* of the charge. Express your answer to an appropriate number of significant figures.

answer = ______________________ C

(3)

(ii) Show that the electric potential at point **N**, due to the charge, is +1.0 V.

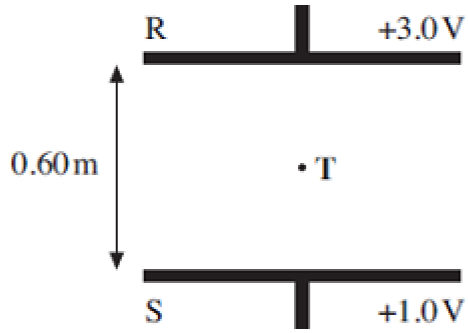
(1)

(iii) Show that the electric field strength at point **M**, which is mid-way between **L** and **N**, is 2.5 Vm^{-1}.

(1)

(c) R and S are two charged parallel plates, 0.60 m apart, as shown in **Figure 2**.
They are at potentials of + 3.0 V and + 1.0 V respectively.

Figure 2



(i) On **Figure 2**, sketch the electric field between R and S, showing its direction.

(2)

(ii) Point **T** is mid-way between R and S.
Calculate the electric field strength at **T**.

answer = ______________________ Vm^{-1}

(1)

(iii) Parts (b)(iii) and (c)(ii) both involve the electric field strength at a point mid-way between potentials of + 1.0 V and + 3.0 V. Explain why the magnitudes of these electric field strengths are different.

___

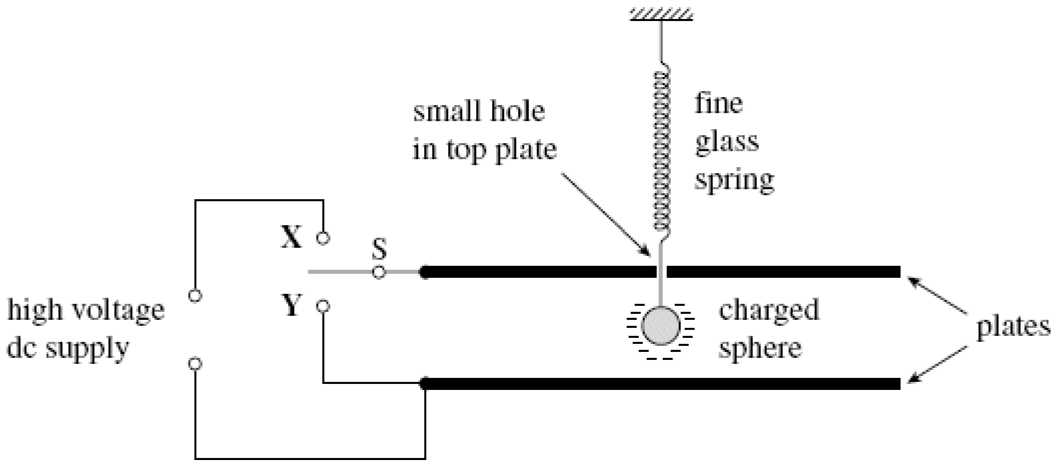
___

___

(1)

(Total 12 marks)

2 A small negatively charged sphere is suspended from a fine glass spring between parallel horizontal metal plates, as shown in the figure below.



(a) Initially the plates are uncharged. When switch S is set to position **X**, a high voltage dc supply is connected across the plates. This causes the sphere to move vertically upwards so that eventually it comes to rest 18 mm higher than its original position.

(i) State the direction of the electric field between the plates.

____

(1)

(ii) The spring constant of the glass spring is 0.24 N m^{-1}. Show that the force exerted on the sphere by the electric field is 4.3×10^{-3} N.

(1)

(iii) The pd applied across the plates is 5.0 kV. If the charge on the sphere is -4.1×10^{-8} C, determine the separation of the plates.

answer = ______________________ m

(3)

(b) Switch S is now moved to position **Y**.

(i) State and explain the effect of this on the electric field between the plates.

___

___

___

___

(2)

(ii) With reference to the forces acting on the sphere, explain why it starts to move with simple harmonic motion.

___

___

___

___

___

___

(3)

(Total 10 marks)

3 (a) (i) Define the *electric field strength*, *E*, at a point in an electric field.

___

___

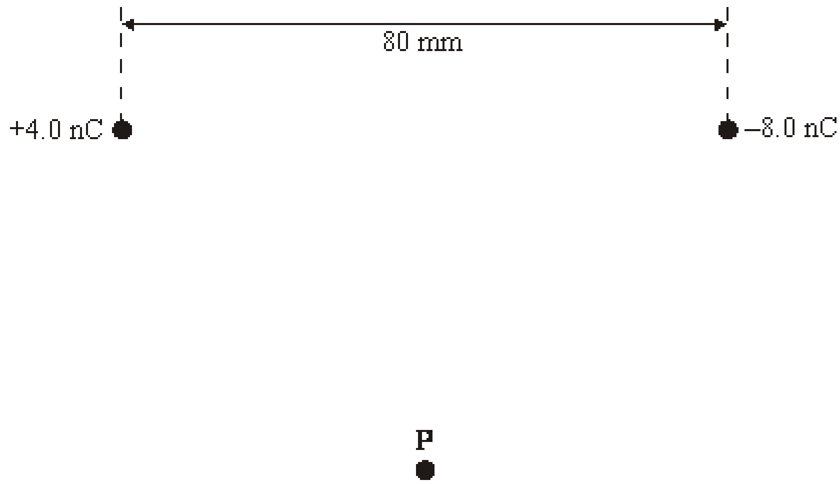
___

(ii) State whether *E* is a scalar or a vector quantity.

___

(3)

(b) Point charges of +4.0 nC and –8.0 nC are placed 80 mm apart, as shown in the figure below.



(i) Calculate the magnitude of the force exerted on the +4.0 nC charge by the –8.0 nC charge.

____

____

____

____

(ii) Determine the distance from the +4.0 nC charge to the point, along the straight line between the charges, where the electric potential is zero.

____

____

____

____

(4)

(c) Point **P** in the figure above is equidistant from the two charges.

(i) Draw two arrows on the figure above at **P** to represent the directions and relative magnitudes of the components of the electric field at **P** due to each of the charges.

(ii) Hence draw an arrow, labelled **R**, on the figure above at **P** to represent the direction of the resultant electric field at **P**.

(3)

(Total 10 marks)

4 (a) **Figure 1** shows the electron gun that accelerates electrons in an electron microscope.

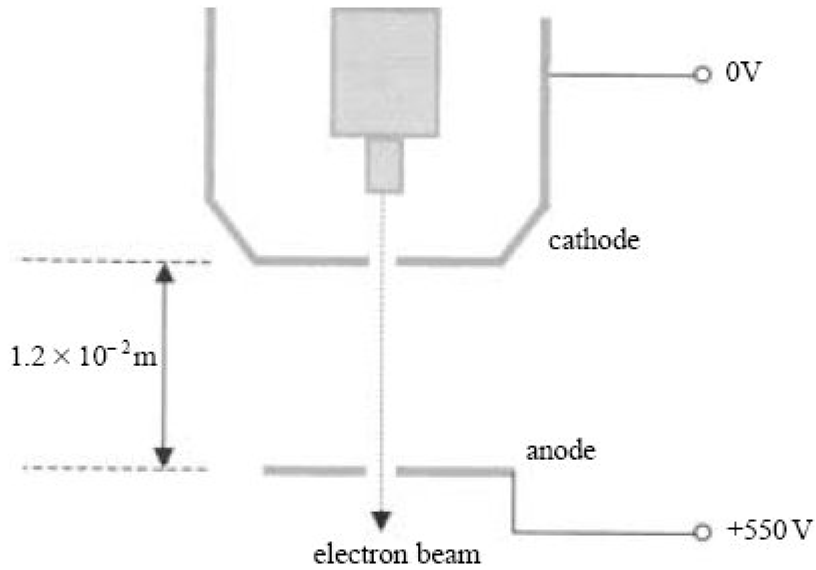


Figure 1

(i) Draw, on **Figure 1**, electric field lines and lines of equipotential in the region between the anode and cathode. Assume that there are no edge effects and that the holes in the plates do not affect the field.
Clearly label your diagram.

(3)

(ii) Calculate the kinetic energy, speed and momentum of an electron as it passes through the hole in the anode.

mass of an electron = 9.1×10^{-31} kg
charge of an electron = -1.6×10^{-19} C

(4)

(b) By calculating the de Broglie wavelength of electrons coming through the anode of this device, state and explain whether or not they will be suitable for the investigation of the crystal structure of a metal.

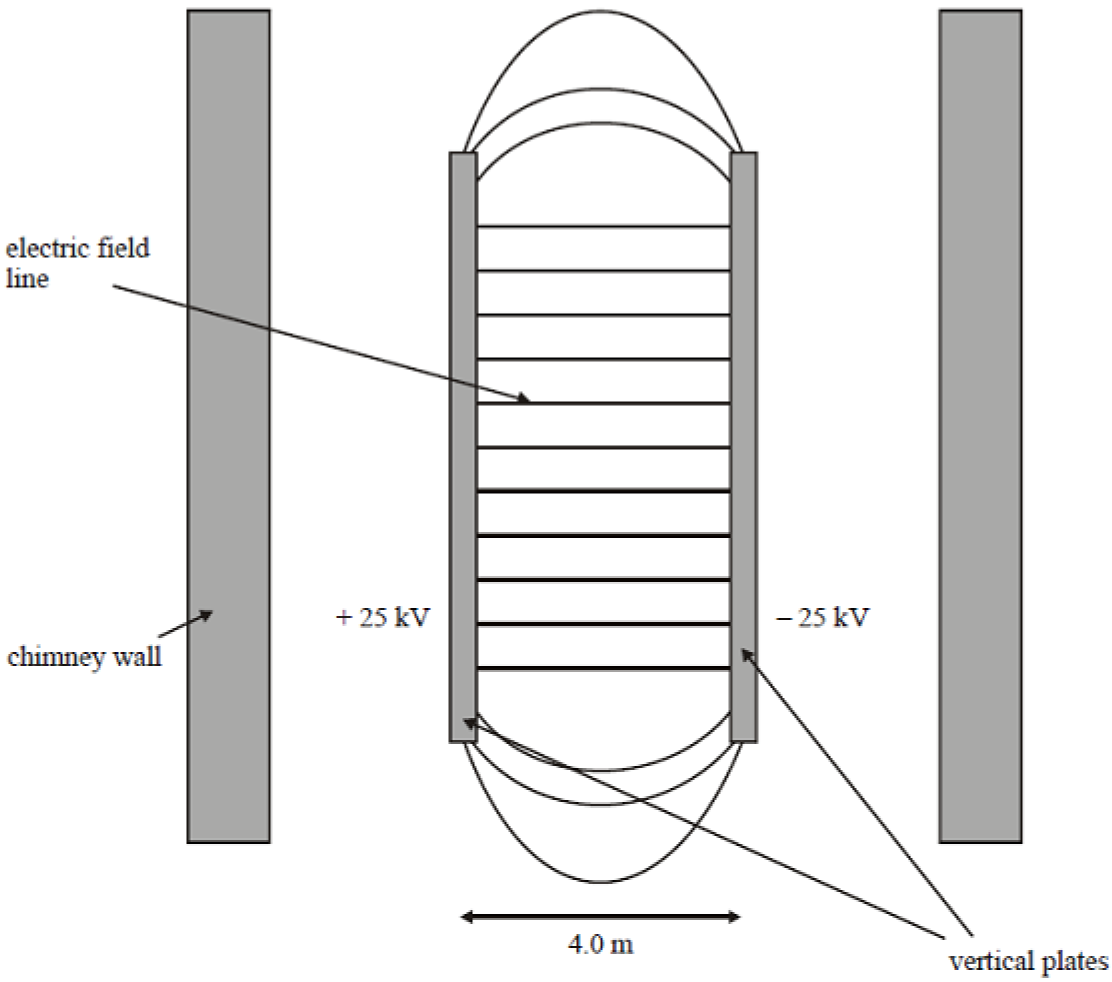
Planck constant = 6.6×10^{-34} J s

(4)

(Total 11 marks)

5 (a) The diagram below shows part of a precipitation system used to collect dust particles in a chimney. It consists of two large parallel vertical plates maintained at potentials of +25 kV and –25 kV.

The diagram below also shows the electric field lines between the plates.



(i) Add arrows to the diagram to show the direction of the electric field.

(1)

(ii) Explain what is meant by an *equipotential surface*.

____

____

____

(1)

(iii) Draw and label on the diagram equipotentials that correspond to potentials of –12.5 kV, 0 V, and +12.5 kV.

(2)

(b) A small dust particle moves vertically up the centre of the chimney, midway between the plates.

(i) The charge on the dust particle is +5.5 nC. Show that there is an electrostatic force on the particle of about 0.07 mN.

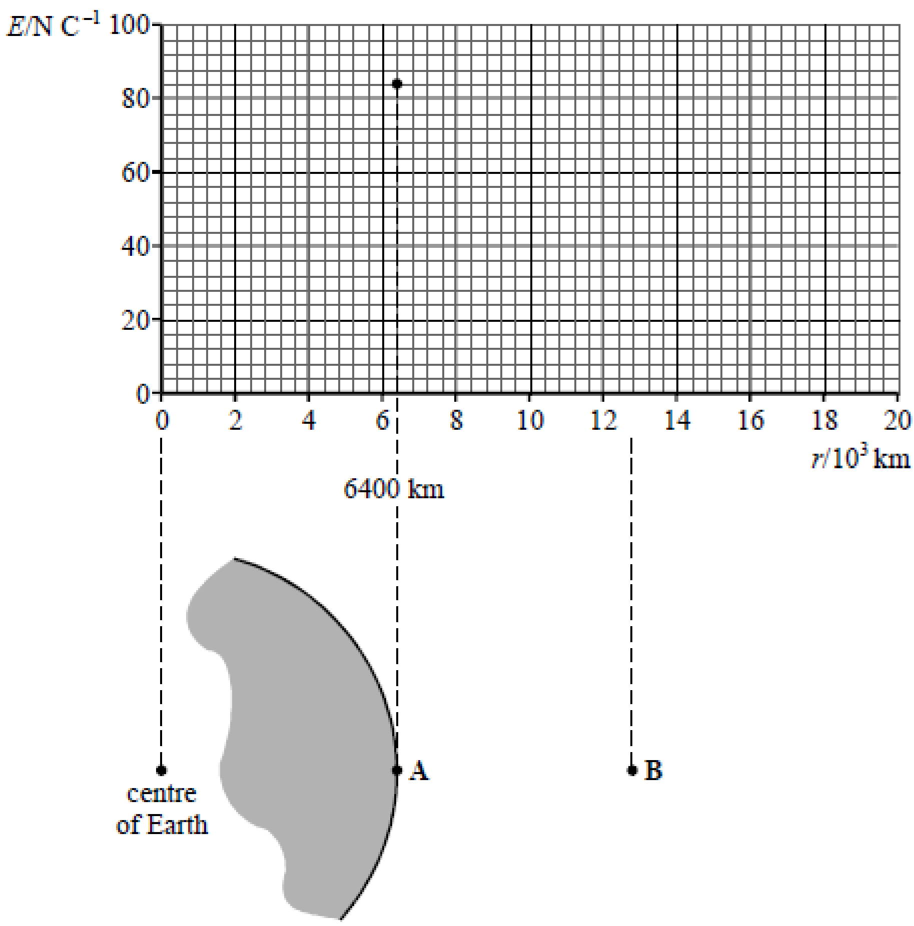
(2)

(ii) The mass of the dust particle is 1.2×10^{-4} kg and it moves up the centre of the chimney at a constant vertical speed of 0.80 m s^{-1}.

Calculate the minimum length of the plates necessary for this particle to strike one of them. Ignore air resistance.

(4)
(Total 10 marks)

6 The Earth has an electric charge. The electric field strength outside the Earth varies in the same way as if this charge were concentrated at the centre of the Earth. The axes in the diagram below represent the electric field strength E and the distance from the centre of the Earth r. The electric field strength at **A** has been plotted.



(a) (i) Determine the electric field strength at **B** and then complete the graph to show how the electric field strength varies with distance from the centre of the Earth for distances greater than 6400 km.

(3)

(ii) State how you would use the graph to find the electric potential difference between the points **A** and **B**.

____

____

(1)

(b) The permittivity of free space ε_0 is 8.9×10^{-12} F m^{-1} .

(i) Calculate the total charge on the Earth.

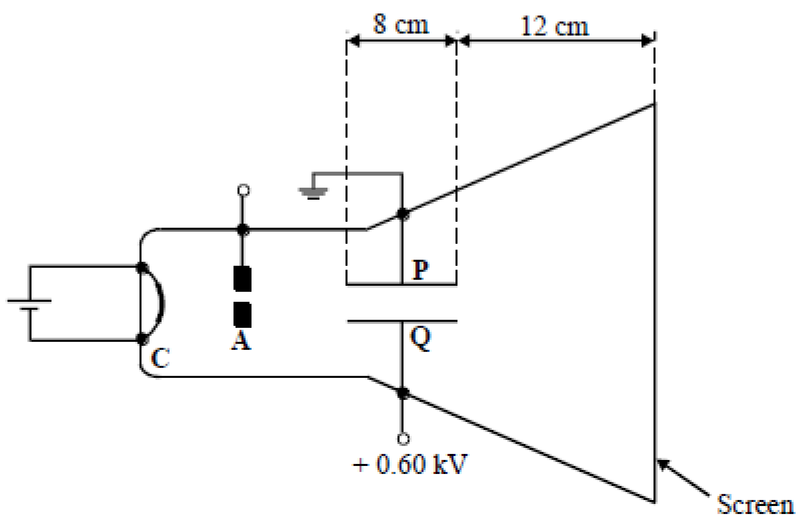
(2)

(ii) The charge is distributed uniformly over the Earth's surface. Calculate the charge per square metre on the Earth's surface.

(2)

(Total 8 marks)

7 In the cathode ray tube illustrated below, electrons are accelerated by a potential difference of 1.8 kV between the cathode (**C**) and the anode (**A**).



(a) (i) Calculate the kinetic energy, in J, of the electrons after they have passed the anode.

charge on an electron, $e = -1.6 \times 10^{-19}$ C

(2)

(ii) Calculate the velocity of the electrons after they have passed the anode.

Mass of an electron = 9.1×10^{-31} kg

(2)

(b) The plates **P** and **Q** are 8.0 cm long and are separated by a gap of 4.0 cm.

(i) Define electric field strength.

____

____

(1)

(ii) Calculate the force acting on an electron when it is between **P** and **Q** and state the direction of the force.

Direction ____

(3)

(iii) Calculate the time taken for an electron to pass between the plates.

(1)

(iv) Calculate the vertical component of velocity at the time the electron leaves the electric field between **P** and **Q**.

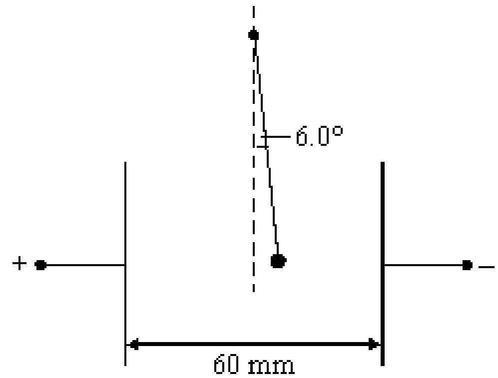
(2)

(v) Calculate the additional vertical displacement of the electron between the time it leaves the electric field between **P** and **Q** and when it reaches the screen.

(1)

(Total 12 marks)

8 A small charged sphere of mass 2.1×10^{-4} kg, suspended from a thread of insulating material, was placed between two vertical parallel plates 60 mm apart. When a potential difference of 4200 V was applied to the plates, the sphere moved until the thread made an angle of 6.0° to the vertical, as shown in the diagram below.



(a) Show that the electrostatic force F on the sphere is given by

$F = mg \tan 6.0°$

where m is the mass of the sphere.

(3)

(b) Calculate

(i) the electric field strength between the plates,

(ii) the charge on the sphere.

(3)

(Total 6 marks)

Mark schemes

1 (a) work done [or energy needed] per unit charge
[**or** (change in) electric pe per unit charge] ✓

on [or of] a (small) positive (test) charge ✓

in moving the charge from infinity (to the point) ✓

[**not** from the point to infinity] ✓

3

(b) (i) $V = \dfrac{Q}{4\pi\varepsilon_0 r}$ gives Q (= $4\pi\varepsilon_0 rV$) = 4π × 8.85 × 10^{-12} × 0.30 × 3.0 ✓

= 1.0 × 10^{-10} (C) ✓

to **2 sf** only ✓

3

(ii) use of $V \propto \dfrac{1}{r}$ gives $V_M = \dfrac{V_L}{3}$ ✓ (= (+) 1.0 V)

1

(iii) $E\left(= \dfrac{Q}{4\pi\varepsilon_0 r^2}\right) = \dfrac{1.0 \times 10^{-10}}{4\pi \times 8.85 \times 10^{-12} \times 0.60^2}$ ✓ (= 2.50 V m^{-1})

1

(c) (i) uniformly spaced vertical parallel lines which start and end on plates ✓

relevant lines with arrow(s) pointing only downwards ✓

2

(ii) = 3.3(3) (V m^{-1}) ✓

1

(iii) part (b) is a radial field whilst part (c) is a uniform field ✓

[**or** field lines become further apart between **L** and **M** but are equally spaced between **R** and **S**]

1

[12]

2 (a) (i) (vertically) downwards [**or** top to bottom, or down the page] **(1)**

1

(ii) force on sphere F (= kx) = 0.24 × 18 × 10^{-3} **(1)** (= 4.32 × 10^{-3} N)

1

(iii) **use of** $F = EQ$ gives $E = \frac{4.32\times10^{-3}}{41\times10^{-9}}$ **(1)** (= 1.05×10^5 V m^{-1})

use of $E = \frac{V}{d}$ gives separation $d = \frac{5.0\times10^{-3}}{1.05\times10^5}$ **(1)**

= 4.8×10^{-2} (m) **(1)** (4.76×10^{-2})

3

(b) (i) electric field becomes zero (or ceases to exist) **(1)**

flow of charge (or electrons) from one plate to the other
[**or** plates discharge] **(1)**

(until) pd across plates becomes zero [**or** no pd across plates,
or plates at same potential] **(1)**

max 2

(ii) net downward force on sphere (when *E* becomes zero)
[**or** gravitational force acts on sphere, **or** force is weight] **(1)**

this force extends spring **(1)**

force (or acceleration) is proportional to (change in)
extension of spring **(1)**
acceleration is in opposite direction to displacement
(or towards equilibrium) **(1)**

for shm, acceleration $\propto$ (−) displacement
[**or** for shm, force $\propto$ (−) displacement] **(1)**

max 3

[10]

3 (a) (i) force per unit charge **(1)**
acting on a positive charge **(1)**

(ii) vector **(1)**

3

(b) (i) $F\left(=\frac{Q_1Q_2}{4\pi\varepsilon_0 r^2}\right) = \frac{4.0\times10^{-9}\times8.0\times10^{-9}}{4\pi\times8.85\times10^{-12}\times(80\times10^{-3})^2}$ **(1)**

=4.5(0) × 10^{-5}N **(1)**

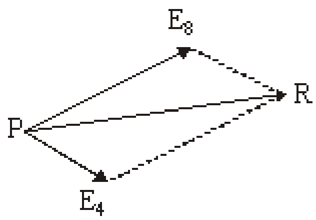
(ii) (use of $V = \frac{Q}{4\pi\varepsilon_0 r}$ gives) $0 = \left(\frac{4.0\times10^{-9}}{4\pi\varepsilon_0 x}\right) - \left(\frac{8.0\times10^{-9}}{4\pi\varepsilon_0(80\times10^{-3}-x}\right)$

or $\frac{4}{x} = \frac{8}{80-x}$ **(1)**

x = 26.7mm **(1)**

4

(c) correct directions for E_4 and E_8 **(1)**
E_8 approx twice as long as E_4 **(1)**
correct direction of resultant R
shown **(1)**



3

[10]

4 (a) (i) Lines of equipotential parallel to the plates

B1

Field lines perpendicular to plates, evenly spaced and with arrows upwards

B1

Lack of clear labelling of at least one of the types of line loses 1 mark
Either field shown to be uniform

B1

3

(ii) KE = 8.8×10^{-17} J

B1

Use of ½ mv^2

C1

Speed = 1.4×10^7 m s^{-1} **ecf**

A1

Momentum =1.27×10^{-23} kg m s^{-1} **ecf**

B1

4

(b) Use of de Broglie wavelength = *h/mv*

C1

5.2×10^{-11} m **ecf**

A1

diffraction of electrons necessary

M1

will work because wavelength is of same order as atomic separation (not just wavelength is too small)/argument consistent with their (a) (ii).

A1

4

[11]

5 (a) (i) shows arrows from + to –

Bl

(ii) surface of constant potential / no work done in moving charge on surface OWTTE

Bl

(iii) 3 correct lines between plates, straight, labelled, +12.5 kV on left

Bl

outwards curvature at edge of plates

Bl

(b) (i) **F** = Vq / d ***or*** $50000 \times 5.5 \times 10^{-9} / 4$

Bl

= 0.0690 [mN] [0.0688]

Bl

(ii) $a = F / m = 0.069 \times 10^{-3} / 0.12 \times 10^{-3}$

= 0.575 / 0.573 m s^{-2}

Cl

use of appropriate kinematic equation

Cl

$t = \sqrt{2} \times 2 / 0.575 = (2.63)$ s

Cl

so length must be 0.8 × 2.63 = 2.11 m [gets mark ecf from third mark if number quoted]
allow alternative energy approach

Bl

[10]

6 (a) (i) E at $2R$ = 20 to 21 (NC^{-1}) i.e. no up **B1**

(i.e. have used inverse square law possibly misreading the E axis)

correct curvature with line through given point
must not increase near tail
(ignore below 6400 km) **B1**

no intercept on distance axis and through correctly calculated point **B1**

(ii) determine the area under the graph **B1**

between **A** and **B** or between the points
ignore any reference to $V = Ed$) **B1**

(b) (i) $E = q/4\pi\varepsilon_0 r^2$ (Q = 84 × 4π 8.9 × 10^{-12} $(6400\ 000)^2$ **C1**

(3.8–3.9) × 10^5 C **A1**

(ii) surface area of the Earth = 5.15 × 10^{14} (m^2) **C1**

or:
charge per square metre = total charge/ surface area of Earth
(may be seen as a numerical substitution with wrong area)

738 – 760 pC (m^{-2}) ecf for Q from (b)(i) **A1**

NB

(i) answer is the same when unit is left in km since r^2 cancels so condone
(ii) Use of $E = q / 4\pi\varepsilon_0 r$ followed by area = $4\pi r$ gives correct value but no marks

[8]

7 (a) (i) $E = eV$ **C1**

2.9 (2.88) × 10^{-16} J **A1**

(2)

(ii) KE = 0.5 mv^2

C1

$v = 2.5(2) \times 10^7$ m s^{-1}

A1

allow e.c.f. for (i) ie $1.5 \times 10^{15} \times \sqrt{}$(their (i)

(2)

(b) (i) force acting per unit charge or F / q with symbols defined

B1

(1)

(ii) $F = eE$ or $F = eV / d$ or $E = V / d$

C1

2.4×10^{-15} N

A1

downwards / towards Q

B1

(3)

(iii) $3.2\ (3.17) \times 10^{-9}$ s
e.c.f. for their (ii)

A1

(1)

(iv) $a = F / m$ or $v = Ft / m$

C1

$8.4\ (8.36) \times 10^6$ m s^{-1}

ecf their (ii) × their (iii)

A1

(2)

(v) 4.0 cm (3.98 cm)

do not allow e.c.f.

B1

(1)

[12]

8 (a) $mg = T \cos 6$ **(1)**
$F = T \sin 6$ **(1)**
hence $F = mg \tan 6$ **(1)**
[or correct use of triangle:
(1) for sides correct, **(1)** for 6°, **(1)** for tan 6 = F/mg

or $F\Delta x = mg\,\Delta h$, $\tan\theta = \dfrac{\Delta h}{\Delta x}$ $\tan 6° = \dfrac{F}{mg}$

3

(b) (i) (use of $E = \frac{V}{d}$ gives) $E = \frac{4200}{60 \times 10^{-3}}$ = 7.0 × 10^{4} V m^{-1} **(1)**

(ii) (use of $Q = \frac{F}{E}$ gives) $Q \left(= \frac{mg \tan 6}{E} \right) = \frac{21 \times 10^{-4} \times 9.8 \tan 6}{7 \times 10^{4}}$

= 3.1 × 10^{-9} C

(allow C.E. for value of E from (i))

3

[6]

Examiner reports

1 The definition of electric potential in part (a) was generally well known. Where students did not score all three marks this was down to oversight; typically either omitting to mention that the charge involved in the definition is *positive* or that the definition involves the work done *per unit* charge.

In part (b) (i), most students successfully applied $V = Q/4\pi\varepsilon_0 r$ in order to determine the magnitude of the charge (1.0×10^{-10} C) from the value of V when $r = 0.30$ m. As the data in the question is given to two significant figures, an answer was expected to two significant figures. Some students need to appreciate that the number of significant figures they should quote in an answer needs to be limited to the least precise data they are working with, not the most (in the *Data Sheet* (see Reference Material) ε_0 is given to three significant figures). At the same time, in these circumstances the answer should never be abbreviated to one significant figure (1×10^{-10} C), as was the case in many answers.

The mark in part (b) (ii) was gained easily, usually by applying $V = Q/4\pi\varepsilon_0 r$, although more perceptive students saw that $V \propto 1/r$ could lead to a more concise answer. Part (b) (iii) caused a little more difficulty for some students. Application of $E = Q/4\pi\varepsilon_0 r^2$ with $r = 0.60$ m was the obvious route. The pitfall for many was that, by first finding V at M (by the same method as before), they then had to apply $E = V/d$ to find the field strength. This last equation specifically applies to a *uniform* field and it therefore cannot be used here. Surprisingly, there were many students who, having obtained an incorrect charge in part (b) (i) as a result of an arithmetical slip, did not revisit part (i) when they could not show either of the required values in parts (ii) and (iii).

Many good attempts to represent the electric field between two plates were seen in part (c) (i), but careless sketching, such as field lines stopping short of the plates, often meant that it was not possible to award both marks. Because this was the field between two plates at different positive potentials, some students were thrown off course both when sketching the field and when the uniform field strength had to be found in part (c) (ii). In part (c) (iii) the respective radial and uniform fields were usually recognised but a precise statement that identified which was which was required to gain the mark.

2 Far fewer correct answers were seen to part (a) (i) than might have been expected. Deducing the correct direction for the electric field involved spotting that the electrostatic force on the sphere acted upwards, and that the sphere carried a negative charge. The vast majority of answers to part (a) (ii) showed that students had not forgotten Hooke's law from Unit 2 of AS Physics; 0.24×0.018 readily gave 4.32×10^{-3} N. Part (a) (iii) was also well answered, either by combining $F = EQ$ and $E = V/d$ before inserting numbers, or by working out E, and then d, separately.

Attempts to answer both sections of part (b) showed that many candidates had little understanding of what would happen when switch S was moved to position **Y**. The fact that the immediate effect would be to short out the plates, causing them to discharge and therefore reduce the field strength to zero, escaped a very large number of candidates. Common answers to part (b) (i) were that the field was reversed, or that the field became an alternating one. Answers which suggested that an electric force would still be acting received no further credit in part (b) (ii). What was required here was an understanding that, when the field was removed, the sphere would fall under its own weight, extending the spring downwards. The resultant force on the sphere would be proportional to the change in the extension of the spring, producing an acceleration that was proportional to the displacement from equilibrium but acted in the opposite direction to the displacement ie the condition for shm.

3 Many candidates appreciated that E is defined as the force acting per unit charge, but very few were able to state that it is the force acting per *mat positive* charge. Consequently in part (a) (i), it was uncommon for more than one of the two available marks to be awarded. Confusion with the definition of electric potential was evident in many candidates' responses. In part (a) (ii), fewer candidates than expected knew that E is a vector quantity.

The Coulomb's law equation was usually correctly recalled at the start of candidates' answers to part (b) (i), and was often followed by an acceptable value for the force. The principal difficulties here included using the wrong constant of proportionality, failing to square the denominator, and not knowing that nano means 10^{-9}. The correct value of 27 mm in part (b) (ii) was usually given after little or no proper explanation, leading to a loss of one of the two marks. Examiners were expecting that something of the form $4/x = 8/(80 - x)$ would be given as a necessary step in the working.

It was clear from their attempts to answer part (c) that a large number of candidates could not follow simple instructions. The direction of the arrows was often wrong, whilst many arrows were not drawn *at P.* The 2:1 length ratio was often correct for the second mark. The third mark was awarded to those candidates who drew an arrow, labelled R, along the correct resultant of two correct component vectors. This final mark was not often awarded.

4 (a) (i) Most of the candidates could draw the field using both lines of equipotential and electric lines. A few omitted to label the lines. A more common mistake was to draft the diagram carelessly so that it was not clear that the field was apparently uniform.

(ii) Weaker candidates got very tangled in this calculation, attempting to use $\frac{1}{2} mv^2$ to calculate kinetic energy rather than using it to calculate speed once they had found the kinetic energy by using the potential difference in the field.

(b) The calculation in this part was done quite well. Few candidates could go on to explain whether or not the de Broglie wavelength made the electrons suitable for the investigation of metallic crystal structures. Some had no idea what the typical values for atomic separations are in metallic crystals. More surprisingly, those who did know the separations tended to be unclear about whether the wavelength was too big or too small or broadly applicable.

5 (a) (i) The vast majority were able to assign the correct direction to the electric field.

(ii) Descriptions of what is meant by an equipotential surface could have been better. There was lack of clarity in the answers and poorer responses were made in terms of potential difference or field strength.

(iii) Parallel lines for the equipotentials were common and correct for the first mark. However, only about half the candidates were able to go on to show the correct shape of the equipotential at the edge of the plates.

(b) (i) This was a 'Show that' question and candidates must endeavour to show complete solutions if they expect to obtain full credit. Although the vast majority of candidates obtained the correct answer, a significant number simply wrote down numbers that occurred in the question, arriving at a number similar to the suggested answer. Examiners wished to see a clear link between the potential gradient between the plates and ratio of force per unit charge. If this link was missing, candidates obtained little credit.

(ii) This question required a sustained effort by candidates to carry out a number of steps in a calculation to arrive at the correct answer. It was done well by many and showed that the traditional skills of the physicist are still accessible by significant numbers of those taking the examination. A common fault was to try to go down an erroneous route involving a spurious centripetal force acting on the dust particle, presumably the candidates thought that magnetic field theory was the appropriate physics here. Additionally, energy arguments, although appropriate, did not score well as candidates often failed to appreciate that they were dealing with a final and not an average velocity. However, despite the common success with the question, the working was usually shown in a poor and scrambled way. Examiners had to work hard to follow a chain of logic, only rarely expressed in clear steps and seldom presented clearly on the page.

6

(a) This question was generally well answered.

(i) Most candidates knew the correct curvature but many failed to produce the correct graph because they either misread the scale or applied a 1 / r law instead of a 1 / r^2 law.

(ii) This was frequently answered correctly but many simply stated '*find the area under the graph*' without stating any limits.

(b) (i) The process was generally well known and there were many correct answers although too many significant figures cost a number of candidates a mark here. The most common error was however failure to convert the radius of the Earth to m.

(ii) Even though the formulae are now on the formula sheet a large number used an incorrect formula for the surface area of the Earth which, at this level, is matter of some concern. Many gained one mark for dividing the charge by what they thought was the area. Those who used 6400 km again without conversion were able to get full credit. A significant number of candidates had a unit penalty applied here by giving the answer in C m^{-1}.

7

(a) (i) This calculation was generally well done.

(ii) This too was well done but there were more computational errors here.

(b) (i) Many candidates defined field strength correctly but referred to point charge rather than unit charge and others used the expression for potential gradient in a uniform field which was not appropriate.

(ii) Good candidates did this calculation well but a lot of weaker candidates introduced expressions relevant to the movement of charged particles in magnetic fields.

(iii) Many performed this calculation correctly but some used an incorrect value for distance.

(iv) Better candidates had no difficulty with this calculation but some weaker candidates omitted this part and the last part of the question.

(v) There was a tendency to use incorrect data in this calculation. Some of those who managed this part were penalised for giving the answer to only one significant figure.

8 It surprised the examiners that only a minority of candidates gained full marks in part (a). Successful solutions were usually based on the triangle of forces. Only the best candidates resolved the tension into components and equated the components to the weight and the electrostatic force respectively. Many candidates incorrectly resolved the weight into components parallel and perpendicular to the thread.

The majority of candidates obtained the correct value of the electric field strength in part (b) and were able to make good progress in part (ii). Candidates who equated g to 10 N kg^{-1} or rounded off incorrectly at the end were penalised. Other candidates attempted inappropriate solutions involving Coulomb's law and did not realise that the force = qE. A small minority of candidates attempted incorrectly to relate the gain of gravitational potential energy to an electrostatic energy formula such as ½QV.