Electric Fields

Long Answer Questions

Name:

Class:

Date:

Time: **280 minutes**

Marks: **241 marks**

Comments:

1 (a) State, in words, Coulomb's law.

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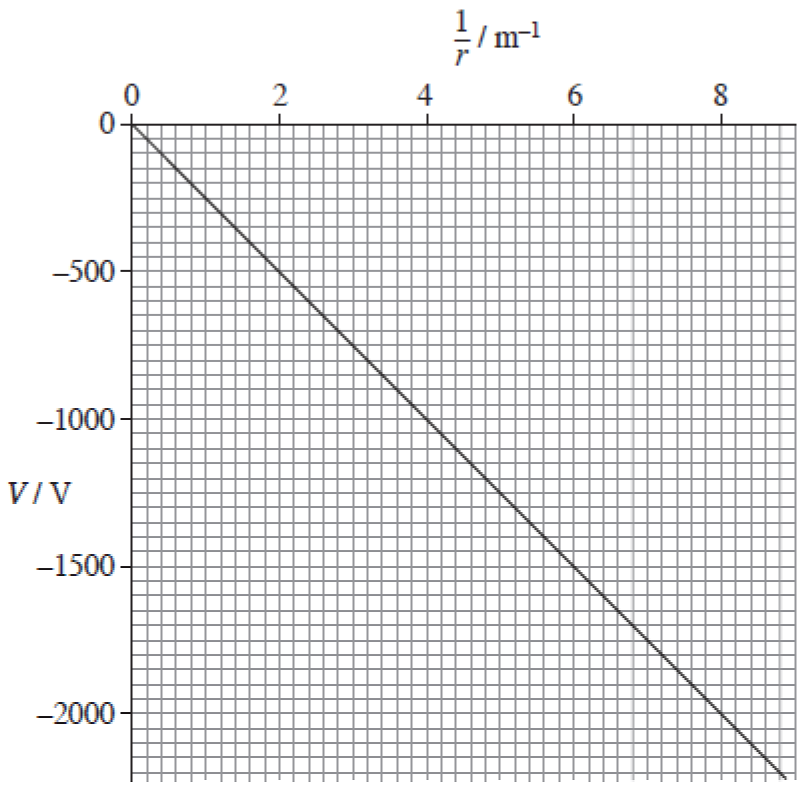
(2)

(b) The graph shows how the electric potential, V, varies with $\frac{1}{r}$, where r is the distance from a point charge Q.



State what can be deduced from the graph about how V depends on r and explain why all the values of V on the graph are negative.

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(2)

(c) (i) Use data from the graph to show that the magnitude of Q is about 30 nC.

(2)

(ii) A +60 nC charge is moved from a point where r = 0.20 m to a point where r = 0.50 m. Calculate the work done.

(2)

work done ____________________ J

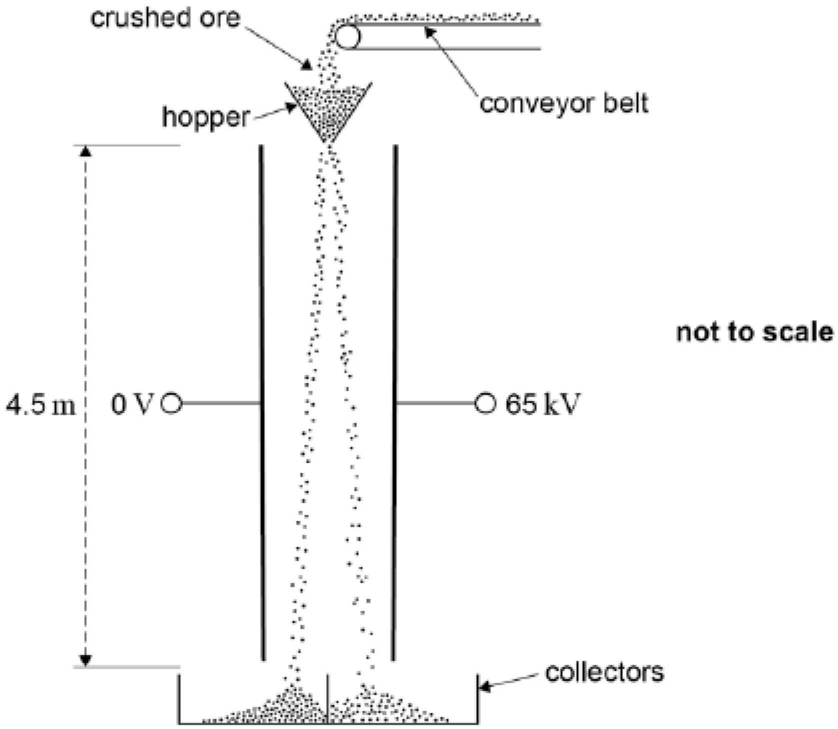
(iii) Calculate the electric field strength at the point where r = 0.40 m.

electric field strength ____________________ V m^{-1}

(2)

(Total 10 marks)

2 The figure below shows a system that separates two minerals from the ore containing them using an electric field.



The crushed particles of the two different minerals gain opposite charges due to friction as they travel along the conveyor belt and through the hopper. When they leave the hopper they fall 4.5 metres between two parallel plates that are separated by 0.35 m.

(a) Assume that a particle has zero velocity when it leaves the hopper and enters the region between the plates.

Calculate the time taken for this particle to fall between the plates.

time taken = ______________s

(2)

(b) A potential difference (pd) of 65 kV is applied between the plates.

Show that when a particle of specific charge 1.2×10^{-6} C kg^{-1} is between the plates its horizontal acceleration is about 0.2 m s^{-2}.

(3)

(c) Calculate the total horizontal deflection of the particle that occurs when falling between the plates.

horizontal deflection = ______________m

(1)

(d) Explain why the time to fall vertically between the plates is independent of the mass of a particle.

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(2)

(e) State and explain **two** reasons, why the horizontal acceleration of a particle is different for each particle.

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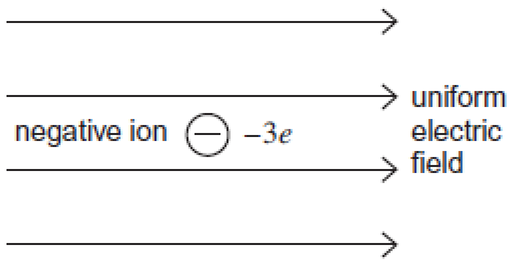
(4)

(Total 12 marks)

3 (a) **Figure 1** shows a negative ion which has a charge of –3*e* and is free to move in a uniform electric field. When the ion is accelerated by the field through a distance of 63 mm parallel to the field lines its kinetic energy increases by 4.0 × 10sup class="xsmall">–16 J.

Figure 1



(i) State and explain the direction of the electrostatic force on the ion.

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(2)

(ii) Calculate the magnitude of the electrostatic force acting on the ion.

magnitude of electrostatic force ____________________ N

(2)

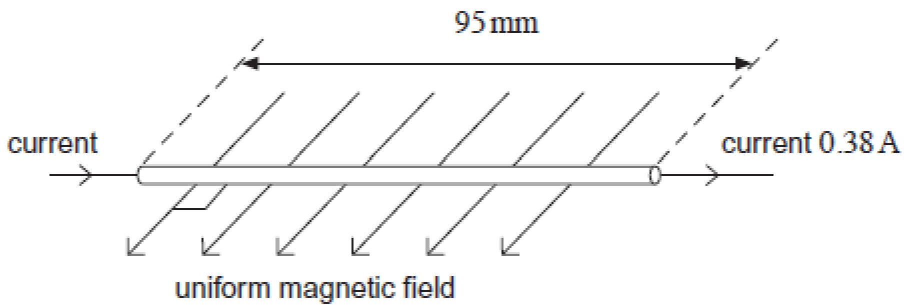
(iii) Calculate the electric field strength.

electric field strength ____________________ NC^{-1}

(1)

(b) **Figure 2** shows a section of a horizontal copper wire carrying a current of 0.38 A.
A horizontal uniform magnetic field of flux density B is applied at right angles to the wire in the direction shown in the figure.

Figure 2



(i) State the direction of the magnetic force that acts on the moving electrons in the wire as a consequence of the current and explain how you arrive at your answer.

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(2)

(ii) Copper contains 8.4×10^{28} free electrons per cubic metre. The section of wire in **Figure 2** is 95 mm long and its cross-sectional area is 5.1×10^{-6} m^2.
Show that there are about 4×10^{22} free electrons in this section of wire.

(1)

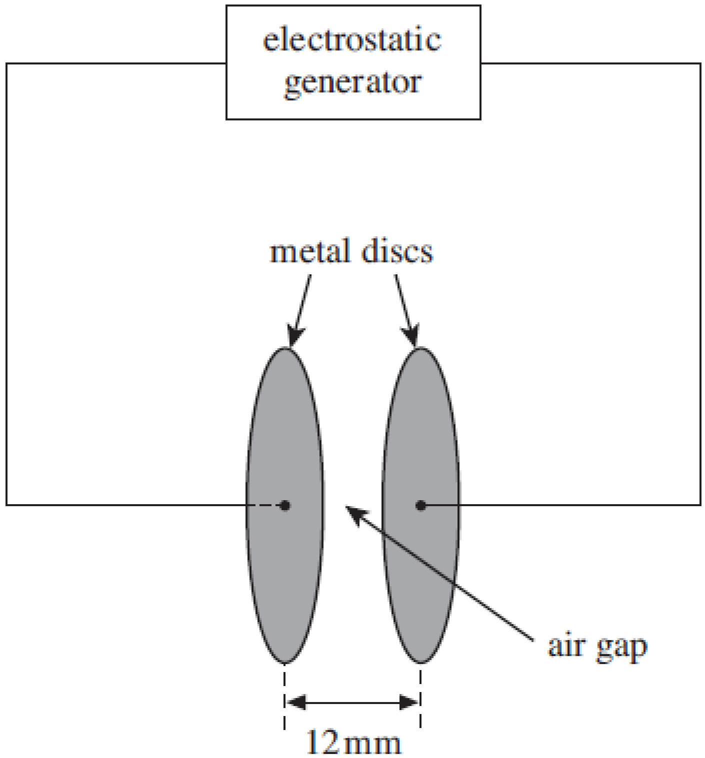
(iii) With a current of 0.38 A, the average velocity of an electron in the wire is 5.5×10^{-6} m s^{-1} and the average magnetic force on one electron is 1.4×10^{-25} N.
Calculate the flux density B of the magnetic field.

flux density ____________________ T

(2)

(Total 10 marks)

4 The diagram below shows an arrangement to demonstrate sparks passing across an air gap between two parallel metal discs. Sparks occur when the electric field in the gap becomes large enough to equal the breakdown field strength of the air. The discs form a capacitor, which is charged at a constant rate by an electrostatic generator until the potential difference (pd) across the discs is large enough for a spark to pass. Sparks are then produced at regular time intervals whilst the generator is switched on.



(a) The electrostatic generator charges the discs at a constant rate of 3.2×10^{-8} A on a day when the minimum breakdown field strength of the air is 2.5×10^{6} V m^{-1}. The discs have a capacitance of 3.7×10^{-12} F.

(i) The air gap is 12 mm wide. Calculate the minimum pd required across the discs for a spark to occur. Assume that the electric field in the air gap is uniform.

pd ____________________ V

(1)

(ii) Calculate the time taken, from when the electrostatic generator is first switched on, for the pd across the discs to reach the value calculated in part (a)(i).

time ____________________ s

(2)

(b) The discs are replaced by ones of larger area placed at the same separation, to give a larger capacitance.

State and explain what effect this increased capacitance will have on:

(i) the time between consecutive discharges,

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(2)

(ii) the brightness of each spark.

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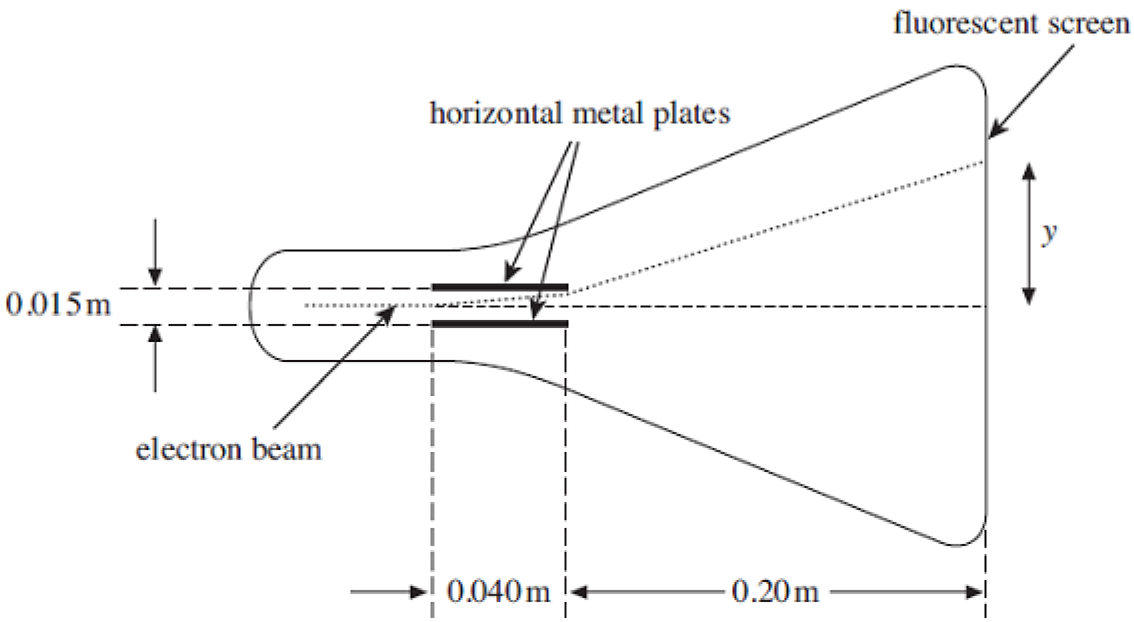
(2)

(Total 7 marks)

5 (a) Describe how a beam of fast moving electrons is produced in the cathode ray tube of an oscilloscope.

(3)

(b) The figure below shows the cathode ray tube of an oscilloscope. The details of how the beam of electrons is produced are not shown.



The electron beam passes between two horizontal metal plates and goes on to strike a fluorescent screen at the end of the tube. The plates are 0.040 m long and are separated by a gap of 0.015 m. A potential difference of 270 V is maintained between the plates.An individual electron takes 1.5×10^{-9} s to pass between the plates.The distance between the right-hand edge of the plates and the fluorescent screen is 0.20 m.

(i) Show that the vertical acceleration of an electron as it passes between the horizontal metal plates is approximately 3.2×10^{15} ms^{-2}.

(3)

(ii) Show that the vertical distance travelled by an electron as it passes between the horizontal metal plates is approximately 3.6 mm.

(2)

(iii) Show that the vertical component of velocity achieved by an electron in the beam by the time it reaches the end of the plates is approximately 4.7×10^6 m s^{-1}.

(2)

(iv) Calculate the vertical displacement, *y*, of the electron beam from the centre of the screen. Give your answer in m.

vertical displacement ______________________ m

(3)

(Total 13 marks)

6 (a) State, in words, Coulomb's law.

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(2)

(b) The diagram below shows two point charges of +4.0 nC and +6.0 nC which are 68 mm apart.

(i) Sketch on the diagram above the pattern of the electric field surrounding the charges.

(3)

(ii) Calculate the magnitude of the electrostatic force acting on the +4.0 nC charge.

magnitude of force ____________________ N

(2)

(c) (i) Calculate the magnitude of the resultant electric field strength at the mid-point of the line joining the two charges in the diagram above.
State an appropriate unit for your answer.

electric field strength ____________________ unit __________

(4)

(ii) State the direction of the resultant electric field at the mid-point of the line joining the charges.

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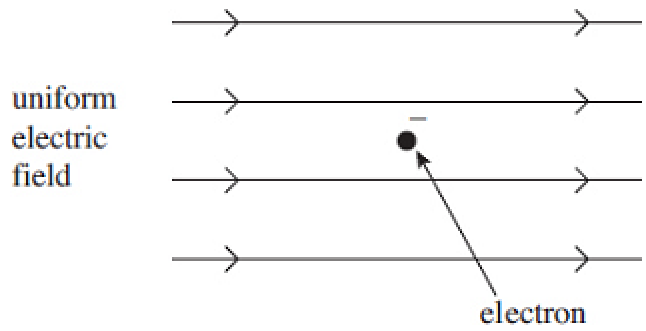
(1)

(Total 12 marks)

7 (a) **Figure 1** shows an electron at a point in a uniform electric field at an instant when it is stationary.

Figure 1



(i) Draw an arrow on **Figure 1** to show the direction of the electrostatic force that acts on the stationary electron.

(1)

(ii) State and explain what, if anything, will happen to the magnitude of the electrostatic force acting on the electron as it starts to move in this field.

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(2)

(b) **Figure 2a** shows a stationary electron in a non-uniform electric field. **Figure 2b** shows a stationary proton, placed in exactly the same position in the same electric field as the electron in **Figure 2a**.

Figure 2a

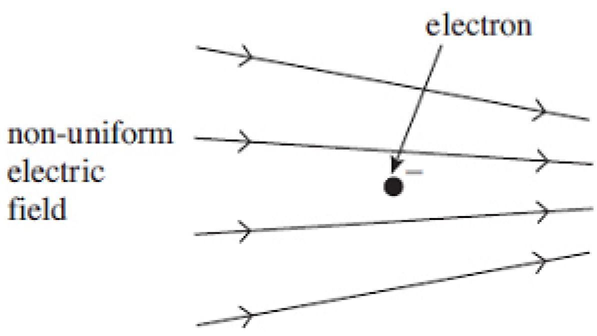
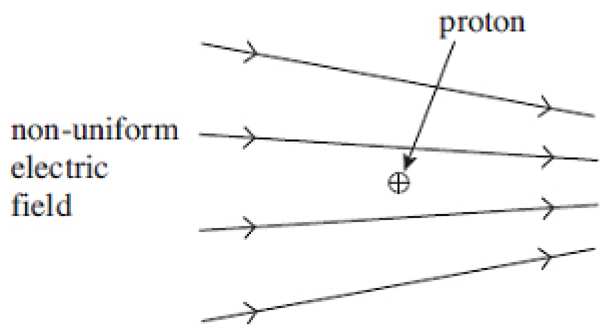


Figure 2b



(i) State and explain how the electrostatic force on the proton in **Figure 2b** compares with that on the electron in **Figure 2a**.

(2)

(ii) Each of the particles starts to move from the positions shown in **Figure 2a** and **Figure 2b**. State and explain how the magnitude of the **initial** acceleration of the proton compares with that of the electron.

(2)

(iii) Describe and explain what will happen to the acceleration of each of these particles as they continue to move in the electric field.

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(2)

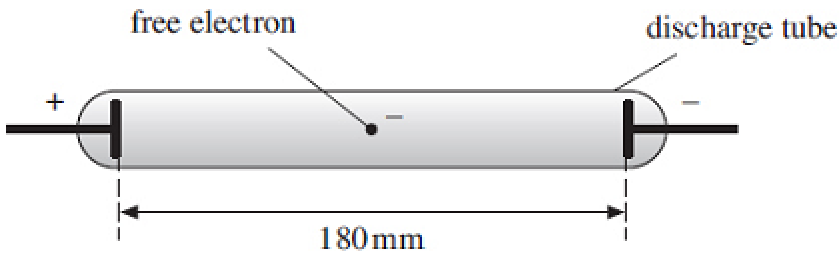
(c) The line spectrum of neon gas contains a prominent red line of wavelength 650 nm.

(i) Show that the energy required to excite neon atoms so that they emit light of this wavelength is about 2 eV.

(3)

(ii) An illuminated shop sign includes a neon discharge tube, as shown in **Figure 3**.
A pd of 4500 V is applied across the electrodes, which are 180 mm apart.

Figure 3



Assuming that the electric field inside the tube is uniform, calculate the minimum distance that a free electron would have to move from rest in order to excite the red spectral line in part (c).

answer = ____________________ m

(3)

(Total 15 marks)

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

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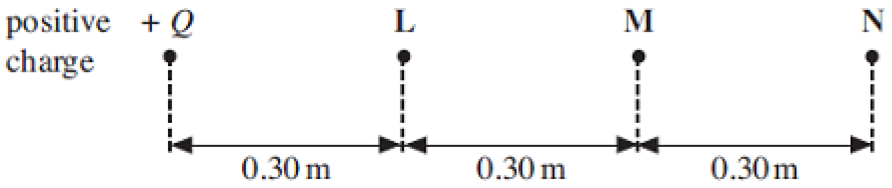
(3)

(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.

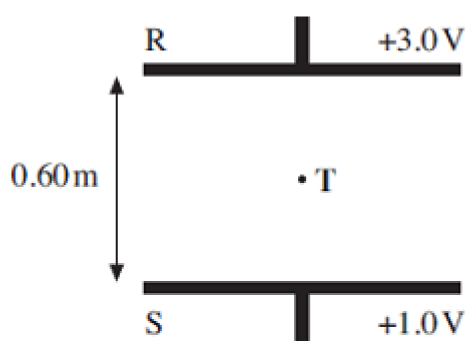
(1)

(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.

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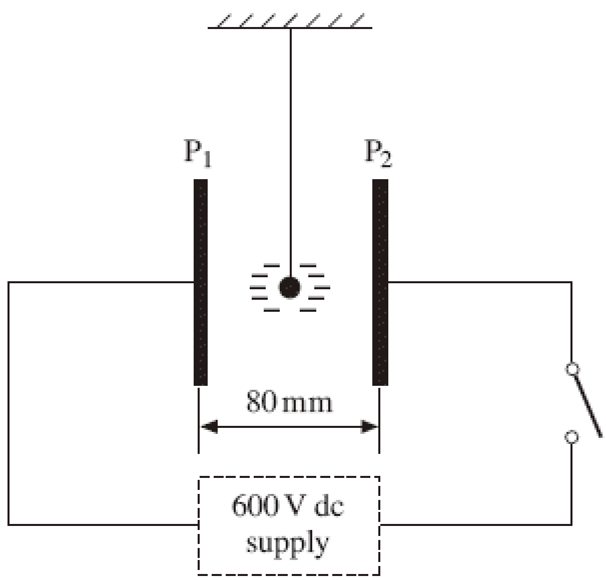
(1)

(Total 12 marks)

9 **Figure 1** shows a small polystyrene ball which is suspended between two vertical metal plates, $\mathbf{P_1}$ and $\mathbf{P_2}$, 80 mm apart, that are initially uncharged. The ball carries a charge of –0.17 μC.

Figure 1



(a) (i) A pd of 600 V is applied between **P_1** and **P_2** when the switch is closed. Calculate the magnitude of the electric field strength between the plates, assuming it is uniform.

answer = ______________________ V m^{-1}

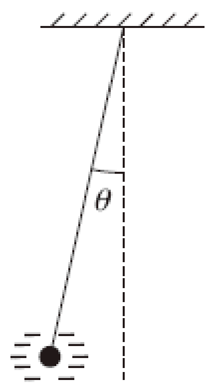
(2)

(ii) Show that the magnitude of the electrostatic force that acts on the ball under these conditions is 1.3 mN.

(1)

(b) Because of the electrostatic force acting on it, the ball is displaced from its original position. It comes to rest when the suspended thread makes an angle θ with the vertical, as shown in **Figure 2**.

Figure 2



(i) On **Figure 2**, mark and label the forces that act on the ball when in this position.

(2)

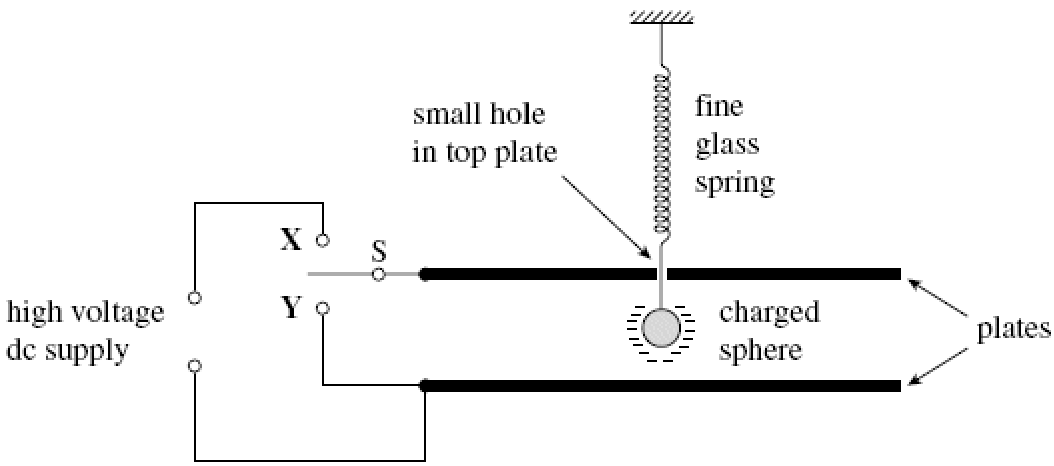
(ii) The mass of the ball is 4.8×10^{-4} kg. By considering the equilibrium of the ball, determine the value of θ.

answer = ______________________ degrees

(3)

(Total 8 marks)

10 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.

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(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.

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(2)

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

(3)

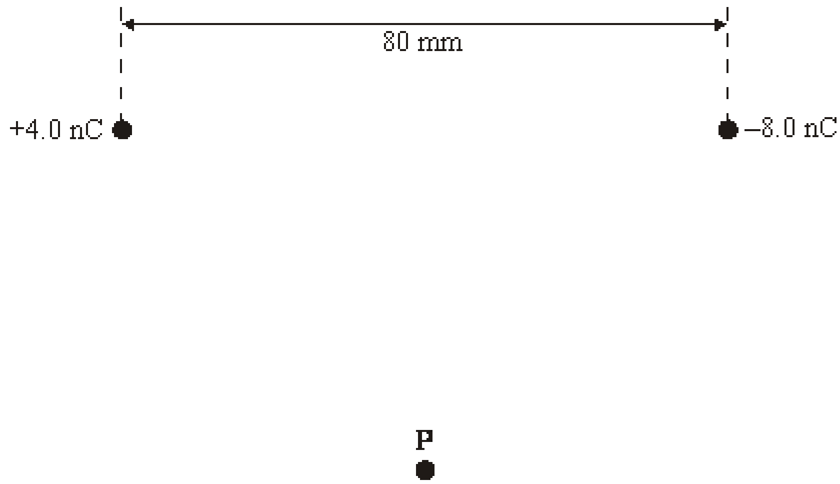
(Total 10 marks)

11 (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)

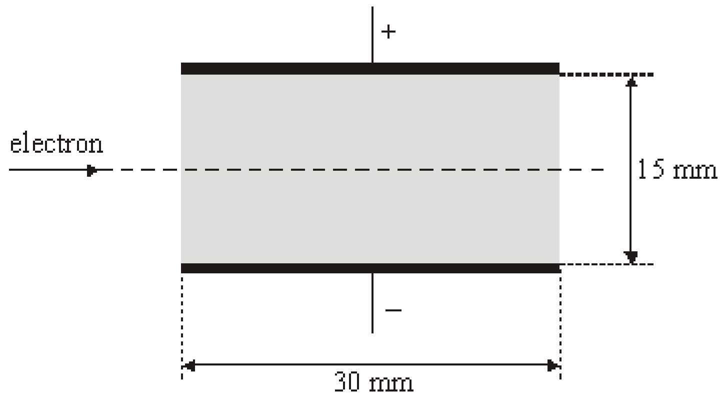
(c) Point **P** in the figure above is equidistant from the two charges.

(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)

12 (a) An electron travels at a speed of 3.2×10^7 ms^{-1} in a horizontal path through a vacuum. The electron enters the uniform electric field between two parallel plates, 30 mm long and 15 mm apart, as shown in the figure below. A potential difference of 1400 V is maintained across the plates, with the top plate having positive polarity. Assume that there is no electric field outside the shaded area.



(i) Show that the electric field strength between the plates is 9.3×10^4 Vm^{-1}.

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(ii) Calculate the time taken by the electron to pass through the electric field.

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(iii) Show that the acceleration of the electron whilst in the field is 1.6×10^{16} m s^{-2} and state the direction of this acceleration.

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(5)

(b) Determine the magnitude and direction of the velocity of the electron at the point where it leaves the field.

(3)
(Total 8 marks)

13 (a) Complete the table of quantities related to fields. In the second column, write an SI unit for each quantity. In the third column indicate whether the quantity is a scalar or a vector.

quantity	SI unit	scalar or vector
gravitational potential		
electric field strength		
magnetic flux density		

(3)

(b) (i) A charged particle is held in equilibrium by the force resulting from a vertical electric field. The mass of the particle is 4.3×10^{-9} kg and it carries a charge of magnitude 3.2×10^{-12} C. Calculate the strength of the electric field.

(ii) If the electric field acts upwards, state the sign of the charge carried by the particle

(3)
(Total 6 marks)

14 (a) An electron moves parallel to, but in the opposite direction to, a uniform electric field, as shown in **Figure 1**.

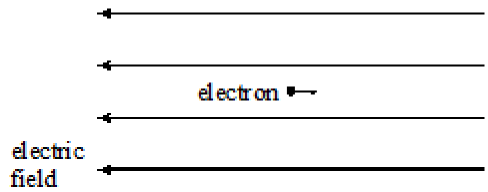

Figure 1

(i) State the direction of the force that acts on the electron due to the electric field.

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(ii) What is the effect of this force on the motion of the electron?

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(2)

(b) An electron, which is travelling in a horizontal path at constant speed, enters a uniform vertical electric field as shown in **Figure 2**.

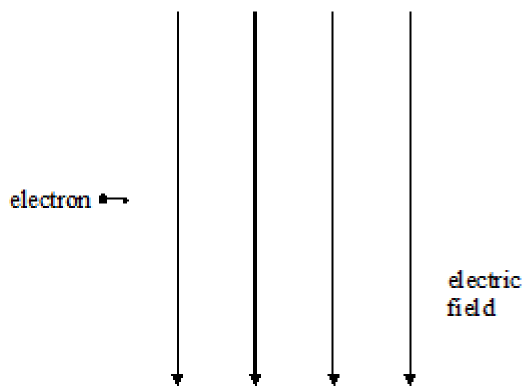

Figure 2

(i) Sketch on **Figure 2** the path followed by the electron.

(ii) Explain the motion of the electron whilst in this field.

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(3)

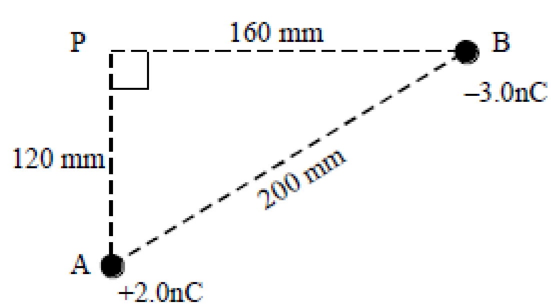
(Total 5 marks)

15 (a) (i) Define *electric field strength*, and state whether it is a scalar quantity or a vector quantity.

(ii) Complete the diagram below to show the electric field lines in the region around two equal positive point charges. Mark with a letter N the position of any point where the field strength is zero.

(6)

(b) Point charges A, of +2.0 nC, and B, of –3.0 nC, are 200 mm apart in a vacuum, as shown by the figure. The point P is 120 mm from A and 160 mm from B.



(i) Calculate the component of the electric field at P in the direction AP.

(ii) Calculate the component of the electric field at P in the direction PB.

(iii) Hence calculate the magnitude and direction of the resultant field at P.

(6)

(c) (i) Explain why there is a point X on the line AB in part (b) at which the **electric potential** is zero.

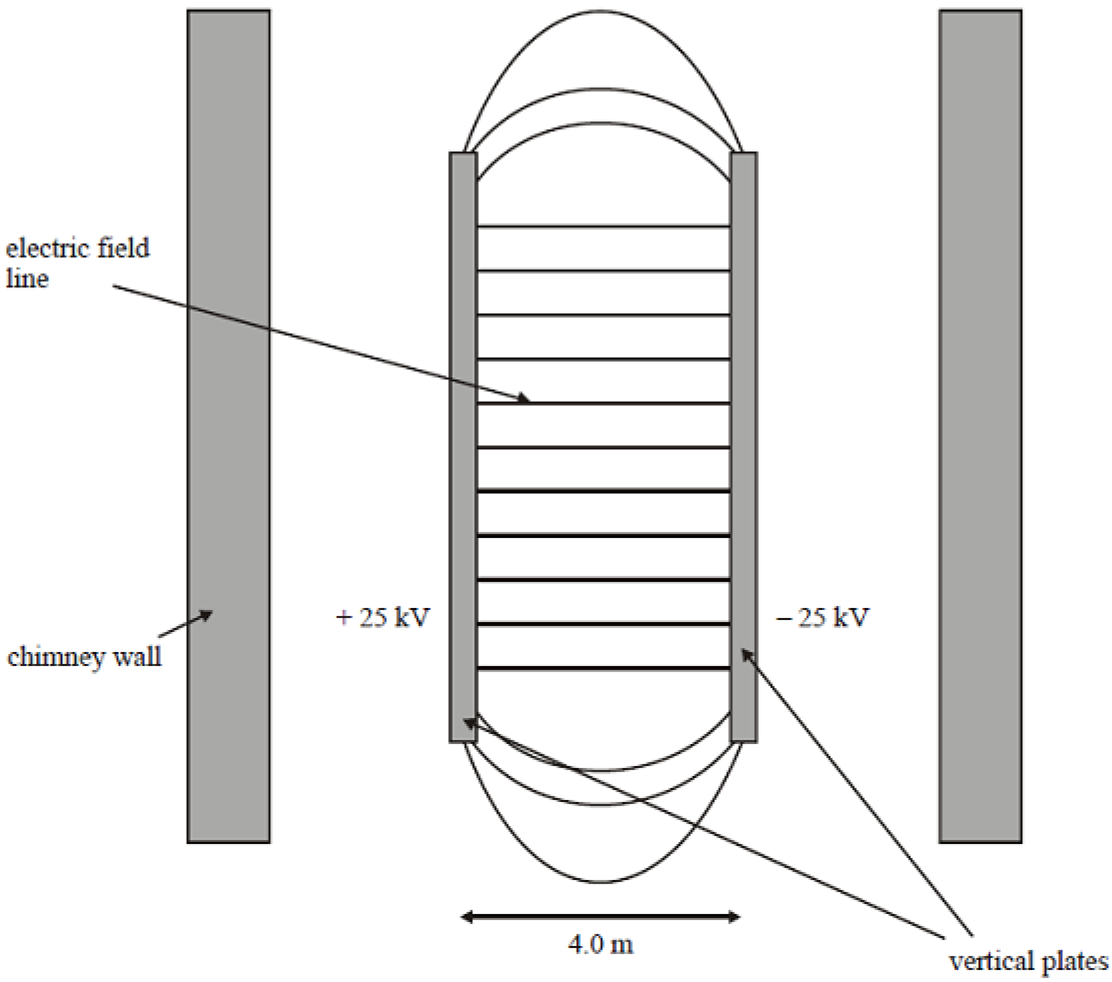
(ii) Calculate the distance of the point X from A.

(4)

(Total 16 marks)

16 (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*.

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(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)

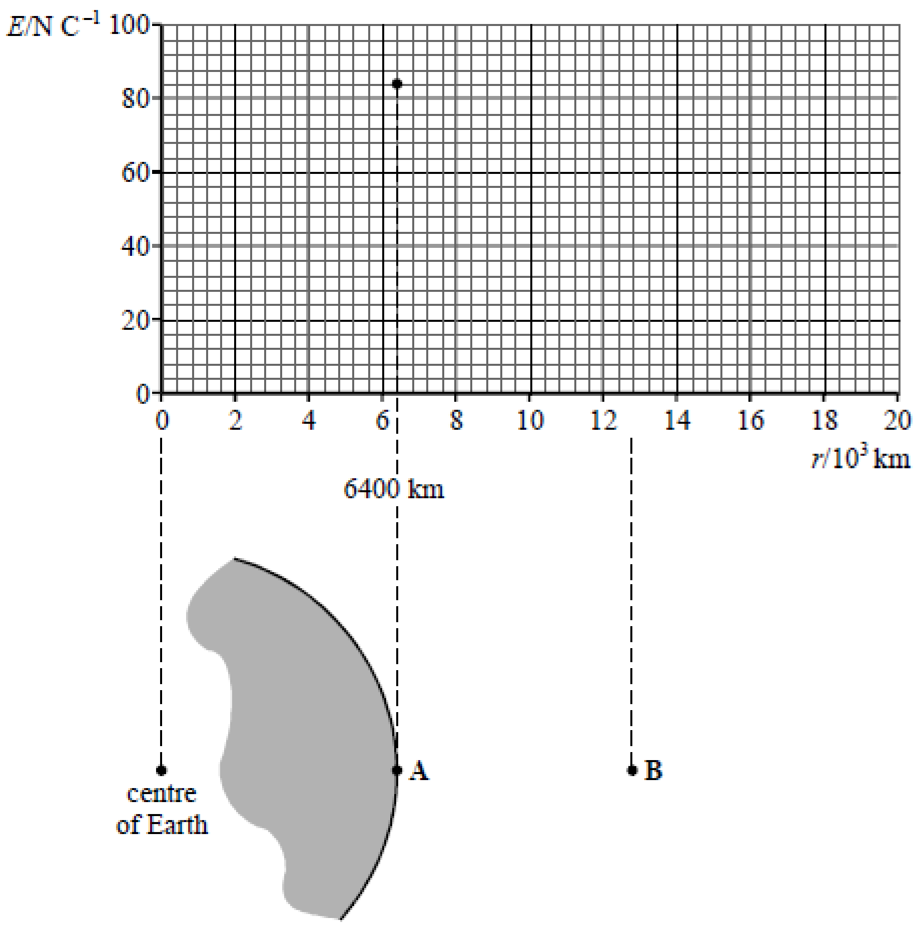
(ii) The mass of the dust particle is 1.2×10^{-4} kg and it moves up the centre of the chimney at a constant vertical speed of 0.80 m s^{-1}.

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

(4)

(Total 10 marks)

17 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**.

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(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)

18 (a) The equation $F = BQv$ may be used to calculate magnetic forces.

(i) State the condition under which this equation applies.

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(1)

(ii) Identify the physical quantities that are represented by the four symbols in the equation.

F ____

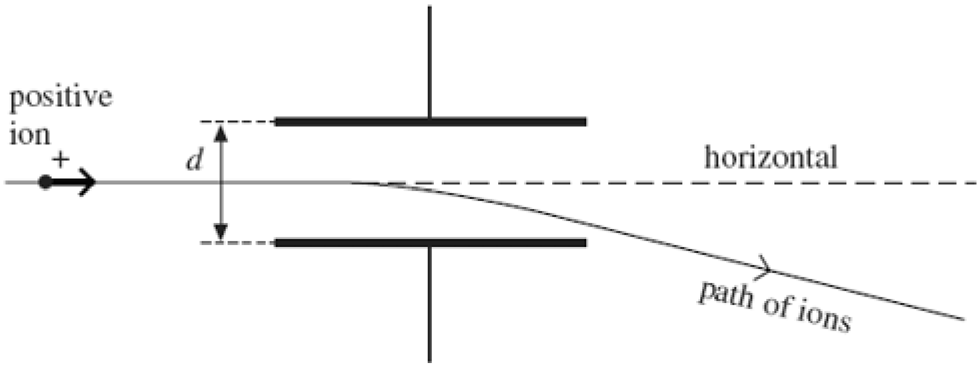
B ____

Q ____

v ____

(1)

(b) The figure below shows the path followed by a stream of identical positively charged ions, of the same kinetic energy, as they pass through the region between two charged plates. Initially the ions are travelling horizontally and they are then deflected downwards by the electric field between the plates.



While the electric field is still applied, the path of the ions may be restored to the horizontal, so that they have no overall deflection, by applying a magnetic field over the same region as the electric field. The magnetic field must be of suitable strength and has to be applied in a particular direction.

(i) State the direction in which the magnetic field should be applied.

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(1)

(ii) Explain why the ions have no overall deflection when a magnetic field of the required strength has been applied.

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(2)

(iii) A stream of ions passes between the plates at a velocity of 1.7 x 10^5ms^{-1}. The separation *d* of the plates is 65 mm and the pd across them is 48 V. Calculate the value of *B* required so that there is no overall deflection of the ions, stating an appropriate unit.

answer = ______________________

(4)

(c) Explain what would happen to ions with a velocity higher than 1.7 x 10^5ms^{-1} when they pass between the plates at a time when the conditions in part (b)(iii) have been established.

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(2)

(Total 11 marks)

19 The first artificially produced isotope, phosphorus $^{30}_{15}\mathrm{P}$, was formed by bombarding an aluminium isotope, $^{27}_{13}\mathrm{Al}$, with an *α* particle.

(a) Complete the following nuclear equation by identifying the missing particle.

$$^{27}_{13}\mathrm{Al} + \alpha \rightarrow {}^{30}_{15}\mathrm{P} + \ldots\ldots\ldots$$

(1)

(b) For the reaction to take place the α particle must come within a distance, *d*, from the centre of the aluminium nucleus. Calculate *d* if the nuclear reaction occurs when the α particle is given an initial kinetic energy of at least 2.18×10^{-12} J.

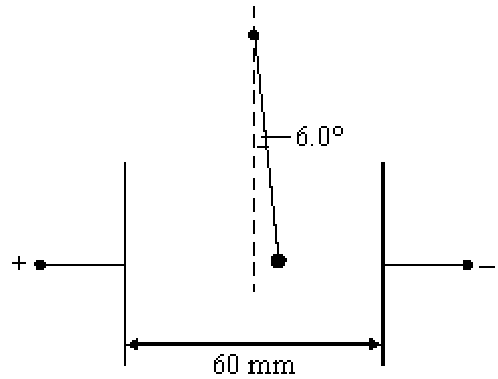
The electrostatic potential energy between two point charges Q_1 and Q_2 is equal to $\frac{Q_1 Q_2}{4\pi\varepsilon_0 r}$ where r is the separation of the charges and ε_0 is the permittivity of free space.

answer = ______________________ m

(3)

(Total 4 marks)

20 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,

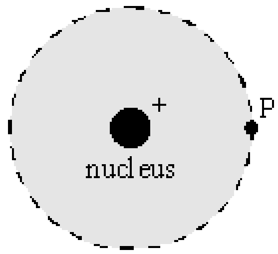
(ii) the charge on the sphere.

(3)

(Total 6 marks)

21 The mass of the nucleus of an isolated copper atom is 63 u and it carries a charge of +29 *e*. The diameter of the atom is 2.3×10^{-10} m.

P is a point at the outer edge of the atom.



(a) Calculate

(i) the electric field strength at P due to the nucleus,

___

___

___

(ii) the gravitational potential at P due to the nucleus.

___

___

___

(5)

(b) Draw an arrow on the above diagram to show the direction of the electric field at the point P.

(1)

(Total 6 marks)

22 (a) Show that the kinetic energy of an α particle travelling at 2.00×10^{7} m s^{-1} is 1.33×10^{-12} J when relativistic effects are ignored.

___

___

___

(2)

(b) Calculate the closest distance of approach for a head-on collision between the α particle referred to in part (a) and a gold nucleus for which the proton number is 79. Assume that the gold nucleus remains stationary during the collision.

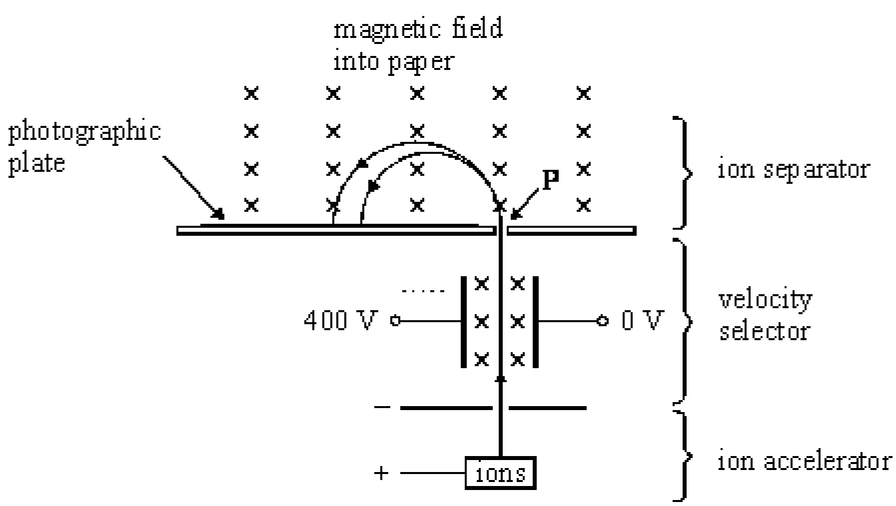
(4)

(c) State **one** reason why methods other than α particle scattering are used to determine nuclear radii.

(1)

(Total 7 marks)

23 The diagram below shows a diagram of a mass spectrometer.



(a) The magnetic field strength in the velocity selector is 0.14 T and the electric field strength is 20 000 V m^{-1}.

(i) Define the unit for magnetic flux density, the tesla.

(2)

(ii) Show that the velocity selected is independent of the charge on an ion.

(2)

(iii) Show that the velocity selected is about 140 km s^{-1}.

(1)

(b) A sample of nickel is analysed in the spectrometer. The two most abundant isotopes of nickel are ${}^{58}_{28}Ni$ and ${}^{60}_{28}Ni$. Each ion carries a single charge of $+1.6 \times 10^{-19}$ C.

mass of a proton or neutron = 1.7×10^{-27} kg

The ${}^{58}_{28}Ni$ ion strikes the photographic plate 0.28 m from the point **P** at which the ion beam enters the ion separator.

Calculate:

(i) the magnetic flux density of the field in the ion separator;

(3)

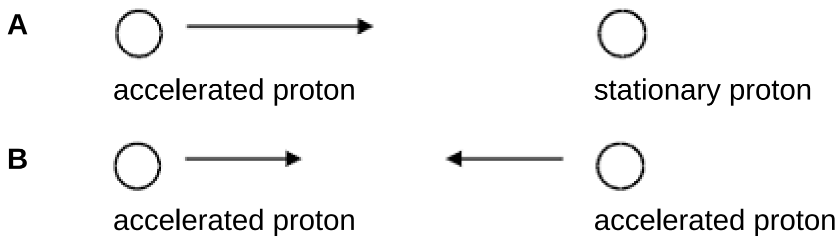
(ii) the separation of the positions where the two isotopes hit the photographic plate.

(2)
(Total 10 marks)

24 A physicist wants to design an experiment in which two free protons collide to produce two delta-plus (Δ^+) particles. This is an allowed reaction and is fully represented by the equation

$$p^+ + p^+ \rightarrow \Delta^+ + \Delta^+$$

Two options are available that are shown as **A** and **B** in the diagram below.



In **A** an accelerated proton collides with a stationary proton and in **B** two accelerated protons, each with the same energy, collide head on.

the charge on a proton = $+1.6 \times 10^{-19}$ C
the rest mass of a proton = 1.7×10^{-27} kg
the permittivity of free space ε_0 = 8.9×10^{-12} F m^{-1}

(a) State the baryon number of a Δ^+ particle.

___

(1)

(b) The radius of a proton is 1.5×10^{-15} m.

(i) Calculate the minimum total kinetic energy that the accelerated protons need so that they will touch each other.

(3)

(ii) State what happens in situation **A** when the energy is less than your answer to part (i).

___

___

(1)

(iii) State and explain what happens in situation **B** when the energy is less than your answer to part (i).

___

___

___

___

(3)

(iv) Explain why the protons can undergo fusion if this energy is exceeded.

____

____

____

(2)

(c) Calculate the minimum total kinetic energy, in J, of the protons that will allow the two protons to collide and produce the two Δ^+ particles.

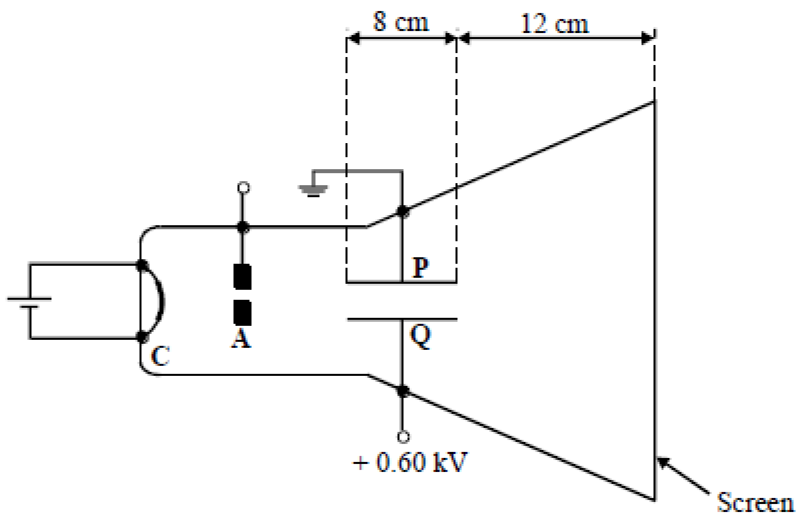
speed of electromagnetic radiation in free space $= 3.0 \times 10^8$ m s^{-1}

rest mass of a Δ^+ particle $= 2.2 \times 10^{-27}$ kg

(3)

(Total 13 marks)

25 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 $= 9.1 \times 10^{-31}$ 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)

Mark schemes

1

(a) force between two (point) charges is

proportional to product of charges ✓

inversely proportional to square of distance between the charges ✓

Mention of force is essential, otherwise no marks.

Condone "proportional to charges".

Do not allow "square of radius" when radius is undefined.

Award full credit for equation with all terms defined.

2

(b) V is inversely proportional to r [**or** $V \propto (-)1 / r$] ✓

(V has negative values) because charge is negative

[**or** because force is attractive on + charge placed near it

or because electric potential is + for + charge and − for − charge] ✓

potential is defined to be zero at infinity ✓

Allow $V \times r$ = constant for 1st mark.

max 2

(c) (i) $Q(= 4\pi\varepsilon_0 rV) = 4\pi\varepsilon_0 \times 0.125 \times 2000$

OR *gradient = $Q / 4\pi\varepsilon_0$ = 2000 / 8* ✓

(for example, using any pair of values from graph) ✓

= 28 (27.8) (± 1) (nC) ✓

(gives Q = 28 (27.8) ±1 (nC) ✓

2

(ii) at r = 0.20m V = −1250V and at r = 0.50m V = −500V

so pd ΔV = −500 − (−1250) = 750 (V) ✓

work done ΔW (= $Q\Delta V$) = $60 \times 10^{-9} \times 750$

$= 4.5(0) \times 10^{-5}$ (J) (45 μJ) ✓

(final answer could be between 3.9 and 5.1×10^{-5})

Allow tolerance of ± 50V on graph readings.

[Alternative for 1st mark:

$$\Delta V = \frac{27.8 \times 10^{-9}}{4\pi\varepsilon_0} \times \left(\frac{1}{0.2} - \frac{1}{0.5}\right)$$ *(**or** similar substitution using 60 nC*

instead of 27.8 nC:

use of 60 nC gives ΔV = 1620V)]

2

(iii) $E\left(=\dfrac{Q}{4\pi\varepsilon_0 r^2}\right)=\dfrac{27.8\times10^{-9}}{4\pi\varepsilon_0\times0.40^2}$ ✓ = 1600 (1560) (V m^{-1}) ✓

[or deduce $E=\dfrac{V}{r}$ by combining $E=\dfrac{Q}{4\pi\varepsilon_0 r^2}$ with $V=\dfrac{Q}{4\pi\varepsilon_0 r}$ ✓

from graph $E=\dfrac{625\pm50}{0.40}$ = 1600 (1560 ± 130) (V m^{-1}) ✓]

Use of Q = 30 nC gives 1690 (V m^{-1}).
Allow ecf from Q value in (i).
If Q = 60 nC is used here, no marks to be awarded.

2

[10]

2

(a) $t=\sqrt{\frac{2s}{g}}$ or $4.5=\frac{1}{2}\times9.81\times t^2$ ✓

t = 0.96 s✓

2

(b) Field strength = 186000V m^{-1}✓

Acceleration = Eq/m

or 186 000 × 1.2 × 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]

3 (a) (i) force acts towards left or in opposite direction to field lines ✓
because ion (or electron) has negative charge
(∴ experiences force in opposite direction to field) ✓

Mark sequentially.
Essential to refer to negative charge (or force on + charge is to right) for 2nd mark.

2

(ii) (use of $W = F s$ gives) force $F = \dfrac{4.0\times10^{-16}}{63\times10^{-3}}$ ✓

$= 6.3(5) \times 10^{-15}$ (N) ✓

If mass of ion m is used correctly ***using algebra*** *with F = ma, allow both marks (since m will cancel). If numerical value for m is used, max 1.*

2

(iii) electric field strength $E\left(=\dfrac{F}{Q}\right)=\dfrac{6.35\times10^{-15}}{3\times1.6\times10^{-19}}$ = 1.3(2) ✓ 10^4 ($N\ C^{-1}$) ✓

[**or** $\Delta V\left(=\dfrac{\Delta W}{Q}\right)=\dfrac{4.0\times10^{-16}}{3\times1.60\times10^{-19}}$ (833 V)

$E\left(=\dfrac{\Delta V}{d}\right)=\dfrac{833}{63\times10^{-3}}$ = 1.3(2) ✓ 10^4 ($V\ m^{-1}$) ✓]

Allow ECF from wrong F value in (ii).

1

(b) (i) (vertically) downwards on diagram ✓
reference to Fleming's LH rule **or** equivalent statement ✓

Mark sequentially.
1st point: allow "into the page".

2

(ii) number of free electrons in wire = $A \times l \times$ number density

$= 5.1 \times 10^{-6} \times 95 \times 10^{-3} \times 8.4 \times 10^{28} = 4.1\ (4.07) \times 10^{22}$ ✓

Provided it is shown correctly to at least 2SF, final answer alone is sufficient for the mark. (Otherwise working is mandatory).

1

(iii) $B\left(=\frac{F}{Qv}\right)=\frac{1.4\times10^{-25}}{1.60\times10^{-19}\times5.5\times10^{-6}}$ ✓ = 0.16 (0.159) (T) ✓

[**or** $B\left(=\frac{F}{Il}\right)=\frac{1.4\times10^{-25}\times4.07\times10^{22}}{0.38\times95\times10^{-3}}$ ✓ = 0.16 (0.158) (T) ✓]

In 2nd method allow ECF from wrong number value in (ii).

2

[10]

4 (a) (i) required pd ($= 2.5 \times 10^{6} \times 12 \times 10^{-3}$) $= 3.0(0) \times 10^{4}$ (V) ✓

1

(ii) charge required Q $(= CV) = 3.7 \times 10^{-12} \times 3.00 \times 10^{4}$ ✓

($= 1.11 \times 10^{-7}$ C)

Allow ECF from incorrect V from (a)(i).

time taken $t\left(=\frac{Q}{I}\right)=\frac{1.11\times10^{-7}}{3.2\times10^{-8}} = 3.5\ (3.47)\ (\text{s})$ ✓

2

(b) (i) time increases ✓

(larger C means) more charge required (to reach breakdown pd)

Mark sequentially *i.e. no explanation mark if effect is wrong.*

or $t = \frac{CV}{I}$ **or** time ∝ capacitance ✓

2

(ii) spark is brighter (**or** lasts for a longer time) ✓

more energy (**or** charge) is stored **or** current is larger

Mark sequentially.

or spark has more energy ✓

2

(Total 7 marks)

5 (a) thermionic emission / by heating

B1

cathode heated / heating done by electric current / overcoming work function

B1

Must mention anode for third mark

anode which is positive wrt cathode / accelerated by electric field between anode and cathode

B1

3

(b) (i) one relevant equation seen: $E = V/d$ / $F = Ee$ / $a = F/m$

B1

Equation should be in symbols

$$a = \frac{1.6 \times 10^{-19} \times 270}{9.1 \times 10^{-31} \times 0.015} \quad / \; F = 2.88 \times 10^{-15}$$

B1

Substitution may be done in several stages

3.16×10^{15} (m s^{-2})

B1

Must be more than 2 sf

3

(ii) $s = (ut) + ½ at^2$ or $v = u + at$ and $s = v_{av}t$ OR $s = vt$ used

B1

Appropriate symbol equation seen and used for 1st mark

3.56×10^{-3}m

B1

Expect at least 3 sf but condone 3.6 for candidates who use $a = 3.2 \times 10^{15}$

2

(iii) $v = u + at$ / $v = at$ $v^2 = u^2 + 2as$ used

B1

May also use $eV = \frac{1}{2}mv^2$

4.74×10^6 m s^{-1} to at least 3 sf

B1

Allow 4.8 (2 or more sf) – consistent with use of $a = 3.2 \times 10^{15}$

2

(iv) $t = 7.5 \times 10^{-9}$ s seen or used

C1

May use ratios for 1st 2 marks: $s_v/s_h = v_v/v_h$ *C1*

3.53×10^{-2} (m) *A1*

3.53×10^{-2} (m) **ecf** for wrong t

A1

adds 3.56×10^{-3} (m) to their 3.53×10^{-2}

B1

clipped with b(i) and b(ii)

Allow reasonable rounding

3

[13]

6 (a) force between two (point) charges is proportional to (product of) charges ✓
and inversely proportional to the square of their distance apart ✓

*Formula not acceptable. Accept "charged particles" for charge **s**.*
Accept separation for distance apart.

2

(b) (i) lines with arrows radiating outwards from each charge ✓
more lines associated with 6nC charge than with 4nC ✓
lines start radially and become non-radial with correct curvature further away from each charge ✓ correct asymmetric pattern (with neutral pt closer to 4nC charge) ✓

3 max

(ii) force $\left(= \frac{Q_1 Q_2}{4\pi\varepsilon_0 r^2}\right) = \frac{4.0 \times 10^{-9} \times 6.0 \times 10^{-9}}{4\pi \times 8.85 \times 10^{-12} \times (68 \times 10^{-3})^2}$ ✓

$= 4.6(7) \times 10^{-5}$ (N) ✓

Treat substitution errors such as 10^{-6}(instead of 10^{-9}) as AE with ECF available.

2

(c) (i) $E_4 = \frac{4.0\times10^{-9}}{4\pi\varepsilon_0 \times (34\times10^{-3})^2}$ (= 3.11 × 10^4 V m^{-1}) (to the right) ✓

*For both of 1st two marks to be awarded, substitution for **either** or both of E_4 **or** E_6 (or a substitution in an expression for E_6 - E_4) must be shown.*

$E_6 \left(= \frac{6.0\times10^{-9}}{4\pi\varepsilon_0 \times (34\times10^{-3})^2}\right)$ = (4.67 × 10^4 V m^{-1}) (to the left) ✓

If no substitution is shown, but evaluation is correct for E_4 and E_6, award one of 1 st two marks.

$E_{resultant}$ = (4.67 − 3.11) × 10^4 = 1.5(6) × 10^4 ✓

Unit: V m^{-1} (or N C^{-1}) ✓

Use of r = 68 × 10^{-3} is a physics error with no ECF.
Unit mark is independent.

4

(ii) *direction:* towards 4 nC charge **or** to the left ✓

1

[12]

7 (a) (i) horizontal arrow to the left ✓

1

(ii) the electrostatic force is unchanged ✓

2

because electric field strength is constant ✓

(b) (i) forces are equal in magnitude but opposite in direction ✓

(*E* is the same for both and) *Q* has same magnitude but opposite sign ✓

2

(ii) acceleration of proton is (much) smaller (than acceleration of electron) ✓

because mass of proton is (much) greater (than mass of electron) ✓

2

(iii) acceleration of proton increases and acceleration of electron decreases ✓

correct reference to changing strength of electric field (for either or both) ✓

2

(c) (i) energy of photon $E\left(=\frac{hc}{\lambda}\right) = \frac{6.63\times10^{-34}\times3.00\times10^{8}}{650\times10^{-9}}$ ✓

$= 3.06 \times 10^{-19}$ (J) ✓

energy required = $\frac{3.06\times10^{-19}}{1.60\times10^{-19}}$ = 1.91 (eV) ✓

3

(ii) electric field strength $\left(=\frac{V}{d}\right) = \frac{4500}{180\times10^{-3}} = 2.50 \times 10^{4}$ (V m^{-1}) ✓

distance = $\left(\frac{V}{E}\right) = \frac{1.91}{2.50\times10^{4}}\left[or = \left(\frac{W}{F}\right)\right]\left[= \frac{3.06\times10^{-19}}{4.0\times10^{-15}}\right]$ ✓

$= 7.64 \times 10^{-5}$(m) ✓

3

[15]

8 (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) $V = \frac{Q}{4\pi\varepsilon_0 r}$ gives Q (= $4\pi\varepsilon_0 rV$) = $4\pi \times 8.85 \times 10^{-12} \times 0.30 \times 3.0$ ✓

$= 1.0 \times 10^{-10}$ (C) ✓

to **2 sf** only ✓

3

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

1

(iii) $E\left(=\frac{Q}{4\pi\varepsilon_0 r^2}\right) = \frac{1.0\times10^{-10}}{4\pi\times8.85\times10^{-12}\times0.60^2}$ ✓ (= 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]

9 (a) (i) $E\left(=\frac{V}{d}\right)=\frac{600}{80\times10^{-3}}$ **(1)**

$= 7.5 \times 10^3$ (V m^{-1}) **(1)**

2

(ii) force F (= EQ) = $7500 \times 0.17 \times 10^{-6}$ **(1)** (= 1.28×10^{-3} N)

1

(b) (i) correct labelled arrows placed on diagram to show the three forces acting;

- electric force F (or 1.3 mN) horizontally to left **(1)**
- W (or mg) vertically down **and**
- tension T upwards along the thread **(1)**

2

(ii) $F = T\sin\theta$ and $mg = T\cos\theta$ give $F = mg\tan\theta$ **(1)**
(or by triangle or parallelogram methods)

$\tan\theta\left(=\frac{F}{mg}\right)=\frac{1.28\times10^{-3}}{4.8\times10^{-4}\times9.81}(=0.272)$ **(1)**

gives θ = 15(.2) (°) **(1)**

3

[8]

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

1

(ii) force on sphere F (= kx) = $0.24 \times 18 \times 10^{-3}$ **(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)**

$= 4.8 \times 10^{-2}$ (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]

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

(ii) vector **(1)**

3

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

$=4.5(0)\times10^{-5}$N **(1)**

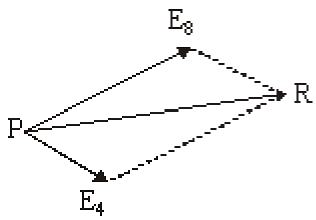
(ii) (use of $V=\dfrac{Q}{4\pi\varepsilon_0 r}$ gives) $0=\left(\dfrac{4.0\times10^{-9}}{4\pi\varepsilon_0 x}\right)-\left(\dfrac{8.0\times10^{-9}}{4\pi\varepsilon_0(80\times10^{-3}-x}\right)$

or $\dfrac{4}{x}=\dfrac{8}{80-x}$ **(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]

12 (a) (i) $E\left(=\frac{V}{d}\right)=\frac{1400}{15\times10^{-3}}$ **(1)** $\left(=9.3\times10^{4}\,\mathrm{V\,m^{-1}}\right)$

(ii) $t\left(=\frac{l}{v}\right)=\frac{30\times10^{-3}}{3.2\times10^{7}}=9.38\times10^{-10}$ s **(1)**

(iii) $ma_y = Ee$ **(1)**

$ay = \frac{9.3\times10^{4}\times1.60\times10^{-19}}{9.11\times10^{31}}$ **(1)** (= 1.64×10^{16} m s^{-2})

acceleration is upwards [or towards + plate]**(1)**

5

(b) vy (= a_yt) = $1.64\times10^{16}\times9.38\times10^{-10}$ **(1)** (= 1.54×10^{7} m s^{-1})

$v=\sqrt{(1.54\times10^{7})^2+(3.2\times10^{7})^2}$ = 3.55×10^{7}m s^{-1}**(1)**

at $\tan^{-1}\left(\frac{1.54}{3.2}\right)=26^\circ$ above the horizontal **(1)**

3

[8]

13 (a)

quantity	**SI unit**	
(gravitational potential)	J kg^{-1} or N m kg^{-1}	scalar
(electric field strength)	N C^{-1} or V m^{-1}	vector
(magnetic flux density	T or Wb m^{-2} or N A^{-1} m^{-1}	vector

6 entries correct **(1) (1) (1)**
4 or 5 entries correct **(1) (1)**
2 or 3 entries correct **(1)**

3

(b) (i) $mg = EQ$ **(1)**

$$E\left(\frac{mg}{Q} = \frac{4.3 \times 10^{-9} \times 9.81}{3.2 \times 10^{-12}}\right) = 1.32 \times 10^4 \text{ (V m}^{-1}\text{)}$$ **(1)**

(ii) positive **(1)**

3

[6]

14 (a) (i) (force) to the right **(1)**

(ii) electrons accelerate or speed increases **(1)**

2

(b) (i) sketch to show path <u>curving</u> upwards in the field (must not become vertical) **(1)**

(ii) horizontal component of velocity is unchanged **(1)**
vertical or upwards acceleration (or force) **(1)**
parabolic path described (or named) **(1)**

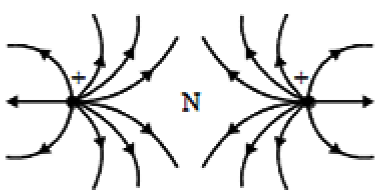
max 3

The Quality of Written Communication marks are awarded for the quality of answers to this question.

[5]

15 (a) (i) force per unit positive charge **(1)(1)**
[force on <u>a</u> unit charge **(1)** only]
vector **(1)**

(ii)



overall correct symmetrical shape **(1)**
outward directions of lines **(1)**
spacing of lines on appropriate diagram **(1)**
neutral point, N, shown midway between charges **(1)**

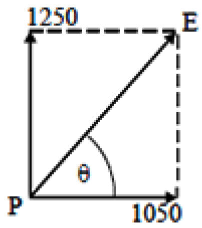
6

(b) (i) $E_{AP}\left(= \frac{Q}{4\pi\varepsilon_0 r^2}\right) = \frac{2 \times 10^{-19}}{4\pi \times 8.85 \times 10^{-12} \times (0.12)^2}$ **(1)**

$= 1250 \text{ V m}^{-1}$ **(1)**

(ii) $E_{PB} = \frac{3.0 \times 10^{-9}}{4\pi \times 8.85 \times 10^{-12} \times (0.16)^2} = 1050 \text{Vm}^{-1}$ **(1)**

(iii)



(1)

allow e.c.f. from wrong numbers in (i) and (ii)

$E = \sqrt{1250^2 + 1050^2}$ **(1)** 1630Vm^{-1} **(1)**

$\theta = \tan^{-1}\left(\frac{1250}{1050}\right)$ = 50.0° to line PB and in correct direction **(1)**

max 6

(c) (i) potential due to A is positive, potential due to B is negative **(1)**
at X sum of potentials is zero **(1)**

(ii) $\frac{2 \times 10^{-9}}{4\pi\varepsilon_0(x)} + \frac{-3 \times 10^{-9}}{4\pi\varepsilon_0(0.20 - x)} = 0$ **(1)**

gives AX (= x) = 0.080m **(1)** (only from satisfactory use of potentials)

4

[16]

16 (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 × 5.5 × 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]

17 (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) $E = q/4\pi\varepsilon_0 r^2$ ($Q = 84 \times 4\pi\ 8.9 \times 10^{-12}\ (6400\ 000)^2$

C1

$(3.8–3.9) \times 10^5$ 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]

18 (a) (i) magnetic field (or B) must be at right angles to velocity (or v) ✓ 1

(ii) F = (magnetic) force (on a charged particle or ion)

B = **flux density** (of a magnetic field)

Q = charge (of particle or ion)

v = velocity [**or** speed] (of particle or ion)
all four correct ✓ 1

(b) (i) into plane of diagram ✓ 1

(ii) magnetic **force** = electric **force** [or $BQv = EQ$] ✓

these forces act in opposite directions [**or** are balanced **or resultant** vertical force is zero] ✓ 2

(iii) $BQv = EQ$ gives flux density $B = \frac{E}{v}$ ✓

$E\left(= \frac{V}{d}\right) = \frac{45}{65 \times 10^{-3}}$ ✓ (= 738 V m^{-1})

$B\left(= \frac{738}{1.7 \times 10^{5}}\right) = 4.3 \times 10^{-3}$ ✓ T ✓ 4

(c) ions would be deflected upwards ✓

magnetic force increases but electrostatic force is unchanged [**or** magnetic force now exceeds electrostatic force] ✓

2

[11]

19 (a) $^{27}_{13}\text{Al} + \alpha \rightarrow ^{30}_{15}\text{P} + ^{(1)}_{(0)}\text{n}$ ✓

1

(b) kinetic energy lost by the α particle approaching the nucleus is equal to the potential energy gain ✓

$2.18 \times 10^{-12} = \dfrac{1}{4\pi \times 8.85 \times 10^{-12}} \times \dfrac{13 \times 1.6 \times 10^{-19} \times 2 \times 1.6 \times 10^{-19}}{r}$ ✓

$r = 2.75 \times 10^{-15}$ (m) ✓

3

[4]

20 (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 $E = \dfrac{V}{d}$ gives) $E = \dfrac{4200}{60 \times 10^{-3}} = 7.0 \times 10^4$ V m^{-1} **(1)**

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

$= 3.1 \times 10^{-9}$ C

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

3

[6]

21 (a) (i) $E \left(= \dfrac{Q}{4\pi\varepsilon_0 r^2}\right) = \dfrac{29 \times 1.6 \times 10^{-19}}{4\pi \times 8.85 \times 10^{-12} \times (1.15 \times 10^{-10})^2}$ **(1)**

$= 3.15 \times 10^{12}$ Vm^{-1} (or (NC^{-1}) **(1)**

(ii) $V(= -\frac{GM}{r}) = (–)\ \frac{6.67 \times 10^{-11} \times 63 \times 1.66 \times 10^{-27}}{1.15 \times 10^{-10}}$ **(1)**

$= (–)\ 6.07 \times 10^{-26}$ **(1)** – sign and J kg^{-1}

5

(b) arrow pointing to the right **(1)**

1

[6]

22 (a) $m = 4.0026 \times 1.66 \times 10^{-27}$ (kg) **(1)** (= 6.6×10^{-27} kg – electron masses are not significant)

kinetic energy $(= \frac{1}{2}mv^2) = 0.5 \times 6.65 \times 10^{-27} \times (2.00 \times 10^7)^2$ **(1)**

(= 1.33×10^{-12} J)

2

(b) loss in k.e. = gain in p.e. **(1)**

loss of ke. [or 1.33×10^{-12}] = $\frac{Q}{4\pi\varepsilon_0 R}$ **(1)** $\left(= \frac{2Ze^2}{4\pi\varepsilon_0 R}\right)$

$R = \frac{2 \times 79 \times (1.6 \times 10^{-19})^2}{4\pi \times 8.85 \times 10^{-12} \times 1.33 \times 10^{-12}}$ **(1)**

$= 2.73 \times 10^{-14}$ m **(1)**

4

(c) *any valid point including:*
strong force complicates the process (*)
scattering caused by distribution of protons not whole nucleon distribution (*)
α particles are massive causing recoil of nucleus which complicates results (*)
(*) any **one (1)**

1

[7]

23 (a) (i) 1 N per A per m
or 1 Wb m^{-2}
or quotes: $B = F/IL$ with terms defined
or induced $EMF = \Delta BAN/t$ with terms defined
or a slightly flawed attempt at the definition in statement form

C1

It is the flux density (perpendicular to a wire) that produces a force of 1N per m on the wire when the current is 1A
or
$B = F/IL$ **and** 1 T is flux density when F = 1N; I = 1A and L = 1 m
or induced $EMF = \Delta BAN/t$ and 1 T is the flux change when emf = 1V for A=1 N =1 and t =1 or similar

A1

2

(ii) force on charge due to E field , $F_E = Eq$ **or** Vq/d
and
force due to B field, $F_B = Bqv$
or $Eq=Bqv$

B1

= Bqv; cancels q **and states explicitly** $v = \frac{E}{B}$

or $v = \frac{V}{dB}$

B1

2

(iii) v = 20000/0.14 (seen) **or** 143 × 10^3 m s^{-1}

B1

1

(b) (i) $Bqv = mv^2/r$ or $r = mv/Bq$ (allow e instead of q)
mass of ion = $1.7 \times 10^{-27} \times 58$ (may be in equation)
or (9.86×10^{-26} kg seen)

C1

or
radius = 0.14 m (may be in equation)

C1

Substitutes and arrives at 0.62 to 0.63 T

A1

3

(ii) Calculates new radius (0.145 m) or diameter (0.288 m) using $r \propto m$ or otherwise **allowing ecf**

C1

0.010 m (condone 0.01 m) or 0.0096 – 0.0097 m
(Allow 0.0079 m or 0.008 m due to use of different sfs for B and v)

A1

2

[10]

24 (a) 1

B1

(1)

(b) (i) $E_k = E_p$ when the protons touch
or $E_k = q^2 / 4\pi\varepsilon_0 r$
or separation when they touch = 3.0×10^{-15} m
or $V = q / 4\pi\varepsilon_0 r$

C1

$E_k = (1.6 \times 10^{-19})^2 / 4\pi (8.9 \times 10^{-12}) (3.0 \times 10^{-15})$
or
$E_k = (1.6 \times 10^{-19})^2 / 4\pi (8.9 \times 10^{-12}) (1.5 \times 10^{-15})$

C1

$7.6(1) \times 10^{-14}$ J (cao)

A1

(3)

(ii) incident proton will stop and the stationary proton will move off at velocity / speed of the incident proton
or
All KE / momentum is transferred to the stationary particle
NB not they will not touch

B1

(1)

(iii) protons travel in the opposite directions or velocity is reversed

Ml

with initial speeds

Al

total momentum before = 0 so momentum after must be 0
or
provided they have said that speeds are the same
total KE is same before and after the collision
or
the collision is elastic

Bl

(3)

(iv) mention of strong nuclear force
or
the repulsive force is overcome

Cl

the strong nuclear force is greater than the electrostatic repulsion
or
the strong nuclear force is effective when the protons touch

Al

(2)

(c) $E = mc^2$

Cl

mass increase = {(2 × 2.2) – (2 × 1.7)} × 10^{-27} kg = 1.0 × 10^{-27} kg
or
calculates initial energy equivalence of 2 protons
or
final energy equivalence of 2 delta + particles

Cl

8.6 or 9 × 10^{-11} J (i.e. allow 1sf) c.a.o.
(NB Adding on the answer to (b) (i) is correct but it has no influence on the answer to 2 sf so its absence is condoned)

Al

(3)

[13]

25 (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) × 10^7 m s^{-1}

A1

allow e.c.f. for (i) ie 1.5 × 10^{15} × √(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) × 10^{-9} s

e.c.f. for their (ii)

A1

(1)

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

C1

8.4 (8.36) × 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]