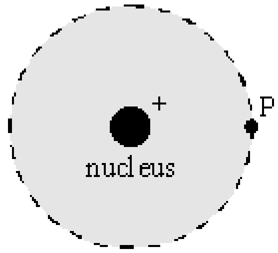
1 The mass of the nucleus of an isolated copper atom is 63 u and it carries a charge of +29 *e*. The diameter of the atom is 2.3×10^{-10} m.

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)

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

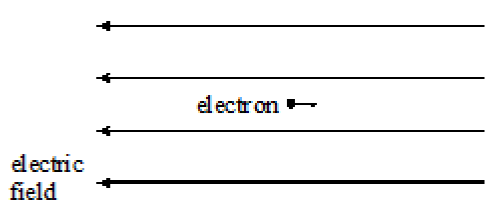


Figure 1

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

___

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

___

___

(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**.

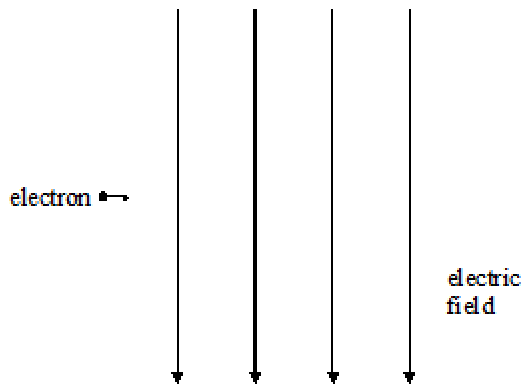


Figure 2

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

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

___

___

___

___

___

(3)

(Total 5 marks)

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

___

___

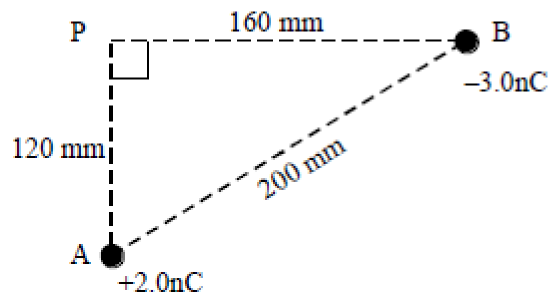
___

___

(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)

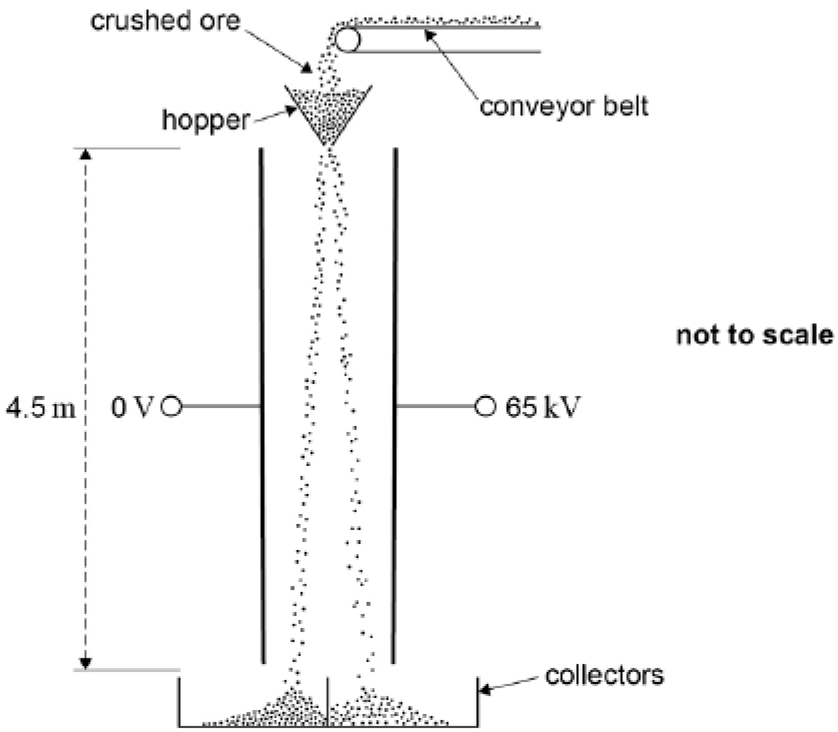
(c) (i) Explain why there is a point X on the line AB in part (b) at which the **electric potential** is zero.

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

(4)

(Total 16 marks)

4 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.

___

___

___

___

(2)

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

___

___

___

___

___

___

___

___

(4)

(Total 12 marks)

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

____

____

____

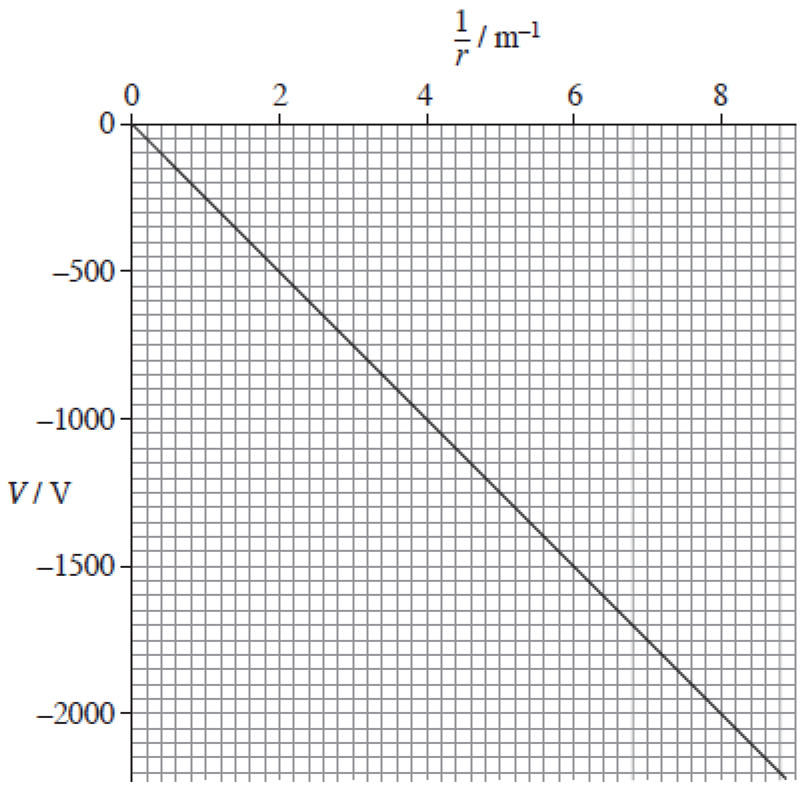
____

____

____

(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.

____

____

____

____

(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

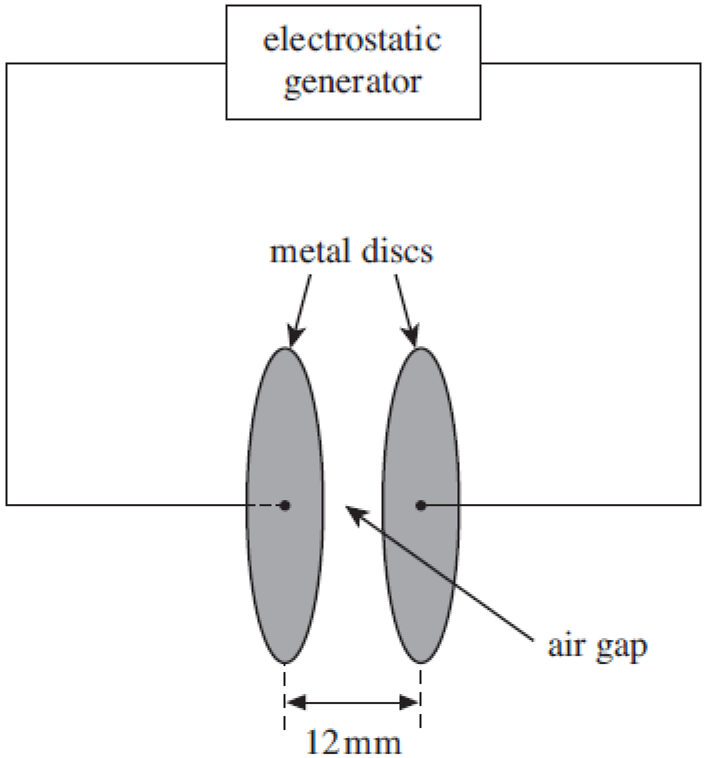
(iii) Calculate the electric field strength at the point where r = 0.40 m.

electric field strength ____________________ V m^{-1}

(2)

(Total 10 marks)

6 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,

____

____

____

____

____

(2)

(ii) the brightness of each spark.

____

____

____

____

____

(2)

(Total 7 marks)

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

___

___

___

___

(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.

____

(1)

(Total 12 marks)

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

____

____

____

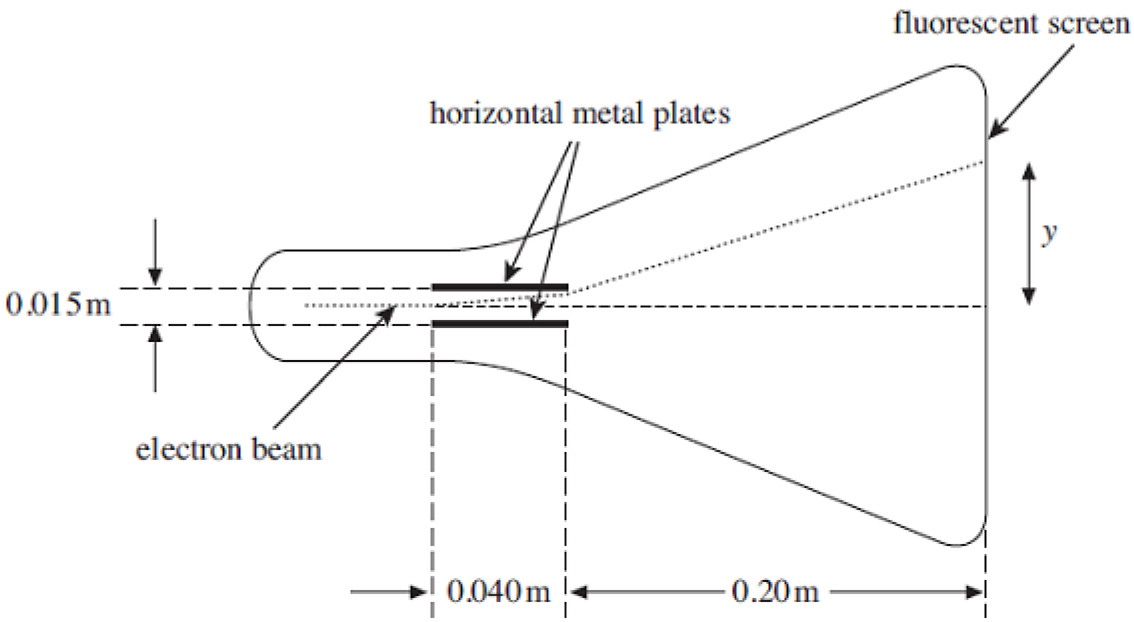
____

____

____

(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.

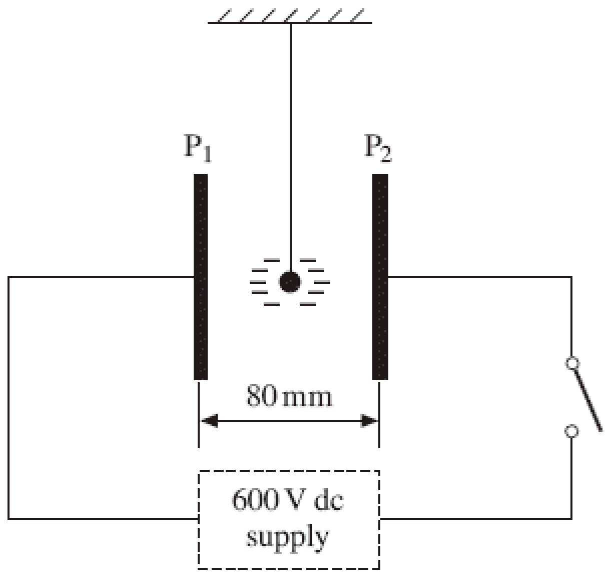
vertical displacement ____________________ m

(3)

(Total 13 marks)

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 $\mathbf{P_1}$ and $\mathbf{P_2}$ when the switch is closed. Calculate the magnitude of the electric field strength between the plates, assuming it is uniform.

answer = ______________________ V m^{-1}

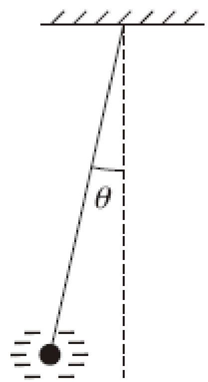
(2)

(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)

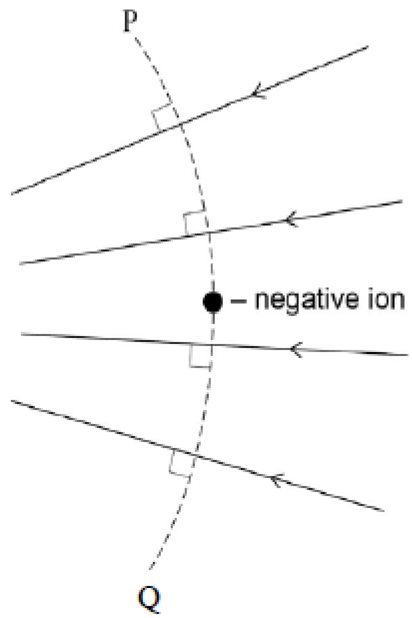
(ii) The mass of the ball is 4.8×10^{-4} kg. By considering the equilibrium of the ball, determine the value of θ.

answer = ______________________ degrees

(3)

(Total 8 marks)

10 The diagram shows a small negative charge at a point in an electric field, which is represented by the arrowed field lines.



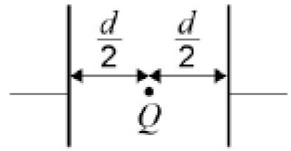
Which of the following statements, about what happens when the charge is displaced, is correct?

When the negative charge is displaced

A	to the left the magnitude of the electric force on it decreases.	⬭
B	to the right its potential energy increases.	⬭
C	along the line PQ towards Q its potential energy decreases.	⬭
D	along the line PQ towards P the magnitude of the electric force on it is unchanged.	⬭

(Total 1 mark)

11 Two parallel metal plates are separated by a distance d and have a potential difference V across them. Which expression gives the magnitude of the electrostatic force acting on a charge Q placed midway between the plates?



A $\frac{2VQ}{d}$ ☐

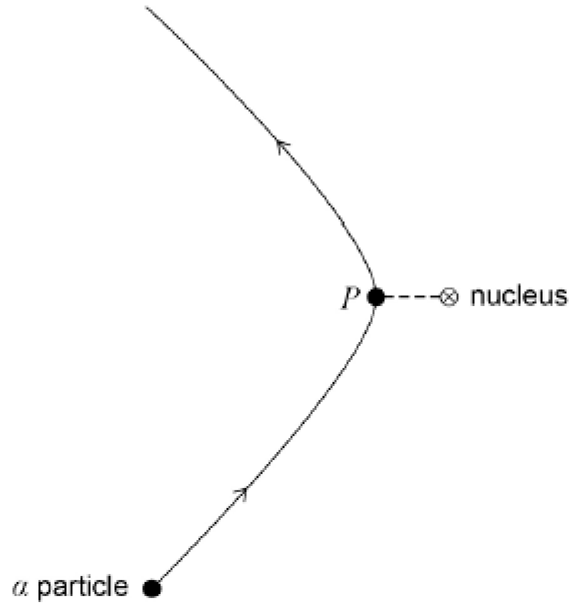
B $\frac{VQ}{d}$ ☐

C $\frac{VQ}{2d}$ ☐

D $\frac{Qd}{v}$ ☐

(Total 1 mark)

12 The diagram shows the path of an α particle deflected by the nucleus of an atom. Point P on the path is the point of closest approach of the α particle to the nucleus.



Which of the following statements about the α particle on this path is correct?

A	Its acceleration is zero at P.	☐
B	Its kinetic energy is greatest at P.	☐
C	Its potential energy is least at P.	☐
D	Its speed is least at P.	☐

(Total 1 mark)

13 The electric potential at a distance *r* from a positive point charge is 45 V. The potential increases to 50 V when the distance from the point charge decreases by 1.5 m. What is the value of *r*?

A	1.3m	☐
B	1.5m	☐
C	7.9m	☐
D	15m	☐

(Total 1 mark)

Mark schemes

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

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

5

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

1

[6]

2 (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)**

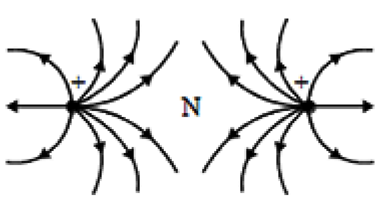
max 3

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

[5]

3 (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)**

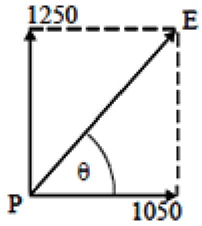
6

(b) (i) $E_{AP}\left(=\frac{Q}{4\pi\varepsilon_0 r^2}\right)=\frac{2\times10^{-19}}{4\pi\times8.85\times10^{-12}\times(0.12)^2}$ **(1)**

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

(ii) $E_{PB}=\frac{3.0\times10^{-9}}{4\pi\times8.85\times10^{-12}\times(0.16)^2}$ = 1050Vm^{-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) $\frac{2\times10^{-9}}{4\pi\varepsilon_0(x)}+\frac{-3\times10^{-9}}{4\pi\varepsilon_0(0.20-x)}$ = 0 **(1)**

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

4

[16]

4

(a) $t=\sqrt{\frac{2s}{g}}$ or 4.5 = $\frac{1}{2}$ × 9.81 × 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]

5 (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 × 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) $E\left(=\frac{Q}{4\pi\varepsilon_0 r^2}\right) = \frac{27.8 \times 10^{-9}}{4\pi\varepsilon_0 \times 0.40^2}$ ✓ = 1600 (1560) (V m^{-1}) ✓

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

from graph $E = \frac{625 \pm 50}{0.40}$ = 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]

6 (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)* = $3.7 \times 10^{-12} \times 3.00 \times 10^{4}$ ✓

(= 1.11×10^{-7} C)

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

time taken $t\left(=\frac{Q}{I}\right) = \frac{1.11 \times 10^{-7}}{3.2 \times 10^{-8}}$ = 3.5 (3.47) (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)

7 (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) $E_4 = \frac{4.0 \times 10^{-9}}{4\pi\varepsilon_0 \times (34 \times 10^{-3})^2}$ (= 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.*

$E_6 \left(= \frac{6.0 \times 10^{-9}}{4\pi\varepsilon_0 \times (34 \times 10^{-3})^2} \right)$ = (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]

8 (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 $eV = ½mv^2$

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]

9 (a) (i) $E\left(=\frac{V}{d}\right) = \frac{600}{80 \times 10^{-3}}$ **(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)

$\tan\theta\left(=\frac{F}{mg}\right) = \frac{1.28 \times 10^{-3}}{4.8 \times 10^{-4} \times 9.81} (= 0.272)$ **(1)**

gives θ = 15(.2) (°) **(1)**

3

[8]

10 D

[1]

11 B

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12 D

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13 D

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Examiner reports

1 There were many pitfalls en route to successful answers to part (a). Most candidates obtained little reward in this question because they could not steer clear of them. Examiners were pleased that so many of the candidates were not put off by the slightly unfamiliar way in which charge was given in part (a)(i), or by the mass given in u in part (a)(ii). This, at least, showed that some learning is taking place across the topic boundaries within Module 4. The really serious problems arose with arithmetic, units and the need to take care in calculations. Typical errors in part (i) were failing to halve the diameter and forgetting to square the denominator. The unit of electric field strength was known by some, yet hardly any of the candidates could give a correct unit for gravitational potential. Carelessness was apparent in the work of all those who omitted the negative sign from the final value for gravitational potential.

The subject area tested in part (a) remains totally confusing for so many candidates, who obviously cannot distinguish between the words gravitational and electric or field and potential. Perhaps they did not read the wording of the question correctly. This may be more excusable than the huge number of wrong answers to the electric field direction in part (c): an arrow pointing inwards at P was common, a tangential arrow at P was fairly frequent, and a vague arrow drawn some distance from P was not exceptional.

2 Many of the attempts to answer this question showed a complete lack of understanding of forces in electric fields and much confusion between magnetic fields and electric fields. Taken as a whole, the question proved to be an excellent discriminator of the proficient physics student.

Perhaps it is understandable that many candidates wrongly chose ‘to the left’ in part (a)(i) and therefore followed it with ‘deceleration’ in part (ii). It is much more difficult to appreciate why the electron might be considered to follow a curved or circular path in part (a) - as stated by some candidates. The parabolic path in part (b) was often shown curving downwards. Part (b)(ii) required an explanation based on an understanding of projectile motion. Quite a large number of candidates preferred to refer to Fleming’s left hand rule!

3 Few of the definitions in part (a) included any reference to a positive charge, and “force on a unit charge” seemed more common than the more correct “force per unit charge”. The only field patterns tested in previous PH03 papers have been magnetic ones, so the need here to draw an electric field caught out the vast majority of candidates. Examiners found that almost all of the drawings more closely resembled the field between two current-carrying wires than that between two point charges.

Attempts to answer part (b) were variable and it was not uncommon for candidates having a good understanding of vector addition to score full marks. Misinterpretation of nanocoulomb was a problem for some candidates. The direction of the resultant field caused some difficulty, principally because candidates did not understand the fact that an electric field is directed inwards towards a negative charge.

Only a minority of able candidates showed a clear understanding of the concept of electric potential in part (c). Most answers tried to present arguments which were concerned with field rather than potential. It needs to be more clearly accepted that potential is a scalar quantity and therefore does not have an associated direction; potential values may add to zero but they can never “balance”. In part (c)(ii) there were many intuitive answers of 80 mm, which quoted 3≤ of 200 mm as the reasoning. Credit was given only for answers which were properly reasoned in terms of potential.

5 Statements of Coulomb's law were generally satisfactory in part (a) and marks were high. Occasionally there was confusion with the law of gravitation (distance between *masses* rather than *charges*) and reference to *indirect* proportion (which was not acceptable) rather than *inverse* proportion.

In part (b), inverse proportion was generally recognised as the relationship between V and r shown on the graph. Many students knew that the negative values of potential were caused by the charge Q being negative. Alternative arguments that approached an answer via the definition of potential usually failed because the positive nature of the charge being moved was not stated. No doubt it was confusion with gravitational potential, which is always attractive, that caused a significant number of students to conclude that electric potential is always negative.

There was a good spread of marks across the three calculations in part (c). Part (c)(i) was usually answered correctly, either by substitution of a data point from the graph or by use of the gradient. Part (c)(ii) was most easily approached by reading the potentials corresponding to r = 0.20 m and r = 0.50 m from the graph, leading to ΔV = 750V, and then applying $\Delta W = Q\Delta V$. The principal failing in the answers that started from first principles, by calculating the two potentials from the Q value in part (i), was to use 60 nC as both the source of the potentials and as the charge being moved. Direct substitution of the charge from part (i) into $E = Q / 4\pi\varepsilon_0 r^2$ gave the most straightforward answer in part (iii). Although the use of $E = V / d$ gave the correct numerical answer here, it should be recognised that this equation is only valid in a uniform field whereas the field in this question is radial. Both marks were therefore awarded for this approach only when the use of $E = V / r$ had been justified.

6 Very few candidates experienced any difficulty in (a)(i), where the product of field strength and plate separation readily led to 30,000 V. In the other parts of Question 2 the principal failing of many of the candidates' attempts was to resort to time variations that were exponential. Part (a) puts this question clearly in the context of a charging current that is constant, so any references to exponential changes or time constants showed misunderstanding and were irrelevant. Arithmetical slips sometimes caused the loss of marks in part (a)(ii), but $Q = CV$ and $t = Q / I$ were usually applied correctly to arrive at 3.5 s.

In part (b) it was essential for candidates to realise that both the charging current and the breakdown pd remain constant at their original values when the capacitance is changed. The majority of candidates could see in part (b)(i) that the time between discharges would increase. Many also gave an acceptable explanation, either by stating that the charge stored would have to be larger before the breakdown pd was reached, or by reference to $t = CV / I$, where V and I are both unchanged. A common misconception in part (b)(ii) was to think that the brightness of the spark would be unchanged because the breakdown pd would be the same as it had been originally. It was expected that candidates would know that increased capacitance at the same pd would mean that the energy stored by the capacitor would be greater, so each spark would transfer more energy and would therefore be brighter. Alternatively, explanations in terms of the greater charge stored were also accepted.

7

Many completely correct statements of Coulomb's law were seen in part (a). Common omissions were failure to state that the law is concerned with the force *between two charges*, or failure to state that the force is inversely proportional to the *square* of the separation. Sometimes the separation distance was called "radius"; when this was undefined no mark could be given.

Responses to the electric field diagram in part (b)(i) were mixed. Many attempts showed vaguely circular lines around each charge. The examiners were looking for radial lines outward from each charge, with more lines starting on the larger charge, lines that curved in the correct directions away from the charges, and a left-of-centre point of zero field strength. Some candidates tried to use longer field lines, instead of more concentrated field lines, in their efforts to represent the field of the larger charge.

The application of Coulomb's law in part (b)(ii) provided two very accessible marks for candidates who could substitute values correctly in the force equation and then use their calculator correctly.Use of 10^{-6} instead of 10^{-9} for nano- was common, leading to the loss of one mark. One mark was also lost when candidates failed to square *r* in their evaluation, after having substituted correctly. In part (c) many successful answers for the resultant field strength were presented but some candidates confused field strength ($\propto 1 / r^{2}$) with potential ($\propto 1 / r$), whilst others added the component values of *E* instead of subtracting them. The unit of electric field strength – either Vm^{-1} or NC^{-1} – was less well known than expected, and the direction given for the resultant field was often incorrect, with some impossibly incorrect responses such as "upwards" and "into the page".

8

Most of the candidates made significant progress in part (a) and there were some very good explanations of thermionic emission. The most common omission was in not describing the role of the electric field between the anode and cathode in accelerating the electrons in the beam.

Many candidates calculated the acceleration correctly and a significant number set out their work clearly and well. Some attempted to use the work done by the electric field between and others tried to use just the equations of motion.

Parts (b) (ii) and (b) (iii) were well done by many candidates.

In part (b) (iv), a significant number of candidates did not know how to proceed but the majority made some progress either by using ratios or equations of motion. For those that made significant headway, the most frequent mistake was to omit to add on the vertical distance that had already been travelled by the time the beam reached the end of the plates.

9 Calculation of the electric field strength in a uniform field by using $E = V/d$ were known well in part (a) (i), as was finding the force on a charge using $F = EQ$ in part (a) (ii). Most candidates therefore achieved full marks in these parts. Answers to the force diagram in part (b) (i) were much less satisfactory. Examiners were expecting to see three clearly labelled force arrows, starting on the ball, showing the electrostatic force to the left, the weight of the ball downwards and the tension acting upwards along the thread. Careless drawing and inadequate labelling caused marks to be lost in a majority of answers. When labelling the downwards force, 'weight', '*W*' or '*mg*' were acceptable, whereas 'gravity', 'mass' or '*g*' were not. The tension force was often omitted, whilst additional horizontal forces such as 'centripetal force' were sometimes shown.

In part (b) (ii), some evidence was expected for the appearance of the equation $F = mg \tan \theta$. This could be from a consideration of the resolved components of the forces acting, or from a force diagram showing θ clearly. Many good answers were seen, but a large proportion of the candidates could make little or no progress.