Mark schemes

1 (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]

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

$= 4.6(7) \times 10^{-5}$ (N) ✓

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

2

(c) (i) $E_4 = \dfrac{4.0\times10^{-9}}{4\pi\varepsilon_0\times(34\times10^{-3})^2}$ (= 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 $\left(=\dfrac{6.0\times10^{-9}}{4\pi\varepsilon_0\times(34\times10^{-3})^2}\right)$ = (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]

3 (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]

4 (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 ∞ $\frac{1}{r}$ 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]

5 (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 $B = \frac{E}{v}$ ✓

$E\left(=\frac{V}{d}\right) = \frac{45}{65\times10^{-3}}$ ✓ (= 738 V m^{-1})

$B\left(=\frac{738}{1.7\times10^{5}}\right) = 4.3\times10^{-3}$ ✓ 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]

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

$= 7.5\times10^{3}$ (V m^{-1}) **(1)**

2

(ii) force F (= EQ) = $7500\times0.17\times10^{-6}$ **(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 $\theta = 15(.2)$ (°) **(1)**

3

[8]

7 **A**

[1]

8 **C**

[1]

9 **D**

[1]

10 D

[1]

Examiner reports

1 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.

2 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".

3 Parts (a) and (b) of this question, about forces and accelerations of charged particles in electric fields, was more demanding than expected. The direction of the arrow in part (a)(i) was frequently wrong, and was often shown in a vertical direction. A clear force arrow, starting on the electron and directed horizontally to the left, was expected. However, in part (a)(ii) most students recognised that this situation produces a constant force; the explanation that the force is caused by a constant electric field strength was sometimes less clear.

More careful consideration of the wording of the questions, and subsequent review of the answers they had written, would have benefitted many students when answering part (b). For example, it was common for a student's attempt at part (i) to try to answer the issues raised in part (iii). Students should know that a force has two attributes, magnitude and direction. Both had to be addressed in satisfactory answers to part (i), where both particles are at exactly the same point in an electric field of exactly the same field strength. In part (ii) the relationship between forces and accelerations was usually well understood and both marks were usually awarded. Failure to discuss the accelerations of the proton and electron separately was common in part (iii), leading to many wrong answers. Parabolic and circular motion were often referred to here. Some of the less able students stated that the electron would decelerate, probably because they were unable to distinguish between deceleration and decreasing acceleration.

Students who had revised their AS Physics, and who presented their working fully, were well rewarded in part (c)(i). Part (c)(ii), although it is basically a simple question, proved to be much more challenging. The common acceptable approach was to calculate the strength E of the uniform electric field and then divide 1.91 (or 2) V by E. A slightly longer procedure was divide the energy calculated in part (i) (3.06×10^{-19} J) by the force on the electron – which had to be calculated. However the question could be answered using simple ratios: (2 / 4500) of 180 mm is 0.080 mm.

4 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.

5 In part (a)(i) many candidates were unaware of the condition under which $F = BQv$ applies, which is given clearly in the specification. A common incorrect answer was to state that the force has to be perpendicular to B, without any reference to v. In part (a)(ii) the main difficulty proved to be the meaning of B; magnetic flux density was correct and the loose 'magnetic field strength' was not accepted. Some candidates thought that v represents voltage.

Part (b)(i) was a test of Fleming' left hand rule when applied to a stream of positive ions. Together with the figure, the first paragraph of part (b) defines 'downwards' as the direction towards the lower (negative) plate. The correct answer in (b)(i) is 'into the plane of the diagram', not downwards.

In part (b)(ii) candidates were expected to consider the force conditions applying to the undeflected ions. A common misconception was that the magnetic field is equal to the electric field. The main errors in part (b)(iii), where the numerical value obtained was often correct, were the omission of clear working and not knowing that the unit of B is T. Some candidates could only quote $F = BQv$ and were at a loss to make further progress without $F = EQ$ and $E = V/d$.

Many candidates were totally lost in part (c). Others correctly explained that the ions would now be the magnetic force (which is proportional to v) increases whilst the electrostatic force (which is independent of v) remains constant.

6

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.