5(a)	potential is (defined as) zero at infinity	**B1**
	proton has a positive charge and so repels another positive charge	**B1**
	work is done on two (positive) charges to move them towards each other **or** work is done by two (positive) charges as they move apart from each other	**B1**

5(b)(i)	arrow drawn through Q in a WSW direction directly away from the centre of the sphere	**B1**

5(b)(ii)	curve in at least one quadrant passing through ($\pm R$, $\pm E_0$) and ($\pm 2R$, $\pm \frac{1}{4} E_0$)	**B1**
	curve between $-3R$ and $-R$ of increasing magnitude of gradient **and** curve between R and $3R$ of decreasing magnitude of gradient	**B1**
	two lines drawn, one in the top right quadrant, the other in the bottom left quadrant	**B1**

5(c)	$E_P = -(1.60 \times 10^{-19})^2 / [4\pi \times 8.85 \times 10^{-12} \times (5.3 \times 10^{-11})]$	**C1**
	$= -4.3 \times 10^{-18}$ J	**A1**

Question 5

(a) Many candidates correctly quoted the definition of electric potential, but this alone was not awarded credit. Many stronger candidates correctly stated that the potential at infinity is defined as zero. Many candidates stated that the force was repulsive without explaining that this was because the charge on a proton is positive. Very few candidates distinguished between 'work done <u>on</u> the charges' and 'work done <u>by</u> the charges'.

(b) (i) Although the majority of the candidates gained credit, many candidates were careless in drawing the arrow (e.g. curved arrows, arrows that did not pass through Q or did not pass sufficiently close to the centre of the sphere when extended), and some candidates had arrows which were pointing towards the centre of the sphere.

(ii) The curves drawn were usually partly or approximately correct but often they did not have precise detail. Examples included not using data to determine values of E (e.g. at $x = 2R$ and $x = –2R$) despite a clear numerical scale, allowing the curve to become horizontal or straight in sections and not showing that E was negative for negative values of x.

(c) The majority of the candidates obtained the correct magnitude, but many candidates omitted the minus sign. Typical errors were omitting one of the charges and dividing by the separation squared. Some weaker candidates substituted the sum of the charges instead of the product.

6(a)	force per unit positive charge	**B1**
6(b)(i)	radial lines	**B1**
	arrows pointing away from the sphere	**B1**
6(b)(ii)	$C = Q / V$	**C1**
	$V = 83 / 69$ $= (+)1.2\ \text{V}$	**A1**
6(b)(iii)	$V = Q / 4\pi\varepsilon_0 r$ $r = (83 \times 10^{-12}) / (4\pi \times 8.85 \times 10^{-12} \times 1.2)$	**C1**
	$= 0.62\ \text{m}$	**A1**
6(b)(iv)	$E = Q / 4\pi\varepsilon_0 r^2$	**C1**
	$= (83 \times 10^{-12}) / (4\pi \times 8.85 \times 10^{-12} \times 0.62^2)$ $= 1.9\ \text{N C}^{-1}$	**A1**
6(c)	$26 = 83 \exp [- t / (120 \times 10^6 \times 69 \times 10^{-12})]$	**C1**
	$t = 9.6 \times 10^{-3}\ \text{s}$	**A1**

Question 6

(a) The definition of electric field as force per unit positive charge was generally well known.

(b) The electric field pattern around the sphere was generally well drawn. The numerical questions that followed in the remaining parts of **(b)** were generally well answered, with many candidates obtaining the correct answers.

(c) This was a difficult question, but many candidates obtained the correct answer. Weaker candidates generally made no attempt to use the exponential equation and were therefore unable to make a start with the question.

5(a)	work done per unit charge	**B1**
	work (done) moving positive charge from infinity (to the point)	**B1**

5(b)(i)	potential (due to proton) = $(1.60 \times 10^{-19}) / (4\pi \times 8.85 \times 10^{-12} \times 10 \times 10^{-12})$ **or** potential (due to electron) = $(-1.60 \times 10^{-19}) / (4\pi \times 8.85 \times 10^{-12} \times 110 \times 10^{-12})$	**C1**
	$V = [(1.60 \times 10^{-19}) / (4\pi \times 8.85 \times 10^{-12})] \times [(10^{-1} - 110^{-1}) \times 10^{12}] = 130\ \text{V}$	**A1**

5(b)(ii)	$V = [(1.60 \times 10^{-19}) / (4\pi \times 8.85 \times 10^{-12})] \times [(30^{-1} - 90^{-1}) \times 10^{12}]$	**C1**
	$= (+)\ 32\ \text{V}$	**A1**

5(b)(iii)	cross drawn midway between the electron and the proton	**B1**

5(b)(iv)	line from (10, +130) to (110, –130)	**B1**
	curve getting shallower until x = 60 pm, crossing V = 0 at (60, 0) and then getting steeper after x = 60 pm	**B1**
	curve passing through (30, ±32) and (90, ±32)	**B1**

Question 5

(a) Most candidates had some recall of the definition. Where full credit was not awarded, this was usually due to one of two omissions, either not making the ratio clear or not clarifying that the charge being moved from infinity was positive.

(b) (i) This ‘show that’ question required the working to be clearly set out, showing the addition of the two contributory potentials. Stronger candidates clearly showed all the values used and the sign of those contributory potentials.

(ii) Most candidates were able to successively replicate their method from **(i)** to the new situation. Some weaker candidates did not realise that the distances to both charges would change, or only considered one charge.

(iii) Many candidates were able to position the cross correctly.

(iv) Credit could be gained for identifying the key elements of a correct start and end point, an increasing steepness of the curve away from the midpoint where there was a sign change, and the correct plotting of a potential at 30 pm and 90 pm. Candidates who used a pencil, and could therefore adjust their sketch where it was inaccurate, were at an advantage.

5(a)	work done per unit charge	**B1**
	work done (on charge) in moving positive charge from infinity (to the point)	**B1**

5(b)(i)	electric field strength inversely proportional to distance^2	**C1**
	$E = 3^2 \times 2.0 \times 10^5$ $= 1.8 \times 10^6\ \text{N C}^{-1}$	**A1**

5(b)(ii)	$V = Q / 4\pi\varepsilon_0 r$ **and** $E = Q / 4\pi\varepsilon_0 r^2$ (so $E = V / r$)	**B1**
	$r = (9.0 \times 10^4) / (1.8 \times 10^6) = 0.050\ \text{m} = 5.0\ \text{cm}$	**A1**

5(b)(iii)	$Q = 4\pi\varepsilon_0 Vr$ $= 4\pi \times 8.85 \times 10^{-12} \times 9.0 \times 10^4 \times 0.050$	**C1**
	$= 5.0 \times 10^{-7}\ \text{C}$	**A1**

5(b)(iv)	$C = Q / V$	**C1**
	$= (5.0 \times 10^{-7}) / (9.0 \times 10^4)$ $= 5.6 \times 10^{-12}\ \text{F}$	**A1**

Question 5

(a) As well as defining electric potential in terms of movement of charge to or from infinity (depending on the sign of the charge) stronger candidates were also aware of the required ratio between work done and charge.

(b) (i) Candidates used a number of different methods to compare the two positions (r and $3r$ from the sphere's centre) and the relative electric field strength and potential values at each position. Each method was equally creditworthy in deriving the field strength at the surface of the sphere. The most common error was to invert the relationships and get a smaller value of electric field strength at the surface than further away at distance $3r$.

(ii) In this 'show that' question, equations for electric field strength and potential needed to first be shown and then compared in order to progress to the final relationship between E, V and sphere radius r. Most candidates missed this beginning and started from that final relationship, into which values were substituted. The calculation produced a value in metres, which needed to be clearly converted into centimetres. Some weaker candidates wrongly used the equation for parallel plates, including an unexplained symbol d.

(iii) The rearrangement of the equation for electric field strength or for electric potential did not prove problematic to most candidates. Weaker candidates were not able to recognise that the precise value of the capacitance was not exactly 0.5 μC, and so they gave their answer to only one significant figure instead of the required minimum of two.

(iv) The majority of the candidates were able to successfully use the data provided to calculate the capacitance of the sphere.

6(a)	plate X marked as negative and plate Y marked as positive	**B1**

6(b)(i)	$E = V / x$	**C1**
	$= (58 \times 10^3) / 0.041$ $= 1.4 \times 10^6\ \text{N C}^{-1}$	**A1**

6(b)(ii)	$ma = eE$	**C1**
	$a = (1.60 \times 10^{-19} \times 1.41 \times 10^6) / (9.11 \times 10^{-31})$ $= 2.5 \times 10^{17}\ \text{m s}^{-2}$	**A1**

6(c)(i)	$eV = hc / \lambda$ **or** $eV = hf$ **and** $f = c / \lambda$	**C1**
	$(1.60 \times 10^{-19} \times 58 \times 10^3) = (6.63 \times 10^{-34} \times 3.00 \times 10^8) / \lambda$	**M1**
	clear conversion from m to pm leading to $\lambda = 21$ pm	**A1**

6(c)(ii)	X-rays	**B1**

6(c)(iii)	*Any two points from:* • waves are passed into structure and transmitted waves detected • different parts of the structure absorb different fractions of energy • difference in detected / transmitted <u>intensities</u> used (to form image)	**B2**

Question 6

(a) This question was generally well answered, with most candidates recognising that negatively charged electrons accelerate from the negative plate to the positive plate.

(b) (i) This question was also generally well answered, with most candidates able to calculate the correct value and give it with a correct unit.

(ii) The more able candidates were generally able to calculate the acceleration correctly. Many of the weaker candidates equated the product of mass and acceleration with an energy or the electric field strength instead of the electric force, and others attempted to use an equation of uniform acceleration.

(c) (i) Most candidates knew the relationship between photon energy and wavelength. Many were unsure of how to determine the photon energy from the energy of the electron. Some candidates calculated the energy by working backwards from the wavelength value. Of candidates that did correctly show the working for the wavelength, some had difficulty in showing the final conversion from m to pm.

(ii) Most candidates were able to identify the electromagnetic waves as X-rays, from a combination of the order of magnitude of the wavelength and the method of production of the radiation.

(iii) Many candidates found it difficult to answer the question that was asked here, with many accounts given of how X-rays are produced. The idea that the image is formed by the differences in transmitted intensities of X-rays that are detected after passing through different parts of the body structure was not well articulated.

2(a)	(electric) force is (directly) proportional to product of charges	**B1**
	force (between point charges) is inversely proportional to the square of their separation	**B1**

2(b)(i)	charge = (+)2e	**A1**

2(b)(ii)	$F = 2 \times (1.60 \times 10^{-19})^2 / [4\pi \times 8.85 \times 10^{-12} \times (170 \times 10^{-12})^2] = 1.6 \times 10^{-8}$ N	**A1**

2(c)(ii)	$F = mr\omega^2$ **and** $\omega = 2\pi / T$ $F = 4\pi^2 mr / T^2$	**C1**
	$T = [(4\pi^2 \times 9.11 \times 10^{-31} \times 170 \times 10^{-12}) / (1.6 \times 10^{-8})]^{½}$ $= 6.2 \times 10^{-16}$ s	**A1**
	or	
	$v = 2\pi r / T$	**(C1)**
	$T = (2\pi \times 170 \times 10^{-12}) / (1.73 \times 10^6)$ $= 6.2 \times 10^{-16}$ s	**(A1)**

2(d)(i)	$E \propto Q / r^2$	**C1**
	ratio = $[1.60 \times 10^{-19} \times (170 \times 10^{-12})^2] / [3.2 \times 10^{-19} \times (340 \times 10^{-12})^2]$ = 0.13	**A1**

2(d)(ii)	resultant force slightly less (than 1.6×10^{-8} N) so speed lower **or** resultant force slightly less (than 1.6×10^{-8} N) so period greater	**B1**

Question 2

(a) Generally, this question was answered well and most candidates earned full credit. A few candidates referred to 'indirect' rather than 'inverse' proportion regarding the distance of separation squared or omitted the word 'squared'.

(b) (i) The most common error was to respond with a value in coulomb rather than in terms of the elementary charge, but most candidates were awarded credit.

(ii) As always with a 'show that' question, marks are not awarded only for the answer, but for showing the working that leads to the answer. The common reason for credit not being awarded was not showing the full substitution by not substituting values for e and/or ε_0.

(c) (i) Most candidates used the correct starting equation for centripetal force and correctly calculated the speed. Some candidates were not familiar with the power of ten indicated by the prefix 'p' for pico.

(ii) Again, most candidates used the correct starting equation or equations and earned full credit.

(d) (i) Although many stronger candidates earned full credit, a significant number approached the question with the correct method but did not reach the correct answer for reasons including the omission of one or both of the differences in charge and radius.

(ii) A common incorrect answer was that the radius of the orbit would change, but the question gave a constant value for the orbital radius. Stronger candidates correctly explained that the change in resultant force would result in a lower speed or longer period.

2(a)	<u>sketch:</u> line from $x = R$ to $x = 4R$ entirely in the negative ϕ region	**B1**
	curve with continuously decreasing magnitude and with gradient of continuously decreasing magnitude, starting at $(R, \pm\phi)$	**B1**
	line passing through $(2R, \pm\frac{1}{2}\phi)$ <u>and</u> $(4R, \pm\frac{1}{4}\phi)$	**B1**

2(b)	horizontal straight line from $t = 0$ to $t = 24$ hours	**B1**
	line starting at $(0, -\phi)$	**B1**

2(c)	straight line with non-zero gradient from 0 to d	**B1**
	line with negative gradient from $(0, V)$ to $(d, 0)$	**B1**

Question 2

(a) Candidates who knew the inverse relationship, understood that gravitational potential is always negative, and took care over their diagrams, were generally able to achieve the marks.

(b) Many candidates realised that, at a constant distance from the Earth's surface, the gravitational potential must be constant.

(c) This question required candidates to realise two things. One, that the potential is zero at the earthed plate and $+V$ at the upper plate. Two, that the electric field between parallel plates is uniform. Candidates who realised both aspects, and took care over the start and end points of their line, were generally able to achieve the marks.

6(a)	(electric) force is (directly) proportional to product of charges	**B1**
	force (between point charges) is inversely proportional to the square of their separation	**B1**

6(b)	at least four straight, radial lines to/from surface of sphere	**B1**
	at least four straight radial lines drawn, approximately equally spaced	**B1**
	arrows pointing away from the surface of the sphere	**B1**

6(c)(i)	radius = 3.2 cm	**A1**

6(c)(ii)	$E = Q / (4\pi\varepsilon_0 x^2)$	**C1**
	Q = e.g. $2.2 \times 10^5 \times 4\pi \times 8.85 \times 10^{-12} \times 0.032^2$	**C1**
	$= 2.5 \times 10^{-8}$ C	**A1**

6(c)(iii)	• the (positive) charge is all the way around the surface • a charge placed inside the sphere is pulled equally in all directions • if the field was not zero, the charges would move (until field is zero) • electric field lines go from positive charge to negative charge, and there are no negative charges inside the sphere *Any point, 1 mark*	**B1**

Question 6

(a) Coulomb's law was generally well known, and many candidates achieved full credit.

(b) Most candidates appreciated that the electric field is radially outwards, though care was needed over the diagram to gain full credit. Radial lines are straight, so candidates should be advised to use a ruler to draw them. The + symbols around the sphere were a useful guide to candidates to help them to ensure that their field lines were evenly distributed.

(c) (i) Most candidates deduced the radius correctly from the graph.

(ii) Candidates generally knew the correct equation for the electric field strength due to a point charge, but care was needed over the powers of ten when substituting a pair of values correctly read from the curved part of the graph. Some candidates chose to use the value on the data page for $1/4\pi\varepsilon_0$ and substituted it into the denominator rather than the numerator; candidates that used the value of the permittivity of free space generally substituted correctly.

(iii) Most candidates found it difficult to offer a plausible explanation, with many cyclic arguments presented such as 'there are no field lines inside the sphere, so the electric field is zero'. There was a variety of ways in which candidates could approach the answer, and stronger candidates generally were awarded credit.

5(a)	(electric) field equals (electric) potential gradient	**M1**
	reference to minus sign	**A1**

5(b)	• for potential to be zero, one potential must be positive and the other potential must be negative • for potential to be zero, the charges must have opposite sign • for field to be zero, the fields (due to X and Y) must be in opposite directions • for field to be zero, the charges must have the same sign • the signs of the charges cannot (simultaneously) be both the same and opposite (so not possible) *Any three points, 1 mark each*	**B3**

5(c)(i)	$V_X = (–)\ Q / 4\pi\varepsilon_0 x$ **and** $V_Y = (–)\ 2Q / 4\pi\varepsilon_0 y$	**C1**
	$(V_X + V_Y = 0$ so$)\ Q / 4\pi\varepsilon_0 x = 2Q / 4\pi\varepsilon_0 y$ leading to $y = 2x$	**A1**

5(c)(ii)	$E_X = Q / 4\pi\varepsilon_0 x^2$	**A1**

5(c)(iii)	$E_Y = 2Q / 4\pi\varepsilon_0 (2x)^2$ $(= Q / 8\pi\varepsilon_0 x^2)$	**C1**
	(opposite charges so fields in same direction so magnitudes add): $E = (Q / 4\pi\varepsilon_0 x^2) + (Q / 8\pi\varepsilon_0 x^2)$ $= 3Q / 8\pi\varepsilon_0 x^2$	**A1**

NOT FOUND:

9702_w24_qp_41 EXAMINER REPORT (Qu 5)

5(a)	work done per unit charge	**B1**
	work (done) moving positive charge from infinity (to the point)	**B1**

5(b)	*Any three points from*: *Up to 2 points from*: • radius of sphere X is 0.30 m • radius of sphere Y is 0.10 m • radius of X is treble the radius of Y *Up to 2 points from*: • charge on X is positive • charge on Y is positive • spheres X and Y carry charges of the same sign *Up to 1 point from*: • (magnitudes of) charges on the spheres are equal • charges on the spheres have the same magnitude	**B3**

5(c)	proton remains at rest (in the position of release)	**M1**
	potential <u>energy</u> of proton is (already) at its minimum **or** (electric) forces (from spheres) on proton are equal and opposite **or** no resultant (electric) force on proton **or** resultant electric field strength (at proton) is zero	**A1**

Question 5

(a) The definition of electric potential was generally well known, although it was common for omission of important detail to result in full credit not being awarded. For example, many candidates gave a definition of an energy, rather than an energy per unit charge.

(b) Many candidates were awarded full credit. In answering this type of question, it is important for candidates to be aware that they need to draw conclusions from the graph, not just describe the graph. This question asked for properties of the spheres that could be deduced from the graph, and the mark scheme provided various ways of achieving credit for discussing the radius of the spheres and the sign and magnitude of the charges on them.

(c) Candidates were expected to deduce that the proton will remain at rest at the point of release, and the mark scheme allowed various ways of achieving credit for explaining why this is the case, either in terms of the resultant force being zero, or in terms of the resultant field strength being zero, or in terms of the fact that the proton is already at the position where its potential energy is a minimum. Many candidates found this a difficult question, with many of them thinking that the proton accelerates towards one or other of the spheres.

5(a)	force per unit charge	**B1**
	force on positive charge	**B1**
5(b)(i)	four straight vertical parallel lines, approximately evenly spaced	**B1**
	arrows downwards	**B1**
5(b)(ii)	$E = V / d$	**C1**
	$E = 430 / 0.067$ $= 6.4 \times 10^3$ N C^{-1}	**A1**
5(b)(iii)	smooth curve within plates and straight lines outside plates	**B1**
	direction of deflection shown as upwards	**B1**
5(c)(i)	into the page	**B1**
5(c)(ii)	forces are in opposite directions	**B1**
	(undeviated) when (magnitudes of) forces are equal	**B1**
5(c)(iii)	$Eq = Bqv$	**C1**
	$B = E / v = (6.4 \times 10^3) / (2.6 \times 10^7)$ $= 2.5 \times 10^{-4}$ T	**A1**

Question 5

(a) Definitions were often incomplete because of the omission of the ratio of force to (positive) charge, indicated by words such as ‘per unit charge’.

(b) (i) Carefully drawn sketches of the electric field lines using a ruler made it more likely that they were evenly spaced and started and finished on the plates, as was required. In most cases the field direction was given correctly.

(ii) Where the correct starting equation was stated, most candidates were able to go on to calculate the electric field strength. A common incorrect starting point was to use the equation for the field around a point charge.

(iii) Most candidates correctly sketched a path deviating in the correct direction. Common errors seen included an electron path that remained undeviated for too long within the plates, a curved path once the electron was beyond the plates, and the electron hitting a plate. The last error could have been avoided with a more careful reading of the question.

(c) (i) Stronger candidates were able to identify both the correct plane and correct direction of the magnetic field for an electron. Although not required or assessed, Fleming’s left-hand rule was sometimes quoted indicating its use to answer the question. Weaker candidates had the magnetic field direction opposite to that of the electric field. This error was then generally repeated in **(ii)**.

(ii) Most candidates were able to explain the equality and opposite direction of the two forces. Weaker candidates equated opposite fields rather than forces.

(iii) Where the starting equation was correctly shown, candidates were usually able to progress to a correct final answer for full credit. Many candidates tried to apply the equation for the force on a current in a wire. Whilst it is then possible to derive the correct equation from that starting point, it was rarely done successfully.

Question	Answer	Marks
5(a)	*any 2 points from*: • (angular) displacement • velocity • momentum • (centripetal) acceleration • (resultant) force	**B2**
5(b)(i)	$Bqv = mv^2 / r$	**M1**
	$v = 2\pi r / T$	**M1**
	completion of algebra leading to $B = 2\pi m / qT$	**A1**
5(b)(ii)	$B = (2\pi \times 4 \times 1.66 \times 10^{-27}) / (2 \times 1.60 \times 10^{-19} \times 2.5 \times 10^{-6})$	**C1**
	$= 0.052$ T	**A1**
5(b)(iii)	**either** the same because T is independent of r **or** the same because B, q and m are unchanged **or** the same because both radius and speed have doubled	**B1**
5(b)(iv)	$qE = Bqv$	**C1**
	$E = Bv = 0.052 \times 1.1 \times 10^6$ $= 5.7 \times 10^4$ N C^{-1}	**A1**

NOT FOUND:

9702_m24_qp_42 EXAMINER REPORT (Qu 5)

4(a)(i)	amplitude $= \frac{1}{2} \times 7.2 \times 10^{-15}$ $= 3.6 \times 10^{-15}$ m	A1

4(a)(ii)	$\omega = 2\pi / (0.20 \times 10^{-6})$ $= 3.1 \times 10^{7}$ rad s^{-1}	A1

4(a)(iii)	$v_0 = \omega x_0$	C1
	$v_0 = 3.1 \times 10^{7} \times 3.6 \times 10^{-15} = 1.1 \times 10^{-7}$ m s^{-1}	A1

4(b)(i)	$I_0 = nAv_0e$ $= 8.5 \times 10^{28} \times 4.3 \times 10^{-4} \times 1.1 \times 10^{-7} \times 1.60 \times 10^{-19}$	C1
	$= 0.64$ A	A1

4(b)(ii)	sketch: two cycles of sinusoidal curve of amplitude I_0 and period 0.20 μs	B1
	correct phase, with $I = +I_0$ at $t = 0$	B1

4(b)(iii)	equation of form $I = I_0 \cos \omega t$	M1
	value of I_0 used matches answer to **(b)(i)** and value of ω used matches answer to **(a)(ii)** [if **(a)(ii)** and **(b)(i)** correct then $I = 0.64 \cos (3.1 \times 10^{7}\ t)$]	A1

4(b)(iv)	$I_{\text{r.m.s.}} = I_0 / \sqrt{2}$ $= 0.64 / \sqrt{2}$ $= 0.45$ A	**A1**

Question 4

(a) (i) This question was generally well answered. Among candidates that did not give the correct answer, the most common mistakes were misreading the scale, omission of the 10^{-15} factor, or forgetting to halve the peak–trough height.

(ii) There was some confusion among weaker candidates between frequency and angular frequency, but otherwise this question was well answered.

(iii) Most candidates knew or were able to deduce the correct relationship between maximum speed and amplitude for simple harmonic motion.

(b) (i) Most candidates realised that a substitution into $I = nAvq$ was required. The common mistake among the more able candidates was a power-of-ten error in the unit conversion for the area. Some of the weaker candidates attempted to square the area, and a small number did not know that the value of q required was the elementary charge.

(ii) Most candidates realised that a sinusoidal curve was required with an amplitude I_0 and a period of 0.20 μs. Many candidates found it difficult to draw the curve with the correct curvature in the different parts of the graph. The stronger candidates were generally able to deduce that the current has the largest magnitude when the electrons are moving with the fastest speed and therefore draw a curve with the correct phase.

(iii) Many candidates found this question difficult. Partial credit was awarded to candidates who substituted their values from **(a)(ii)** and **(b)(i)** into $I = I_0 \sin \omega t$ but, as with **(b)(ii)**, it was generally only the stronger candidates that realised it was a cosine rather than sine equation that was required here.

(iv) This question was generally well answered.

5(a)	(electric) force is (directly) proportional to product of charges	**B1**
	(electric) force (between point charges) is inversely proportional to the square of their separation	**B1**

5(b)	$F = Q^2 / 4\pi\varepsilon_0 x^2$ $6.3 \times 10^{-17} = Q^2 / [4\pi \times 8.85 \times 10^{-12} \times (3.8 \times 10^{-6})^2]$	**C1**
	charge = 3.2×10^{-19} C	**A1**

5(c)(i)	negative	**B1**

5(c)(ii)	four straight lines perpendicular to the plates, starting on one plate and finishing on the other	**B1**
	lines equally spaced	**B1**
	arrows indicating direction downwards	**B1**

5(c)(iii)	$E = V / d$	**C1**
	$mg = EQ$	**C1**
	mass = $(1200 \times 3.2 \times 10^{-19}) / (9.81 \times 0.052)$ = 7.5×10^{-16} kg	**A1**

Question 5

(a) This question was well answered, with most candidates able to give a correct statement of Coulomb's law.

(b) Many candidates made a correct substitution into the equation, but some candidates then had difficulty with the subsequent arithmetic (often forgetting to take the square root of Q^2). A common mistake among weaker candidates was either to confuse the equation for force with the equation for field strength, thereby starting with Q rather than Q^2, or to think that the two charges should be added (giving $2Q$) rather than multiplied.

(c) (i) Most candidates realised that, for the droplet to be held in equilibrium, the electric force must be upwards leading correctly to a conclusion that the droplet must be negatively charged. A small number of candidates did not seem to understand the situation and concluded that, despite having calculated a charge in **(b)**, the droplet is uncharged (and so the sign is neutral).

(ii) This question was generally well answered. In most instances where full credit was not awarded, this was due to carelessness with drawing the diagram rather than the candidate not knowing what the pattern should be.

(iii) Most candidates realised that the electric field strength between the plates can be calculated from the potential gradient. The more able candidates realised that the electric force needed to be equated with the weight of the oil droplet, and many then went on to calculate the correct mass.

5(a)	work done per unit charge	**B1**
	work (done on charge) moving positive charge from infinity (to the point)	**B1**

5(b)	*Any three points from*: *Up to 2 points from*: • radius of sphere X is 2.0 m • radius of sphere Y is 4.0 m • radius of Y is double the radius of X *Up to 2 points from*: • charge on X is negative • charge on Y is positive • spheres carry opposite charges *Up to 1 point from*: • magnitudes of charges on the spheres are equal	**B3**

5(c)	particle is attracted to X or repelled from Y **or** resultant force on particle is towards X / away from Y / to the left	**B1**
	particle accelerates towards X / away from Y / to the left	**B1**
	(magnitude of) acceleration of particle increases	**B1**

NOT FOUND:

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1(a)(i)	force per unit mass	**B1**

1(a)(ii)	force per unit positive charge	**B1**

1(a)(iii)	similarity: • inversely proportional to distance (from point) • points of equal potential lie on concentric spheres • zero at infinite distance *Any point, 1 mark*	**B1**
	difference: • gravitational potential is (always) negative • electric potential can be positive or negative *Any point, 1 mark*	**B1**

1(b)(i)	$g = GM / r^2$	**M1**
	$E = Q / 4\pi\varepsilon_0 r^2$	**M1**
	algebra showing the elimination of r leading to $M / Q = (1 / 4\pi G\varepsilon_0)\ (g / E)$	**A1**

1(b)(ii)	$\alpha = 1 / (4\pi \times 6.67 \times 10^{-11} \times 8.85 \times 10^{-12}) = 1.35 \times 10^{20}$ (kg^2 C^{-2}) **or** $\alpha = (8.99 \times 10^9) / (6.67 \times 10^{-11}) = 1.35 \times 10^{20}$ (kg^2 C^{-2})	**A1**

1(c)(i)	$E = \alpha gQ / M$ $= (1.35 \times 10^{20} \times 9.81 \times 4.80 \times 10^5) / (5.98 \times 10^{24})$	**C1**
	$= 106$ N C^{-1} **or** 106 V m^{-1}	**A1**

1(c)(ii)	same (direction)	**B1**

Question 1

(a) (i) Only a minority of candidates knew the syllabus 'bookwork' that defines gravitational field as force per unit mass. Many candidates did not give the definition of a quantity but instead answered a different question, asking what is meant by the concept of a gravitational field. As this was such a common misunderstanding of the question, the Examiners did award credit on this occasion for responses that answered the latter question. However, teachers should be aware that candidates are expected to know the syllabus definition that gravitational field is a vector quantity, given by the force per unit mass on an object.

(ii) The comments for **(a)(i)** are also relevant here for the definition of electric field. Candidates are expected to know the syllabus definition that electric field is force per unit positive charge.

(iii) There were many correct similarities and differences stated here. Some candidates gave responses that were correct for forces or fields rather than potentials, such as "both are inversely proportional to distance squared" or "one is attractive and the other is repulsive".

(b) (i) This proof proved to be challenging for many candidates. A significant number of candidates started with the definition of electric field strength as F / Q which is correct, but they needed to extend it to the field due to a point charge. Some candidates were attempted to equate the two field strengths, when they have different dimensions so cannot be equated.

(ii) Candidates who did not reach the required expression in **(b)(i)** were unable to show the numerical value for α here. They did not know the combination of constants that was represented by α. It should be noted that full substitution is required in 'show that' calculations, including all constants. Here it was necessary to see the numerical values for ε_0 and G being used to determine the value of α.

(c) (i) Many candidates used the expression stated in **(b)(i)** to calculate the electric field strength at the surface of the Earth. However, some then gave their answer to two significant figures when the data were given to three significant figures. The requirement for a unit also proved challenging to many candidates. Weaker candidates often tried to answer this by starting once again from first principles, only to find that they did not have enough information to do this.

(ii) There were many correct answers here comparing the directions of the two fields. Some candidates did not realise the significance of the information at the start of **(c)** that the charge carried by the Earth is negative. Some gave the general case and said the direction of the electric field could be towards or away from the surface of the Earth. Some candidates said the directions were opposite, presumably assuming that the charge of the Earth was positive.

4(a)	(electric) force is (directly) proportional to product of charges	**B1**
	force (between point charges) is inversely proportional to the square of their separation	**B1**

4(b)(i)	arrows showing tension upwards in direction of string, electric force horizontally to the right and weight vertically downwards and all three labelled	**B1**

4(b)(ii)	$F_E = \dfrac{96 \times 10^{-9} \times 64 \times 10^{-9}}{4 \times \pi \times 8.85 \times 10^{-12} \times 0.080^2}$ $(= 8.63 \times 10^{-3}\text{ N})$	**C1**
	either angle to vertical $= \sin^{-1} 0.080 / 1.2$ $(= 3.82°)$	**C1**
	weight $= F_E / \tan 3.82 = 8.63 \times 10^{-3} / \tan 3.82$ $(= 0.129\text{ N})$	**C1**
	mass $= 0.129 / 9.81$ $= 0.013\text{ kg}$	**A1**
	or $T \sin \theta = mg$ **and** $T \cos \theta = F_E$ **or** $\tan \theta = mg / F_E$	**(C1)**
	$\tan \theta = 1.2 / 0.080$	**(C1)**
	$m = (1.2 \times 8.63 \times 10^{-3}) / (0.080 \times 9.81)$ $= 0.013\text{ kg}$	**(A1)**

4(b)(iii)	$E_p = \dfrac{Q_1Q_2}{4\pi\varepsilon_o r} = \dfrac{96 \times 10^{-9} \times 64 \times 10^{-9}}{4 \times \pi \times 8.85 \times 10^{-12} \times 0.080}$ $= 6.9 \times 10^{-4}$ J	**A1**

4(c)(i)	towards the top of the page / towards plate P	**B1**

4(c)(ii)	$F = QE$ **and** $E = V / d$	**C1**
	$F = 1.6 \times 10^{-19} \times 250 / 0.018$ $= 2.2 \times 10^{-15}$ N	**A1**

4(c)(iii)	**either** the force is not (always) perpendicular to the velocity **or** the force is always in the same direction	**B1**

Question 4

(a) The majority of candidates were able to correctly state Coulomb's law. A small proportion omitted the squaring of the separation or used indirectly in place of inversely in the relationship. Indirectly covers a range of relationships, but only inverse square is correct here.

(b) (i) Candidates struggled with this force diagram. Some did not include all the forces, some added quantities that were not forces. Finally, the direction of the correct forces was sometimes incorrect – the electrostatic repulsion was drawn perpendicular to the string and the weight was drawn parallel to the string.

(ii) This multistage calculation proved to be challenging to most candidates. Many candidates were able to determine the magnitude of the electrostatic force. However, only the strongest candidates were able to resolve forces and apply the equilibrium conditions.

(iii) This calculation of potential energy was correctly carried out by most candidates. Some incorrectly squared the separation, and a few halved the separation.

(c) (i) The direction of the force was correctly stated by many candidates but there was a range of incorrect responses including downwards, to the right and to the left.

(ii) The stronger candidates were able to combine the two necessary formulae. However, a significant number used the incorrect expression $F = V / d$.

(iii) Many candidates appear to think that magnetic fields are the only type of field that can give rise to circular motion. Some candidates stated that there is no centripetal force, but only the stronger candidates were able to articulate the reason why there was no circular motion.

5(a)	work done per unit charge	**B1**
	work done (on charge) in moving positive charge from infinity (to the point)	**B1**

5(b)(i)	radius = 0.060 m	**A1**

5(b)(ii)	$V = Q / 4\pi\varepsilon_0 x$ $Q = (–)\ 850 \times 4\pi \times 8.85 \times 10^{–12} \times 0.060$ **or** $Q = (–)\ 850 \times 0.060 / 8.99 \times 10^{9}$ (*any correct pair of V and x values from curve*)	**C1**
	$Q = –5.7 \times 10^{–9}$ C	**A1**

5(c)(i)	$E_P = Q^2 / 4\pi\varepsilon_0 x$ $= (5.67 \times 10^{–9})^2 / (4\pi \times 8.85 \times 10^{–12} \times 0.46)$	**C1**
	$= 6.3 \times 10^{–7}$ J	**A1**

5(c)(ii)	• force is repulsive so spheres move apart • force in direction of motion so speed increases • potential energy converted to kinetic energy so speed increases • force decreases with distance so acceleration decreases • momentum is conserved (at zero) (and masses are equal) so velocities are always equal and opposite *Any three points, 1 mark each*	**B3**

Question 5

(a) Most candidates could be awarded at least partial credit for this definition.

(b) (i) Whilst there were many candidates who found this question difficult, most realised that they had to read off the value of *x* at the point where the horizontal straight line ends and the curve begins.

(ii) Most candidates were able to correctly read off a set of values for *V* and *x* from the curve and then to substitute these values into the equation for the potential due to a point charge. Comparatively few candidates appreciated that the negative nature of the potential curve meant that the sign of the charge on the sphere must be negative. A common mistake in substituting for the permittivity of free space is to use the data given on the data page for $1/4\pi\varepsilon_0$ but to incorrectly substitute it as the value of $4\pi\varepsilon_0$.

(c) (i) Most candidates realised that they had to use the equation for the potential energy between two point charges from the formula page, but many experienced problems with using it. Common errors were to double, rather than to square, the charge, to use the charge on an electron rather than the charge on the spheres, and to use the radius of the spheres rather than the distance between them. A small number of candidates who did reach the correct numerical answer gave the potential energy as negative, not appreciating that the energy stored between two negative charges must be positive.

(ii) Most candidates found it difficult to give a complete answer to this question. Candidates were expected to draw upon their knowledge of the AS Level part of the syllabus and to realise that, when describing motion, the concepts of displacement, velocity and acceleration need to be considered, and that the concepts of force or energy need to be used to explain them. The mark scheme was structured in such a way as to enable various ways of accessing the credit, but very few candidates attempted to go beyond the fact that the spheres move apart because the force between them is repulsive. Some candidates did not appreciate that ‘opposite directions’ is not enough to convey the idea of the spheres moving apart because it could equally well mean towards each other.

4(a)	(field line indicates) direction of force	**B1**
	force on a positive charge	**B1**

4(b)(i)	one straight line perpendicular to plates, starting on one plate and finishing on the other	**B1**
	five straight lines perpendicular to plates between the plates, uniformly spaced	**B1**
	downwards arrows on lines	**B1**

4(b)(ii)	$E = V / d$	**C1**
	$= 2400 / 0.046$ $= 5.2 \times 10^4$ N C^{-1}	**A1**

4(c)(i)	smooth curve in region of field and straight line outside field	**B1**
	direction of deflection shown as downwards in region of field	**B1**

4(c)(ii)	helium nucleus has double the charge but four times the mass	**B1**
	velocity parallel to plates same and acceleration perpendicular to plates smaller (for helium)	**B1**
	final speed is lower (for helium)	**B1**

Question 4

(a) Many candidates stated that electric field lines go from positive to negative rather than what the field lines indicate.

(b) (i) The field pattern was drawn well by most candidates. A few candidates had the arrow pointing in the opposite direction and a few drew lines that did not reach the metal plates.

(ii) There were many correct answers here. Weaker candidates sometimes used the formula of the field strength around a point charge, which is incorrect physics in this situation.

(c) (i) Candidates found drawing the path of the proton challenging. Most candidates gained credit for the correct direction of deflection. However, many did not have the proton beginning to deflect near to the point where the region of the electric field began and many did not draw the path as a straight line after leaving the region of the electric field.

(ii) This explanation was challenging. A significant number of candidates correctly stated that the final speed of the helium nucleus is less than the final speed of the proton. However, it was not clear that the candidates realised that the speed was the combination of the constant horizontal velocity and the increasing velocity perpendicular to the plates. Some candidates realised that the charge-to-mass ratio was important in this question but very few candidates separated the velocities into their vertical and horizontal components. A number of candidates thought the helium nucleus was not charged so would not be affected by the electric field at all.