Question			Answer	Marks	Guidance
1	(a)		A region in which a charged particle experiences a force / acceleration	B1	**Allow**: Where a charge experiences a force **Allow**: Force per (unit positive) charge **Note**: Must have reference to charge and force/acceleration for the mark
	(b)		Difference: Any one from • gravitational field / force is attractive (AW) • electric field / force can be either attractive or repulsive (AW)	B1	**Allow**: Gravitational force is in the direction of the field / towards the mass **Note**: For the second bullet point, must have reference to both attractive and repulsive or 'towards charge' and 'away from charge'
			Similarity: Any one from: • Force / field (strength) inversely proportional to distance squared • Radial fields	B1	**Allow**: (Both) obey the inverse-square law (with distance) or (Both) have $F \propto 1/r^2$ or $g \propto 1/r^2$ and $E \propto 1/r^2$ **Allow**: 'radius or separation' for 'distance'
	(c)		Any three from: • The electron is repelled by **B** / attracted by **A** / experience a force to the left • (Initially the) electron decelerates / slows down • It does not reach plate **B** / It reverses direction • When it returns to **A** it has 4 eV (of KE) • It stops 2/3 of the distance across the plates (AW)	B1 × 3	
	(d)	(i)	$E = 60 \times 10^3 \div 0.25$ / $E = 2.4 \times 10^5$ (V m^{-1}) $F = 2.4 \times 10^5 \times 1.5 \times 10^{-13}$ force = 3.6×10^{-8} (N)	C1 A1	**Allow**: $F = [1.5 \times 10^{-13} \times 60 \times 10^3]/0.25$ for the first C1 mark **Allow**: 1 mark for 7.2×10^{-8} (N); d = 12.5 cm used

Question			Answer	Marks	Guidance
		(ii)	t = 1.8/1.2 (= 1.5 s) **or** $a = \frac{3.6\times10^{-8}}{8.0\times10^{-7}}$ (= 4.5 × 10^{-2} m s^{-2}) ($s = ut + \frac{1}{2}at^2$ and u = 0)	C1	Possible ecf from **(d)(i)**
			$s = \frac{1}{2}\times4.5\times10^{-2}\times1.5^2$	C1	**Note**: No ecf within calculation if $t \neq$ 1.8/1.2
			displacement = 5.1 × 10^{-2} (m)	A1	**Note**: Answer to 3 sf is 5.06 × 10^{-2} (m)
			Total	**11**	

Question			Answers	Marks	Guidance
2	(a)		Correct direction of the electric field. A minimum of 5 field lines shown. Correct shape of field lines.	B1 B1	 Expect a minimum of 3 field lines to be normal (by eye) to the plate - ignore the angles made by the field lines at the sphere. Also there must not be any field lines within the sphere.
	(b)	(i)	($E \propto Q/r^2$ and the magnitude of E is the same due to each charge **A** and **B** at **X**. Therefore) **B** has a greater charge because **X** is further away from **B**.	B1	
		(ii)	Curve showing $E = 0$ at position of **X**. Curve showing E is positive between **A** and **X** and negative between **X** and **B** (or vice versa). The magnitude of E is small close to **A** and large close to **B**.	B1 M1 A1	**Allow** any graph, including a straight line. Tolerance for $E = 0$: $\pm$ ½ large square about **X.** **Note**: The curve must be continuous and pass through position of **X**. Ignore any curve to the right of **B** and to the left of **A**. **Note**: This mark can only be scored if the previous M1 has been awarded.
	(c)		Both E and g vary with 1/distance^2. (Hence the ratio is independent of the distance.)	B1	**Allow**: $E = \frac{Q}{4\pi\varepsilon_0 r^2}$ and $g = \frac{GM}{r^2}$ **or** $E \propto \frac{1}{r^2}$ and $g \propto \frac{1}{r^2}$ **Allow** 'both are inverse square laws'.
			Total	**7**	

Question			Answer	Marks	Guidance
3	(a)		number = $\frac{2.8\times10^{-9}}{1.6\times10^{-19}}$ number = 1.75×10^{10} or 1.8×10^{10}	B1	Ignore a negative sign
	(b)		$F = \frac{Qq}{4\pi\varepsilon_0 r^2}$ $F = \frac{2.8\times10^{-9}\times2.8\times10^{-9}}{4\pi\times8.85\times10^{-12}\times(2.0\times10^{-2})^2}$ force = 1.76×10^{-4} (N) or 1.8×10^{-4} (N)	C1 A1	**Note**: No credit for using charge equal to *e*
	(c)	(i)	Tension and weight	B1	**Allow**: force provided by the string / force in the string instead of tension **Not**: 'gravity' for weight **Allow**: force due to gravity **Allow**: gravitational (force)
		(ii)	(weight =) $6.5 \times 10^{-5} \times g$ $\tan\theta = 1.76 \times 10^{-4}/6.38 \times 10^{-4}$ $\theta = 15°$ Or Scale drawing of triangle of force θ in the range 13° to 18° θ in the range 14° to 16°	C1 C1 A1 C1 A1 A1	Deduct 1 mark for the use of 10 (m s^{-2}) followed by ecf **Note** that getting to this stage scores both C1 marks Possible ecf from **(b)** **Note**: No marks if mass is used instead of the weight
			Total	**7**	

Question			Expected Answers	Marks	Additional guidance
4	(a)		(Electric field strength is the) force per (unit positive) charge	B1	**Allow:** $E = F/Q$, *F* is the force on a (positive) charge *Q*
	(b)		Parallel and equally spaced lines at right angles to plates Correct upward direction of field shown on at least one field line	B1 B1	
	(c)	(i)	An arrow vertically downwards at **P**	B1	
		(ii)	$E = \frac{3400}{0.050}$ or $E = 6.8 \times 10^4$ (V m^{-1}) $a = \frac{EQ}{m}$ $a = \frac{6.8\times10^{4}\times1.6\times10^{-19}}{9.11\times10^{-31}}$ or $a = \frac{1.09\times10^{-14}}{9.11\times10^{-31}}$ acceleration = 1.19×10^{16} (m s^{-2}) or 1.2×10^{16} (m s^{-2})	C1 C1 A0	**Vital:** Candidates using separation of 0.050 cm must be awarded full credit for the analysis shown below $E = \frac{3400}{0.050\times10^{-2}}$ or $E = 6.8 \times 10^6$ (V m^{-1}) C1 $a = \frac{EQ}{m}$ $a = \frac{6.8\times10^{6}\times1.6\times10^{-19}}{9.11\times10^{-31}}$ C1 acceleration = 1.19×10^{18} (m s^{-2}) A0
		(iii)	$t = \frac{0.04}{4.0\times10^{7}}$ time = 1.0×10^{-9} (s)	B1	**Allow:** 1×10^{-9} (s) or 10^{-9} (s)
		(iv)	initial vertical velocity = 0, final vertical velocity = *at* vertical velocity = $1.2 \times 10^{16} \times 1.0 \times 10^{-9}$ (**Allow:** $1 \times 10^{16} \times 1.0 \times 10^{-9}$) vertical velocity = 1.2×10^7 (m s^{-1})	 M1 A0	**Vital:** Candidates using separation of 0.050 cm must be awarded full credit for the analysis shown below vertical velocity = $1.2 \times 10^{18} \times 1.0 \times 10^{-9}$ M1 vertical velocity = 1.2×10^9 (m s^{-1}) A0

Question			Expected Answers	Marks	Additional guidance
		(v)	$v^2 = (4.0\times10^7)^2 + (1.2\times10^7)^2$ velocity = 4.2×10^7 (m s^{-1}) Or $v^2 = (4.0\times10^7)^2 + (1\times10^7)^2$ velocity = 4.1×10^7 (m s^{-1})	C1 A1 C1 A1	Possible ecf from **(iv)**
		(vi)	KE = ½ mv^2 KE = $0.5 \times 9.11 \times 10^{-31} \times (4.2 \times 10^7)^2$ kinetic energy = 8.04×10^{-16} (J) or 8.0×10^{-16} (J)	C1 A1	Possible ecf from **(v)** **Allow:** 1 sf answer if the answer comes out as 8.0×10^{-16} (J)
		(vii)	Graph starts at non-zero value for E_k Between 0 and 0.08 (m) the graph has increasing gradient Horizontal line after 0.080 (m)	B1 B1 B1	 **Note:** The E_k value for the horizontal line > E_k value at x = 0
			Total	**15**	

Question			Expected Answers	Marks	Additional guidance
5	(a)		$E = \frac{Q}{4\pi\varepsilon_0 r^2}$ $\frac{(-)4.0\times10^{-9}}{4\pi\varepsilon_0\times(1.75\times10^{-2})^2}$ and $\frac{5.0\times10^{-9}}{4\pi\varepsilon_0\times(1.75\times10^{-2})^2}$ $E_B = 1.17 \times 10^5$ (N C^{-1}) and $E_A = 1.47 \times 10^5$ (N C^{-1}) field strength = $(1.17 + 1.47) \times 10^5$ (N C^{-1}) field strength = 2.64×10^5 (N C^{-1}) or 2.6×10^5 (N C^{-1}) direction = to the left / towards B	C1 C1 A1 B1	Ignore signs **Allow:** 2 marks for $2.9(4) \times 10^4$ (N C^{-1}) when the fields are subtracted **Allow:** 2 marks for 6.6×10^4 (N C^{-1}) for using 3.5×10^{-2} m
	(b)		$F = \frac{Qq}{4\pi\varepsilon_0 r^2}$ force = $\frac{4.0\times10^{-9}\times5.0\times10^{-9}}{4\pi\times8.85\times10^{-12}\times(3.5\times10^{-2})^2}$ force = 1.47×10^{-4} (N)	C1 C1 A0	Ignore signs **Allow:** ε_0 in the equation
	(c)		(weight =) $4.5 \times 10^{-5} \times 9.81$ or (weight =) $4.4(1) \times 10^{-4}$ (N) $\tan\theta = \frac{1.5\times10^{-4}}{4.41\times10^{-4}}$ angle = 18.8 (°) or 19 (°) (**Allow**: Full credit when angle is determined using a scale diagram)	C1 C1 A1	**Allow:** weight = $4.5 \times 10^{-5} \times g$ **Note:** Using force = 1.47×10^{-4} (N) gives an angle of 18.4°; hence allow 18° **Allow:** 2 marks for $\theta = 71°$; this is the complementary angle **Allow:** 1 mark for '$\tan\theta = \frac{1.5\times10^{-4}}{4.5\times10^{-5}}, \theta = 73^0$' when mass is used instead of weight.
			Total	**9**	