1)

a	i	force acts towards left **or** in opposite direction to field lines ✓ because ion (or electron) has negative charge (∴ experiences force in opposite direction to field) ✓	2	Mark sequentially. Essential to refer to negative charge (or force on + charge is to right) for 2nd mark.

a	ii	(use of $W = F s$ gives) force $F = \frac{4.0\times10^{-16}}{63\times10^{-3}}$ ✓ $= 6.3(5) \times 10^{-15}$ (N) ✓	2	If mass of ion m is used correctly **using algebra** with $F = ma$, allow both marks (since m will cancel). If numerical value for m is used, max 1.

a	iii	electric field strength $E\left(=\frac{F}{Q}\right)=\frac{6.35\times10^{-15}}{3\times1.6\times10^{-19}}$ = $1.3(2) \times 10^4$ ($N C^{-1}$) ✓ [or $\Delta V\left(=\frac{\Delta W}{Q}\right)=\frac{4.0\times10^{-16}}{3\times1.60\times10^{-19}}$ (833 V) $E\left(=\frac{\Delta V}{d}\right)=\frac{833}{63\times10^{-3}}$ = $1.3(2) \times 10^4$ ($V m^{-1}$) ✓]	1	Allow ECF from wrong F value in (a)(ii).

2)

2(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	
2(b)	V is inversely proportional to r [**or** $V \propto (-)1/r$] ✓ (V has negative values) because charge is negative [**or** because force is attractive on + charge placed near it **or** because electric potential is + for + charge and – for – charge] ✓ potential is defined to be zero at infinity ✓	Allow $V \times r$ = constant for 1st mark	max 2	
2(c)(i)	$Q(=4\pi\varepsilon_0 rV)=4\pi\varepsilon_0\times0.125\times2000$ (for example, using any pair of values from graph) ✓ = 28 (27.8) (± 1) (nC) ✓	**or** gradient = $Q/4\pi\varepsilon_0$ = 2000/8 ✓ (gives Q = 28 (27.8) ±1 (nC) ✓	2	
2(c)(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 × 10^{-9} × 750 = 4.5(0) × 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: $\Delta V=\frac{27.8\times10^{-9}}{4\pi\varepsilon_0}\times\left(\frac{1}{0.2}-\frac{1}{0.5}\right)$ (or similar substitution using 60 nC instead of 27.8 nC: use of 60 nC gives ΔV = 1620V)]	2	
2(c)(iii)	$E\left(=\frac{Q}{4\pi\varepsilon_0 r^2}\right)=\frac{27.8\times10^{-9}}{4\pi\varepsilon_0\times0.40^2}$ ✓ = 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 $E=\frac{625\pm50}{0.40}$ = 1600 (1560 ± 130) ($V m^{-1}$) ✓]	Use of Q = 30 nC gives 1690 ($V m^{-1}$). Allow ecf from Q value in (c)(i). If Q = 60 nC is used here, no marks to be awarded.	2	
Total			10	

3)

a	i	horizontal arrow to the left ✓	1
a	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
b	ii	acceleration of proton is (much) smaller (than acceleration of electron) ✓ because mass of proton is (much) greater (than mass of electron) ✓	2
b	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
c	ii	electric field strength $\left(=\frac{V}{d}\right)=\frac{4500}{180\times10^{-3}}$ $= 2.50 \times 10^4$ (V m^{-1}) ✓ distance = $\left(\frac{V}{E}\right)=\frac{1.91}{2.50\times10^4}\left[\text{or}=\left(\frac{W}{F}\right)=\frac{3.06\times10^{-19}}{4.0\times10^{-15}}\right]$ ✓ $= 7.64 \times 10^{-5}$ (m) ✓	3

4)

(a)	(i)	(vertically) downwards [**or** top to bottom, or down the page] ✓	**1**
(a)	(ii)	force on sphere F (= kx) = $0.24 \times 18 \times 10^{-3}$ ✓ (= 4.32×10^{-3} N)	**1**
(a)	(iii)	**use of** $F = EQ$ gives $E = \frac{4.32\times10^{-3}}{41\times10^{-9}}$ ✓ (= 1.05×10^5 V m^{-1}) **use of** $E = \frac{V}{d}$ gives separation $d = \frac{5.0\times10^{3}}{1.05\times10^{5}}$ ✓ = 4.8×10^{-2} (m) ✓ (4.76×10^{-2})	**3**
(b)	(i)	electric field becomes zero (or ceases to exist) ✓ flow of charge (or electrons) from one plate to the other [**or** plates discharge] ✓ (until) pd across plates becomes zero [**or** no pd across plates, **or** plates at same potential] ✓	**max 2**
(b)	(ii)	net downward force on sphere (when E becomes zero) [**or** gravitational force acts on sphere, **or** force is weight] ✓ this force extends spring ✓ force (or acceleration) is proportional to (change in) extension of spring ✓ acceleration is in opposite direction to displacement (or towards equilibrium) ✓ for shm, acceleration ∝ (–) displacement [**or** for shm, force ∝ (–) displacement] ✓	**max 3**
		Total	**10**

5)

a		force between two (point) charges is proportional to (product of) charges ✓ and inversely proportional to the square of their distance apart ✓	2	Formula not acceptable. Accept "charged particles" for charges. Accept separation for distance apart.
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) ✓	max 3	
b	ii	force $\left(=\frac{Q_1Q_2}{4\pi\varepsilon_0 r^2}\right)=\frac{4.0\times10^{-9}\times6.0\times10^{-9}}{4\pi\times8.85\times10^{-12}\times(68\times10^{-3})^2}$ ✓ $= 4.6(7)\times10^{-5}$ (N) ✓	2	Treat substitution errors such as 10^{-6} (instead of 10^{-9}) as AE with ECF available.
c	i	$E_4=\frac{4.0\times10^{-9}}{4\pi\varepsilon_0\times(34\times10^{-3})^2}$ (= 3.11×10^4 V m^{-1}) (to the right)✓ $E_6\left(=\frac{6.0\times10^{-9}}{4\pi\varepsilon_0\times(34\times10^{-3})^2}\right)$ = (4.67×10^4 V m^{-1}) (to the left) ✓ $E_{resultant}$ = (4.67 – 3.11) × 10^4 = 1.5(6) × 10^4 ✓ Unit: V m^{-1} (or N C^{-1}) ✓	4	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. If no substitution is shown, but evaluation is correct for E_4 and E_6, award one of 1st two marks. Use of $r = 68\times10^{-3}$ is a physics error with no ECF. Unit mark is independent.

6)

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 (=$4\pi\varepsilon_0 rV$) = $4\pi\times8.85\times10^{-12}\times0.30\times3.0$ ✓ = 1.0×10^{-10} (C) ✓ to **2 sf** only ✓	**3**
b	ii	use of $V\propto\frac{1}{r}$ gives $V_M=\frac{V_L}{3}$ ✓ (= (+) 1.0 V)	**1**
b	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**
c	ii	= 3.3(3) (V m^{-1}) ✓	**1**
c	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**
		Total	**12**

7)

(a)	(i)	$E\left(=\frac{V}{d}\right)=\frac{600}{80\times10^{-3}}$ ✓ $= 7.5 \times 10^3 (\text{V m}^{-1})$ ✓	2
(a)	(ii)	force F (= EQ) = $7500 \times 0.17 \times 10^{-6}$ ✓ (= 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 ✓ • W (or mg) vertically down **and** • tension T upwards along the thread ✓	2
(b)	(ii)	$F = T\sin\theta$ and $mg = T\cos\theta$ give $F = mg\tan\theta$ ✓ (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) ✓ gives θ = 15(.2)(°) ✓	3
		Total	**8**

8)

		The candidate's writing should be legible and the spelling, punctuation and grammar should be sufficiently accurate for the meaning to be clear. The candidate's answer will be assessed holistically. The answer will be assigned to one of three levels according to the following criteria. **High Level (Good to excellent): 5 or 6 marks** The information conveyed by the answer is clearly organised, logical and coherent, using appropriate specialist vocabulary correctly. The form and style of writing is appropriate to answer the question. *The candidate gives a comprehensive account of the similarities and differences between gravitational and electric fields, referring to both radial and uniform fields. There are clear statements showing good to excellent understanding of the forces between masses/charges, gravitational and electric field strengths, and gravitational and electric potentials and of how aspects of them differ for gravitational and electric effects.* **Intermediate Level (Modest to adequate): 3 or 4 marks** The information conveyed by the answer may be less well organised and not fully coherent. There is less use of specialist vocabulary, or specialist vocabulary may be used incorrectly. The form and style of writing is less appropriate.	max 6	A **High Level** answer must refer to at least **two valid** similarities and at least **two valid** differences, and must also contain information about **both** radial and uniform fields. An **Intermediate Level** answer must refer to at least **two valid** similarities and at least **one valid** difference, and must also consider **either** radial or uniform fields, or both.

		The candidate's comparisons are less complete but good understanding is shown of the factors affecting the respective forces and of the definitions of field strength and potential. There may be limited reference to radial and uniform fields. Similarities between gravitational and electric effects are better known than differences. **Low Level (Poor to limited): 1 or 2 marks** The information conveyed by the answer is poorly organised and may not be relevant or coherent. There is little correct use of specialist vocabulary. The form and style of writing may be only partly appropriate. *The candidate has a much weaker ability to convey the similarities and differences between gravitational and electric fields. There is likely to be little or no reference to radial and uniform fields. Factors affecting the respective forces are known, but understanding of field strength is likely to be weaker and understanding of potential may be poor or absent..* **The explanation expected in a competent answer should include a coherent selection of the following points.** ***Forces*** • In a radial field, both gravitational and electric involve an inverse square relationship. • In both cases the force is proportional to a product (masses/charges).		A **Low Level** answer must refer to at least **one valid** similarity but may not identify any **valid** differences. **(D)** = valid difference. Good candidates are likely to mention other valid differences e.g. electrostatic forces depend on the medium whereas gravitational forces don't, possibility of shielding an electric field but impossibility of shielding a gravitational field.
		• In both cases a spherical body may be considered to act as a point mass or charge placed at the centre of the sphere. • In a uniform field the force is constant at all points. • Gravitational forces are always an attraction whilst electric forces may be attraction or repulsion. **(D)** • Gravitational forces are usually much smaller than electric forces (unless very large masses are involved). **(D)** ***Field Strengths*** • Both are defined as a *force per unit* mass or charge. • In both cases the field strength in a radial field is proportional to $1/r^2$. • In both cases the field strength in a radial field is proportional to the magnitude of the mass or charge that produces it. • In a uniform field the field has the same magnitude and same direction at all points. • A gravitational field is always directed towards the mass producing it whereas an electric field is directed towards a negative charge but away from a positive charge. **(D)** • A mass of 1 kg is small in terms of the gravitational field it produces but a charge of 1 C would produce a very strong electric field. **(D)** ***Potentials*** • Definitions of both involve work done in moving a mass or charge from infinity to a point.		

		• Both definitions involve the work done *per unit* mass or charge. • Both types of potential are proportional to 1/r in a radial field. • Both types of potential are proportional to the mass or charge producing them. • In a uniform field the potential varies linearly with distance. • The work done in moving a mass or charge across a potential difference is calculated by multiplying the mass or charge by the potential difference. • Gravitational potential is always a negative quantity but electric potential is negative for negative charges and positive for positive charges. **(D)**		