Q1.

4 (a) field causes forces on the electrons M1
and the nucleus in opposite directions A1
(field causes) electrons (to be) stripped off the atom............ B1 [3]

(b) (i) $E = Q/4\pi\varepsilon_0 r^2$ C1
$20 \times 10^3 \times 10^2 = Q/(4\pi \times 8.85 \times 10^{-12} \times 0.21^2$............ C1
charge = 9.8×10^{-6} C .... A1 [3]

(ii) $V = Q/4\pi\varepsilon_0 r$
$= (9.8 \times 10^{-6})/(4\pi \times 8.85 \times 10^{-12} \times 0.21)$............ C1
$= 4.2 \times 10^5$ V............ A1 [2]

(c) e.g. sphere not smooth, humid air, etc .... B1 [1]

Q2.

1 (a) charge is quantised/enabled electron charge to be measured B1 [1]

(b) <u>all</u> are (approximately) $n \times (1.6 \times 10^{-19}$ C) M1
so $e = 1.6 \times 10^{-19}$ C (allow 2 sig. fig. only A1 [2]
summing charges and dividing ten, without explanation scores 1/2
Total [3]

Q3.

5 (a) field strength = potential gradient [- sign not required] **B1** **[1]**
[allow $E = \Delta V/\Delta x$ but not $E = V/d$]

(b) No field for $x < r$ **B1**
for $x > r$, curve in correct direction, not going to zero **B1**
discontinuity at $x = r$ (vertical line required) **B1** **[3]**

Q4.

5 (a) (i) force per unit positive charge (ratio idea essential)	B1	**[1]**
(ii) $E = Q / 4\pi\varepsilon_0 r^2$	M1	
ε_0 being the permittivity of free space	A1	**[2]**
(b) (i) $2.0 \times 10^6 = Q / (4\pi \times 8.85 \times 10^{-12} \times 0.35^2)$	C1	
$Q = 2.7 \times 10^{-5}$ C	A1	**[2]**
(ii) $V = (2.7 \times 10^{-5}) / (4\pi \times 8.85 \times 10^{-12} \times 0.35)$	C1	
$= 7.0 \times 10^5$ V	A1	**[2]**
(c) electrons are stripped off the atoms	B1	
electrons and positive ions move in opposite directions, (giving rise to a current)	B1	**[2]**

Q5.

3 (a) field strength = potential gradient	M1	
correct sign OR directions discussed	A1	[2]
(b) area is $21.2\ cm^2 \pm 0.4\ cm^2$	C2	
(if outside $\pm 0.4\ cm^2$ but within $\pm 0.8\ cm^2$, allow 1 mark)		
$1.0\ cm^2$ represents $(1.0 \times 10^{-2} \times 2.5 \times 10^3 =)$ 25 V	C1	
potential difference = 530 V	A1	[4]
(c) $\frac{1}{2}mv^2 = qV$		
$\frac{1}{2} \times 9.1 \times 10^{-31} \times v^2 = 1.6 \times 10^{-19} \times 530$	C1	
$v = 1.37 \times 10^7\ ms^{-1}$	A1	[2]
(d) (i) $d = 0$	B1	[1]
(ii) acceleration decreases then increases	B1	
some quantitative analysis (e.g. minimum at 4.0 cm)	B1	[2]
(any suggestion that acceleration becomes zero or that there is a deceleration scores 0/2)		

Q6.

4 (a) work done moving unit positive charge	M1	
from infinity to the point	A1	[2]
(b) (i) $x = 18$ cm	A1	[1]
(ii) $V_A + V_B = 0$	C1	
$(3.6 \times 10^{-9}) / (4\pi\varepsilon_0 \times 18 \times 10^{-2}) + q / (4\pi\varepsilon_0 \times 12 \times 10^{-2}) = 0$	C1	
$q = -2.4 \times 10^{-9}$ C	A1	[3]
(use of $V_A = V_B$ giving 2.4×10^{-9} C scores one mark)		
(c) field strength = (–) gradient of graph	B1	
force = charge × gradient / field strength *or force $\propto$ gradient*	B1	
force largest at $x = 27$ cm	B1	[3]

Q7.

4 (a)	ability to do work	B1	
	as a result of the position/shape, etc. of an object	B1	[2]
(b) (i) 1	$\Delta E_{gpe} = GMm / r$	C1	
	$= (6.67 \times 10^{-11} \times \{2 \times 1.66 \times 10^{-27}\}^2) / (3.8 \times 10^{-15})$	C1	
	$= 1.93 \times 10^{-49}$ J	A1	[3]
2	$\Delta E_{epe} = Qq / 4\pi\varepsilon_0 r$	C1	
	$= (1.6 \times 10^{-19})^2 / (4\pi \times 8.85 \times 10^{-12} \times 3.8 \times 10^{-15})$	C1	
	$= 6.06 \times 10^{-14}$ J	A1	[3]
(ii)	idea that $2E_K = \Delta E_{epe} - \Delta E_{gpe}$	B1	
	$E_K = 3.03 \times 10^{-14}$ J		
	$= (3.03 \times 10^{-14}) / 1.6 \times 10^{-13}$	M1	
	$= 0.19$ MeV	A0	[2]
(iii)	fusion may occur / may break into sub-nuclear particles	B1	[1]

Q8.

4 (a)	force $= q_1 q_2 / 4\pi\varepsilon_0 x^2$	C1	
	$= (6.4 \times 10^{-19})^2 / (4\pi \times 8.85 \times 10^{-12} \times \{12 \times 10^{-6}\}^2)$	C1	
	$= 2.56 \times 10^{-17}$ N	A1	[3]
(b)	potential at P is same as potential at Q	B1	
	work done $= q\Delta V$	M1	
	$\Delta V = 0$ so zero work done	A0	[2]
(c)	at midpoint, potential is $2 \times (6.4 \times 10^{-19}) / (4\pi\varepsilon_0 \times 6 \times 10^{-6})$	C1	
	at P, potential is $(6.4 \times 10^{-19}) / (4\pi\varepsilon_0 \times 3 \times 10^{-6}) + (6.4 \times 10^{-19}) / (4\pi\varepsilon_0 \times 9 \times 10^{-6})$	C1	
	change in potential $= (6.4 \times 10^{-19}) / (4\pi\varepsilon_0 \times 9 \times 10^{-6})$		
	energy $= 1.6 \times 10^{-19} \times (6.4 \times 10^{-19}) / (4\pi\varepsilon_0 \times 9 \times 10^{-6})$	C1	
	$= 1.0 \times 10^{-22}$ J	A1	[4]

Q9.

4 (a)	work done in bringing unit positive charge	M1	
	from infinity (to that point)	A1	[2]
(b) (i)	field strength is potential gradient	B1	[1]
(ii)	field strength proportional to force (on particle Q)	B1	
	potential gradient proportional to gradient of (potential energy) graph	B1	
	so force is proportional to the gradient of the graph	A0	[2]

(c) energy = $5.1 \times 1.6 \times 10^{-19}$ (J) C1
potential energy = $Q_1Q_2 / 4\pi\varepsilon_0 r$ C1
$5.1 \times 1.6 \times 10^{-19} = (1.6 \times 10^{-19})^2 / 4\pi \times 8.85 \times 10^{-12} \times r$ C1
$r = 2.8 \times 10^{-10}$ m A1 [4]

(d) (i) work is got out as x decreases M1
so opposite sign A1 [2]

(ii) energy would be doubled B1
gradient would be increased B1 [2]

Q10.

5 (a) force per unit positive charge acting on a stationary charge B1 [1]

(b) (i) $E = Q / 4\pi\varepsilon_0 r^2$ C1
$Q = 1.8 \times 10^4 \times 10^2 \times 4\pi \times 8.85 \times 10^{-12} \times (25 \times 10^{-2})^2$ M1
$Q = 1.25 \times 10^{-5}$ C = 12.5 μC A0 [2]

(ii) $V = Q / 4\pi\varepsilon_0 r$
$= (1.25 \times 10^{-5}) / (4\pi \times 8.85 \times 10^{-12} \times 25 \times 10^{-2})$ C1
$= 4.5 \times 10^5$ V A1 [2]
(Do not allow use of V = Er unless explained)

Q11.

4 (a) (i) as r decreases, energy decreases/work got out (due to) M1
attraction so point mass is negatively charged A1 [2]

(ii) electric potential energy = charge × electric potential B1
electric field strength is potential gradient B1
field strength = gradient of potential energy graph/charge A0 [2]

(b) tangent drawn at (4.0, 14.5) B1
gradient = 3.6×10^{-24} A2
(for < ±0.3 allow 2 marks, for < ±0.6 allow 1 mark)
field strength= $(3.6 \times 10^{-24}) / (1.6 \times 10^{-19})$
$= 2.3 \times 10^{-5}$ V m^{-1} *(allow ecf from gradient value)* A1 [4]
(one point solution for gradient leading to 2.3×10^{-5} Vm^{-1} scores 1 mark only)

Q12.

4	(a)	work done moving unit positive charge from infinity (to the point)	M1 A1	 [2]
	(b)	(gain in) kinetic energy = change in potential energy $\frac{1}{2}mv^2 = qV$ leading to $v = (2Vq/m)^{\frac{1}{2}}$	B1 B1	 [2]
	(c)	*either* $(2.5 \times 10^5)^2 = 2 \times V \times 9.58 \times 10^7$ $V = 330\,V$ this is less than 470V and so 'no'	C1 M1 A1	 [3]
		or $v = (2 \times 470 \times 9.58 \times 10^7)$ $v = 3.0 \times 10^5\,m\,s^{-1}$ this is greater than $2.5 \times 10^5\,m\,s^{-1}$ and so 'no'	(C1) (M1) (A1)	
		or $(2.5 \times 10^5)^2 = 2 \times 470 \times (q/m)$ $(q/m) = 6.6 \times 10^7\,C\,kg^{-1}$ this is less than $9.58 \times 10^7\,C\,kg^{-1}$ and so 'no'	(C1) (M1) (A1)	

Q13.

4	(a)	(i)	$V = q / 4\pi\varepsilon_0 R$	B1	[1]
		(ii)	(capacitance is) ratio of charge and potential or q/V $C = q/V = 4\pi\varepsilon_0 R$	M1 A0	 [1]
	(b)	(i)	$C = 4\pi \times 8.85 \times 10^{-12} \times 0.45$ $= 50$ pF	C1 A1	 [2]
		(ii)	either energy = $\frac{1}{2} CV^2$ or energy = $\frac{1}{2} QV$ and $Q = CV$ energy of spark = $\frac{1}{2} \times 50 \times 10^{-12} \{(9.0 \times 10^5)^2 - (3.6 \times 10^5)^2\}$ $= 17$ J	C1 C1 A1	 [3]

Q14.

2	(a)	(i)	grav. pot. energy = GM_1M_2/R energy $= \{6.67 \times 10^{-11} \times 197 \times 4 \times (1.66 \times 10^{-27})^2\}/9.6 \times 10^{-15}$ $= 1.51 \times 10^{-47}$ J	1 1 1	 **[3]**
		(ii)	elec. pot. energy = $Q_1Q_2/4\pi\varepsilon_0 R$ energy $= \{79 \times 2 \times (1.6 \times 10^{-19})^2\}/4\pi \times 8.85 \times 10^{-12} \times 9.6 \times 10^{-15}$ $= 3.79 \times 10^{-12}$ J	1 1 1	 **[3]**
			*(For the substitution, -1 each error or omission to max 2 in **(i)** and in **(ii)**)*		
	(b)		electric potential energy >> gravitational potential energy	1	**[1]**
	(c)		*either* 6 MeV = 9.6×10^{-13} J *or* 3.79×10^{-12} J = 24 MeV not enough energy to get close to the nucleus	1 1	 **[2]**

Q15.

4 (a) (i) *either* lines directed away from sphere
or lines go from positive to negative
or line shows direction of force on positive charge M1
so positively charged ....A1 [2]

(ii) *either* all lines (appear to) radiate from centre
or all lines are normal to surface of sphere ....B1 [1]

(b) tangent to curve B1
in correct position and direction ....B1 [2]

(c) (i) $V = (0.76 \times 10^{-9}) / (4\pi \times 8.85 \times 10^{-12} \times 0.024)$ C1
$= 285$ V ....A1 [2]

(ii) negative charge is induced on (inside of) box M1
formula applies to isolated (point) charge
OR less work done moving test charge from infinity A1
so potential is lower ....A1 [3]

(d) *either* gravitational field is <u>always</u> attractive
or field lines must be directed towards both box and sphere ....B1 [1]

Q16.

5 (a) work done per / on unit positive charge M1
moving charge from infinity to the point ....A1 [2]

(b) (i) α-particle and gold nucleus repel each other B1
<u>all</u> kinetic energy of α-particle converted into electric potential energy ....B1 [2]

(ii) **1** potential energy $= (79 \times 2 \times \{1.6 \times 10^{-19}\}^2) / (4\pi \times 8.85 \times 10^{-12} \times d)$ C1
kinetic energy $= 4.8 \times 1.6 \times 10^{-13} = 7.68 \times 10^{-13}$ J C1
equating to give $d = 4.7 \times 10^{-14}$ m ....A1 [3]

(ii) **2** $F = Qq / 4\pi\varepsilon_0 d \times 1 / d = 7.68 \times 10^{-13} \times 1 / (4.7 \times 10^{-14})$ C1
$= 16$ N ....A1 [2]

[Total: 9]

Q17.

4	(a)	(i)	zero field (strength) inside spheres	B1	[1]
		(ii)	*either* field strength is zero *or* the fields are in opposite directions at a point between the spheres	 M1 A1	 [2]
	(b)	(i)	field strength is (–) potential gradient *(not V/x)*	B1	[1]
		(ii)	**1.** field strength has maximum value at x = 11.4 cm	B1 B1	 [2]
			2. field strength is zero *either* at x = 7.9 cm *(allow ±0.3 cm)* *or* at 0 to 1.4 cm *or* 11.4 cm to 12 cm	B1 B1	 [2]

Q18.

3	(a)	(i)	(tangent to line gives) direction of force on a (small test) mass	B1	[1]
		(ii)	(tangent to line gives) direction of force on a (small test) charge charge is positive	M1 A1	 [2]
	(b)		similarity: e.g. radial fields lines normal to surface greater separation of lines with increased distance from sphere field strength $\propto$ 1 / (distance to centre of sphere)^2 (*allow any sensible answer*)	 B1	
			difference: e.g. gravitational force (always) towards sphere electric force direction depends on sign of charge on sphere / towards or away from sphere e.g. gravitational field/force is attractive electric field/force is attractive or repulsive (*allow any sensible comparison*)	 B1 B1 (B1) (B1)	 [3]
	(c)		gravitational force = $1.67 \times 10^{-27} \times 9.81$ = 1.6×10^{-26} N electric force = $1.6 \times 10^{-19} \times 270 / (1.8 \times 10^{-2})$ = 2.4×10^{-15} N electric force very much greater than gravitational force	 A1 C1 A1 B1	 [4]

Q19.

4	(a)	(i)	force proportional to product of (two) charges and inversely proportional to square of separation	M1	
			reference to point charges	A1	[2]
		(ii)	$F = 2 \times (1.6 \times 10^{-19})^2 / \{4\pi \times 8.85 \times 10^{-12} \times (20 \times 10^{-6})^2\}$	C1	
			$= 1.15 \times 10^{-18}$ N	A1	[2]
	(b)	(i)	force per unit charge	M1	
			on *either* a stationary charge *or* a positive charge	A1	[2]
		(ii)	1. electric field is a vector quantity electric fields are in opposite directions charges repel *Any two of the above, 1 each*	B2	[2]
			2. graph: line always between given lines	M1	
			crosses *x*-axis between 11.0 μm and 12.3 μm	A1	
			reasonable shape for curve	A1	[3]

Q20.

3	(a)		work done bringing unit positive charge	M1	
			from infinity (to the point)	A1	[2]
	(b)	(i)	*either* both potentials are positive/same sign	M1	
			so same sign	A1	[2]
			or gradients are positive & negative (so fields in opposite directions)	(M1)	
			so same sign	(A1)	
		(ii)	the individual potentials are summed	B1	[1]
		(iii)	allow value of *x* between 10 nm and 13 nm	A1	[1]
		(iv)	$V = 0.43$ V (*allow 0.42 V → 0.44 V*)	M1	
			energy $= 2 \times 1.6 \times 10^{-19} \times 0.43$	A1	
			$= 1.4 \times 10^{-19}$ J	A1	[3]

Q21.

5	(a)	graph: straight line at constant potential = V_0 from $x = 0$ to $x = r$	B1	
		curve with decreasing gradient	M1	
		passing through $(2r, 0.50V_0)$ and $(4r, 0.25V_0)$	A1	[3]
	(b)	graph: straight line at $E = 0$ from $x = 0$ to $x = r$	B1	
		curve with decreasing gradient from (r, E_0)	M1	
		passing through $(2r, ¼E_0)$ (*for 3rd mark line must be drawn to x = 4r and must not touch x-axis*)	A1	[3]

Q22.

4	(a)	(i)	$F_E = Q_1Q_2/4\pi\varepsilon_0 r^2$	C1	
			$= 8.99 \times 10^9 \times (1.6 \times 10^{-19})^2 / (2.0 \times 10^{-15})^2$		
			$= 58$ N	A1	[2]
		(ii)	$F_G = Gm_1m_2/r^2$	C1	
			$= 6.67 \times 10^{-11} \times (1.67 \times 10^{-27})^2 / (2.0 \times 10^{-15})^2$		
			$= 4.7 \times 10^{-35}$ N	A1	[2]
	(b)	(i)	force of repulsion (much) greater than force of attraction	B1	
			must be some other force of attraction	M1	
			to hold nucleus together	A1	[3]
			*(Do not allow if $F_G > F_E$ in **(a)** or one of the forces not calculated in **(a)**)*		
		(ii)	outside nucleus there is repulsion between protons	B1	
			either attractive force must act only in nucleus		
			or if not short range, all nuclei would stick together	B1	[2]

Q23.

5	(a)		work done in moving unit positive charge	M1	
			from infinity (to the point)	A1	[2]
	(b)	(i)	inside the sphere, the potential would be constant	B1	[1]
		(ii)	for point charge, Vx is constant	B1	
			co-ordinates clear and determines two values of Vx at least 4 cm apart	M1	
			conclusion made clear	A1	[3]
	(c)		$q = 4\pi\varepsilon_0 Vx$		
			$q = 4\pi \times 8.85 \times 10^{-12} \times 180 \times 1.0 \times 10^{-2}$	M1	
			$= 2.0 \times 10^{-10}$ C	A1	[2]

Q24.

5	**(a)** work done/energy in moving unit positive charge	M1	
	from infinity (to the point)	A1	[2]
	(b) **(i)** $V = q/4\pi\varepsilon_0 r$		
	at 16 kV, $q = 3.0 \times 10^{-8}$ C		
	$r = (3.0 \times 10^{-8})/(4\pi \times 8.85 \times 10^{-12} \times 16 \times 10^{3})$	C1	
	$= 1.69 \times 10^{-2}$ m (*allow 2 s.f.*)	A1	[2]
	(*allow any answer which rounds to* 1.7×10^{-2})		
	(ii) energy is/represented by area 'below' line	C1	
	energy $= \frac{1}{2}qV$		
	$= \frac{1}{2} \times 24 \times 10^{3} \times 4.5 \times 10^{-8}$	C1	
	$= 5.4 \times 10^{-4}$ J	A1	[3]
	(c) $V = q/4\pi\varepsilon_0 r$ and $E = q/4\pi\varepsilon_0 r^2$ giving $Er = V$	B1	
	$2.0 \times 10^{6} \times 1.7 \times 10^{-2} = V$	C1	
	$V = 3.4 \times 10^{4}$ V	A1	[3]