

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) $E = Q/4\pi\epsilon_0 r^2$ 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]

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- (ii) $V = Q/4\pi\epsilon_0 r$
 $= (9.8 \times 10^{-6})/(4\pi \times 8.85 \times 10^{-12} \times 0.21)$ 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) all 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) $E = Q / 4\pi\epsilon_0 r^2$ 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
 $Q = 2.7 \times 10^{-5} \text{ C}$ A1 [2]
- (ii) $V = (2.7 \times 10^{-5}) / (4\pi \times 8.85 \times 10^{-12} \times 0.35)$ C1
 $= 7.0 \times 10^5 \text{ V}$ 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 $21.2 \text{ cm}^2 \pm 0.4 \text{ cm}^2$ C2
(if outside $\pm 0.4 \text{ cm}^2$ but within $\pm 0.8 \text{ cm}^2$, 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) $\frac{1}{2}mv^2 = qV$ C1
 $\frac{1}{2} \times 9.1 \times 10^{-31} \times v^2 = 1.6 \times 10^{-19} \times 530$ A1 [2]
 $v = 1.37 \times 10^7 \text{ ms}^{-1}$
- (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) $x = 18 \text{ cm}$ A1 [1]
- (ii) $V_A + V_B = 0$ C1
 $(3.6 \times 10^{-9}) / (4\pi\epsilon_0 \times 18 \times 10^{-2}) + q / (4\pi\epsilon_0 \times 12 \times 10^{-2}) = 0$ C1
 $q = -2.4 \times 10^{-9} \text{ C}$ A1 [3]
(use of $V_A = V_B$ giving $2.4 \times 10^{-9} \text{ C}$ scores one mark)
- (c) field strength = (-) gradient of graph B1
 force = charge \times gradient / field strength or force \propto gradient B1
 force largest at $x = 27 \text{ cm}$ B1 [3]

Q7.

- 4 (a) ability to do work as a result of the position/shape, etc. of an object B1
B1 [2]
- (b) (i) 1 $\Delta E_{\text{gpe}} = GMm/r$ C1
 $= (6.67 \times 10^{-11} \times \{2 \times 1.66 \times 10^{-27}\}^2) / (3.8 \times 10^{-15})$ C1
 $= 1.93 \times 10^{-49} \text{ J}$ A1 [3]
- 2 $\Delta E_{\text{epe}} = Qq / 4\pi\epsilon_0 r$ C1
 $= (1.6 \times 10^{-19})^2 / (4\pi \times 8.85 \times 10^{-12} \times 3.8 \times 10^{-15})$ C1
 $= 6.06 \times 10^{-14} \text{ J}$ A1 [3]
- (ii) idea that $2E_K = \Delta E_{\text{epe}} - \Delta E_{\text{gpe}}$ B1
 $E_K = 3.03 \times 10^{-14} \text{ J}$
 $= (3.03 \times 10^{-14}) / 1.6 \times 10^{-13}$ M1
 $= 0.19 \text{ MeV}$ A0 [2]
- (iii) fusion may occur / may break into sub-nuclear particles B1 [1]

Q8.

- 4 (a) force = $q_1 q_2 / 4\pi\epsilon_0 x^2$ C1
 $= (6.4 \times 10^{-19})^2 / (4\pi \times 8.85 \times 10^{-12} \times \{12 \times 10^{-6}\}^2)$ C1
 $= 2.56 \times 10^{-17} \text{ N}$ 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 $2 \times (6.4 \times 10^{-19}) / (4\pi\epsilon_0 \times 6 \times 10^{-6})$ C1
 at P, potential is $(6.4 \times 10^{-19}) / (4\pi\epsilon_0 \times 3 \times 10^{-6}) + (6.4 \times 10^{-19}) / (4\pi\epsilon_0 \times 9 \times 10^{-6})$ C1
 change in potential = $(6.4 \times 10^{-19}) / (4\pi\epsilon_0 \times 9 \times 10^{-6})$
 energy = $1.6 \times 10^{-19} \times (6.4 \times 10^{-19}) / (4\pi\epsilon_0 \times 9 \times 10^{-6})$ C1
 $= 1.0 \times 10^{-22} \text{ J}$ A1 [4]

Q9.

- 4 (a) work done in bringing unit positive charge from infinity (to that point) M1
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 = $Q_1 Q_2 / 4\pi\epsilon_0 r$ 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) $E = Q / 4\pi\epsilon_0 r^2$ 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 μ C A0 [2]
- (ii) $V = Q / 4\pi\epsilon_0 r$ C1
 $= (1.25 \times 10^{-5}) / (4\pi \times 8.85 \times 10^{-12} \times 25 \times 10^{-2})$ A1 [2]
 $= 4.5 \times 10^5$ V
 (Do not allow use of $V = Er$ unless explained)

Q11.

- 4 (a) (i) as r decreases, energy decreases/work got out (due to attraction) so point mass is negatively charged M1
 A1 [2]
- (ii) electric potential energy = charge \times 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 B1
 $\frac{1}{2}mv^2 = qV$ leading to $v = (2Vq/m)^{1/2}$ B1 [2]
- (c) either $(2.5 \times 10^5)^2 = 2 \times V \times 9.58 \times 10^7$ C1
 $V = 330V$ M1
this is less than 470V and so 'no' A1 [3]
- or $v = (2 \times 470 \times 9.58 \times 10^7)$ (C1)
 $v = 3.0 \times 10^5 \text{ ms}^{-1}$ (M1)
this is greater than $2.5 \times 10^5 \text{ ms}^{-1}$ and so 'no' (A1)
- or $(2.5 \times 10^5)^2 = 2 \times 470 \times (q/m)$ (C1)
 $(q/m) = 6.6 \times 10^7 \text{ C kg}^{-1}$ (M1)
this is less than $9.58 \times 10^7 \text{ C kg}^{-1}$ and so 'no' (A1)

Q13.

- 4 (a) (i) $V = q / 4\pi\epsilon_0 R$ B1 [1]
- (ii) (capacitance is) ratio of charge and potential or q/V M1
 $C = q/V = 4\pi\epsilon_0 R$ A0 [1]
- (b) (i) $C = 4\pi \times 8.85 \times 10^{-12} \times 0.45$ C1
 $= 50 \text{ pF}$ A1 [2]
- (ii) either energy = $\frac{1}{2} CV^2$ or energy = $\frac{1}{2} QV$ and $Q = CV$ C1
energy of spark = $\frac{1}{2} \times 50 \times 10^{-12} \{(9.0 \times 10^5)^2 - (3.6 \times 10^5)^2\}$ C1
 $= 17 \text{ J}$ A1 [3]

Q14.

- 2 (a) (i) grav. pot. energy = GM_1M_2/R 1
energy = $\{6.67 \times 10^{-11} \times 197 \times 4 \times (1.66 \times 10^{-27})^2\} / 9.6 \times 10^{-15}$ 1
 $= 1.51 \times 10^{-47} \text{ J}$ 1 [3]
- (ii) elec. pot. energy = $Q_1Q_2/4\pi\epsilon_0 R$ 1
energy = $\{79 \times 2 \times (1.6 \times 10^{-19})^2\} / 4\pi \times 8.85 \times 10^{-12} \times 9.6 \times 10^{-15}$ 1
 $= 3.79 \times 10^{-12} \text{ J}$ 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 $6 \text{ MeV} = 9.6 \times 10^{-13} \text{ J}$ or $3.79 \times 10^{-12} \text{ J} = 24 \text{ MeV}$ 1
not enough energy to get close to the nucleus 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 chargeM1
 so positively chargedA1 [2]
- (ii) *either* all lines (appear to) radiate from centre
 or all lines are normal to surface of sphereB1 [1]
- (b) tangent to curveB1
 in correct position and directionB1 [2]
- (c) (i) $V = (0.76 \times 10^{-9}) / (4\pi \times 8.85 \times 10^{-12} \times 0.024)$ C1
 = 285 VA1 [2]
- (ii) negative charge is induced on (inside of) boxM1
 formula applies to isolated (point) charge
 OR less work done moving test charge from infinityA1
 so potential is lowerA1 [3]
- (d) *either* gravitational field is always attractive
 or field lines must be directed towards both box and sphereB1 [1]

Q16.

- 5 (a) work done per / on unit positive chargeM1
 moving charge from infinity to the pointA1 [2]
- (b) (i) α -particle and gold nucleus repel each otherB1
all kinetic energy of α -particle converted into electric potential energyB1 [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 = $4.8 \times 1.6 \times 10^{-13} = 7.68 \times 10^{-13}$ JC1
 equating to give $d = 4.7 \times 10^{-14}$ mA1 [3]
- (ii) 2 $F = Qq / 4\pi\epsilon_0 d \times 1 / d = 7.68 \times 10^{-13} \times 1 / (4.7 \times 10^{-14})$ C1
 = 16 NA1 [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 B1
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 [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 $\propto 1 / (\text{distance to centre of sphere})^2$
 (*allow any sensible answer*) B1
- difference:
 e.g. gravitational force (always) towards sphere B1
 electric force direction depends on sign of charge on sphere / towards or
 away from sphere B1
 e.g. gravitational field/force is attractive (B1)
 electric field/force is attractive or repulsive (B1)
 (*allow any sensible comparison*) [3]
- (c) gravitational force = $1.67 \times 10^{-27} \times 9.81$
 = 1.6×10^{-26} N A1
 electric force = $1.6 \times 10^{-19} \times 270 / (1.8 \times 10^{-2})$ C1
 = 2.4×10^{-15} N A1
 electric force very much greater than gravitational force B1 [4]

Q19.

- 4 (a) (i) force proportional to product of (two) charges and inversely proportional to square of separation
reference to point charges M1
A1 [2]
- (ii) $F = 2 \times (1.6 \times 10^{-19})^2 / \{4\pi \times 8.85 \times 10^{-12} \times (20 \times 10^{-6})^2\}$
 $= 1.15 \times 10^{-18} \text{ N}$ C1
A1 [2]
- (b) (i) force per unit charge
on *either* a stationary charge
or a positive charge M1
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
crosses x-axis between 11.0 μm and 12.3 μm
reasonable shape for curve M1
A1
A1 [3]

Q20.

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

Q21.

- 5 (a) graph: straight line at constant potential = V_0 from $x = 0$ to $x = r$
curve with decreasing gradient
passing through $(2r, 0.50V_0)$ and $(4r, 0.25V_0)$ B1
M1
A1 [3]
- (b) graph: straight line at $E = 0$ from $x = 0$ to $x = r$
curve with decreasing gradient from (r, E_0)
passing through $(2r, \frac{1}{4}E_0)$
(for 3rd mark line must be drawn to $x = 4r$ and must not touch x-axis) B1
M1
A1 [3]

Q22.

- 4 (a) (i) $F_E = Q_1Q_2/4\pi\epsilon_0r^2$ C1
 $= 8.99 \times 10^9 \times (1.6 \times 10^{-19})^2 / (2.0 \times 10^{-15})^2$
 $= 58 \text{ N}$ A1 [2]
- (ii) $F_G = Gm_1m_2/r^2$ C1
 $= 6.67 \times 10^{-11} \times (1.67 \times 10^{-27})^2 / (2.0 \times 10^{-15})^2$
 $= 4.7 \times 10^{-35} \text{ N}$ A1 [2]
- (b) (i) force of repulsion (much) greater than force of attraction
 must be some other force of attraction
 to hold nucleus together B1
 M1
 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
 from infinity (to the point) M1
 A1 [2]
- (b) (i) inside the sphere, the potential would be constant B1 [1]
- (ii) for point charge, V_x is constant B1
 co-ordinates clear and determines two values of V_x at least 4 cm apart M1
 conclusion made clear A1 [3]
- (c) $q = 4\pi\epsilon_0Vx$
 $q = 4\pi \times 8.85 \times 10^{-12} \times 180 \times 1.0 \times 10^{-2}$ M1
 $= 2.0 \times 10^{-10} \text{ C}$ A1 [2]

Q24.

- 5 (a) work done/energy in moving unit positive charge from infinity (to the point)

M1
A1 [2]

- (b) (i) $V = q/4\pi\epsilon_0 r$
at 16 kV, $q = 3.0 \times 10^{-8} \text{ C}$

$$r = (3.0 \times 10^{-8}) / (4\pi \times 8.85 \times 10^{-12} \times 16 \times 10^3)$$

$$= 1.69 \times 10^{-2} \text{ m (allow 2 s.f.)}$$

(allow any answer which rounds to 1.7×10^{-2})

C1
A1 [2]

- (ii) energy is/represented by area 'below' line
energy = $\frac{1}{2}qV$

$$= \frac{1}{2} \times 24 \times 10^3 \times 4.5 \times 10^{-8}$$

$$= 5.4 \times 10^{-4} \text{ J}$$

C1
C1
A1 [3]

- (c) $V = q/4\pi\epsilon_0 r$ and $E = q/4\pi\epsilon_0 r^2$ giving $Er = V$
 $2.0 \times 10^6 \times 1.7 \times 10^{-2} = V$
 $V = 3.4 \times 10^4 \text{ V}$

B1
C1
A1 [3]

