

Solutions

Original-task marks: M1 = method, A1 = accuracy, B1 = stated reasoning point.

2.1 Uniform field is p.d. per perpendicular separation.

$$E = \frac{V}{d} = \frac{600 \text{ V}}{0.020 \text{ m}} = 3.00 \times 10^4 \text{ V m}^{-1}$$

Field strength.

$$|F| = eE = 1.60 \times 10^{-19} \text{ C} \times 3.00 \times 10^4 \text{ N C}^{-1} = 4.80 \times 10^{-15} \text{ N}$$

Force magnitude; opposite field for the electron.

2.2 Surface potential uses sphere radius.

$$Q = \frac{Vr}{k} = \frac{4.5 \times 10^3 \text{ V} \times 0.10 \text{ m}}{8.99 \times 10^9 \text{ N m}^2 \text{C}^{-2}} = 5.01 \times 10^{-8} \text{ C}$$

Positive charge. Use the new centre-distance in the inverse square law.

$$E = \frac{kQ}{r^2} = \frac{8.99 \times 10^9 \text{ N m}^2 \text{C}^{-2} \times 5.01 \times 10^{-8} \text{ C}}{(0.30 \text{ m})^2} = 5.00 \times 10^3 \text{ N C}^{-1}$$

Field strength outward.

2.3 Use final minus initial potential.

$$\Delta U = q(V_f - V_i) = 2.0 \times 10^{-9} \text{ C} \times (50 - 120) \text{ V} = -1.40 \times 10^{-7} \text{ J}$$

Energy change.

$$W_{\text{field}} = -\Delta U = -(-1.40 \times 10^{-7} \text{ J}) = +1.40 \times 10^{-7} \text{ J}$$

Work. Potential energy falls as the field does positive work; losing the sign loses that distinction.

3.1 With zero potential at infinity, integrate the signed radial field from r to infinity; this gives potential, not the area from zero to r . Field is perpendicular to equipotentials and points towards lower potential. Potential value and potential gradient differ: opposing sources can cancel signed potentials while their fields add, or a reference can assign zero potential where the gradient is nonzero.

3.2 Neglect other forces and balance electrical force upwards against weight. A downwards field requires negative charge for upwards force. Use $|q|E = mg$.

$$|q| = \frac{mg}{E} = \frac{6.52 \times 10^{-15} \text{ kg} \times 9.81 \text{ m s}^{-2}}{2.00 \times 10^5 \text{ N C}^{-1}} = 3.20 \times 10^{-19} \text{ C}$$

Signed charge $-3.20 \times 10^{-19} \text{ C}$.

$$n = \frac{|q|}{e} = \frac{3.20 \times 10^{-19} \text{ C}}{1.60 \times 10^{-19} \text{ C}} = 2.00$$

Two excess electrons.

3.3 Set threshold electrical force equal to weight using sphere volume.

$$qE = \rho \frac{4\pi r^3}{3} g \quad \Rightarrow \quad d_{\text{max}} = 2 \left(\frac{3qE}{4\pi \rho g} \right)^{1/3}$$

Rearrangement and diameter factor.

$$d_{\text{max}} = 2 \left(\frac{3qE}{4\pi \rho g} \right)^{1/3} = 2 \left(\frac{3 \times 8.0 \times 10^{-15} \text{ C} \times 1.0 \times 10^5 \text{ N C}^{-1}}{4\pi \times 2500 \text{ kg m}^{-3} \times 9.81 \text{ m s}^{-2}} \right)^{1/3} = 3.96 \times 10^{-5} \text{ m}$$

Magnitude $39.6 \mu\text{m}$. Only $30 \mu\text{m}$ is below threshold; 40 is not justified by rounding the threshold up. On the tilt, normal detachment requires $qE > mg \cos 30^\circ$, while the weight also has a downslope component and adhesion is still excluded.