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WORKSHEETS
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Electric potential and energy

Electric fields 5 A charged spacecraft probe and dust

35–40 minutes independent work + 15–20 minutes review

OCR A H556 | A-level physics | Module 6 | 42 marks

Specification points covered

6.2.4(a–e) Electric potential, energy, force–distance work and isolated-sphere capacitance.

Prior learning applied: radial fields, kinetic energy, conservation of energy and C = Q/V.

Use $\varepsilon_0 = 8.85 \times 10^{-12}$ F m^{-1} and $k = 8.99 \times 10^{9}$ N m^2 C^{-2}. Take V = 0 at infinity.

Use a calculator and your OCR A data booklet. Show working, units and directions where relevant.

1 Choose the reference

A spherical spacecraft probe of radius R = 0.500 m carries a fixed uniformly distributed charge Q = +20.0 nC. Model it as isolated, with its source charge fixed.

Study a tiny dust grain relative to the freely falling probe. Neglect external gravitational gradients, drag, magnetic effects and changes to the source caused by the grain.

Position A is r_A = 2.00 m from O. Position B is at the surface. Distances in radial-field equations are measured from O, not from the surface.

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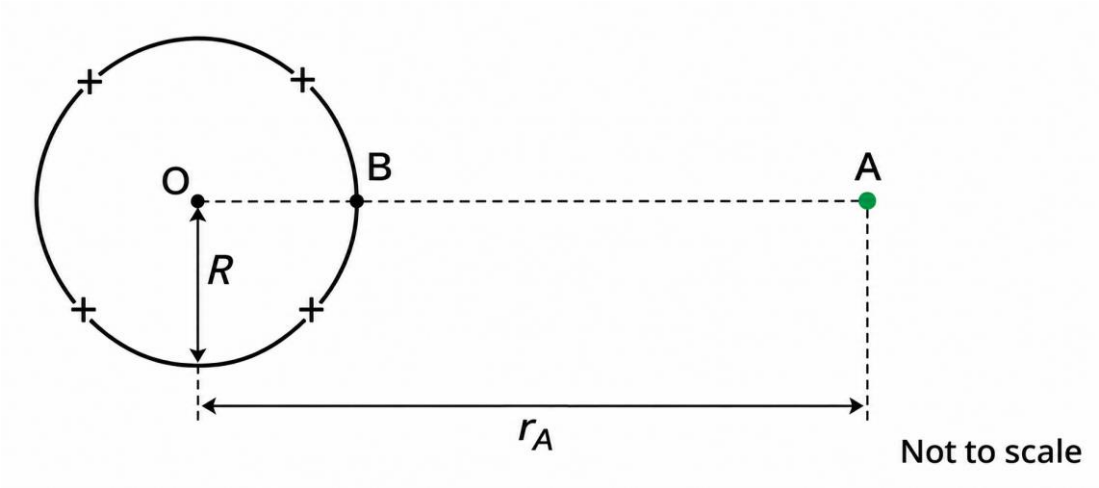


Figure 1 Ideal isolated probe and radial positions

1(a) Define electric potential at a point. Be clear about the charge and the reference position used. **[2 marks]**

1(b) State whether electric potential V, electric field strength E and electric potential energy U are scalar or vector quantities. **[1 mark]**

2 Calculate the probe potential

2(a) Calculate the potential at the probe surface. **[1 mark]**

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2(b) A sensor 1.50 m from the probe surface reads +90.0 V. Use this reading and the 0.500 m radius to estimate Q independently. **[2 marks]**

2(c) Using the stated Q = +20.0 nC, calculate the change in potential from A to B. Explain why this potential change does not depend on the dust grain's charge. **[2 marks]**

3 Compare radial relationships

3(a) The centre distance is doubled from any point outside the probe. State the factors by which the potential magnitude and field magnitude change. **[1 mark]**

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3(b) Sketch V against r and, on separate axes, E against r for the positive probe outside its surface. Label the axes and show how each approaches zero. The sketches need not be to scale. **[2 marks]**

3(c) If the probe carried −20.0 nC instead, describe how the V–r graph and the field direction would change. **[2 marks]**

3(d) A pupil uses the electric force at the surface multiplied by the entire distance from A to B to calculate work. Explain why that method is invalid. **[1 mark]**

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4 Track the dust grain’s energy

4(a) A grain has $q = -5.00 \times 10^{-15}$ C and mass 2.00×10^{-12} kg. Calculate its potential energy at A and B, the change from A to B and the work done by the electric field. **[3 marks]**

4(b) If the negative grain starts from rest at A, calculate its speed immediately before reaching B. **[2 marks]**

4 Initial speed and closest approach

4(c) Instead, the same negative grain is already moving inward at 0.800 m s^{-1} at A. Find its speed at B. **[2 marks]**

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4(d) A positive grain has the same mass and |q| and starts at A moving inward at 0.800 m s^{-1}. Determine its closest centre distance and decide whether it reaches the surface. **[3 marks]**

5 Connect force and work

Use q = −5.00 × 10^{-15} C and the original source. The table values are rounded. Numerical work must use the table, not a measurement from a sketch.

Table 1

r / m	|F| / 10^{-12} N
0.500	3.60
0.750	1.60
1.00	0.899
1.50	0.400
2.00	0.225

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5(a) Table 1 gives the force magnitude on the negative grain. Sketch |F| against r, include units and shade the area between r = 0.500 m and r = 2.00 m. State what the area represents. **[2 marks]**

5 Estimate and interpret the work

Use the rounded force readings in Table 1 in Question 5.

5(b) Estimate that area using a trapezium for each adjacent pair of readings in Table 1. Show your calculation in joules. **[2 marks]**

5(c) For the negative grain travelling from A to B, state the sign of work by the field. Compare your area estimate with the exact potential-energy result and explain a likely source of the difference. **[2 marks]**

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6 Derive isolated-sphere capacitance

6(a) Starting with the surface-potential equation and $C = Q/V$, derive $C = 4\pi\varepsilon_0 R$ for an isolated conducting sphere. **[2 marks]**

6(b) Calculate the capacitance of the original 0.500 m radius probe. **[1 mark]**

6(c) At the same radius, the probe's charge is doubled. State and explain the changes in its capacitance and surface potential. **[2 marks]**

7 Advise the probe designer

7(a) A design must hold +24.0 nC while keeping surface potential at or below 450 V. Compare isolated spheres of radius 0.250 m and 0.500 m. Choose a suitable design using calculated potentials. **[3 marks]**

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7(b) Evaluate this response: ‘The negative grain has negative potential energy, so its kinetic energy must also be negative and a real speed cannot be calculated.’ **[2 marks]**

7(c) In the actual spacecraft, a large conducting body is placed close to the probe. Explain why the isolated-sphere capacitance calculation may then be inaccurate. **[2 marks]**

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