Coulomb’s law and radial fields

Electric fields 1 Calibrating an electrostatic sorting line

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

OCR A H556 | A-level physics | Module 6 | 47 marks

Specification points covered

6.2.1(a–d) Charges, the spherical model, field lines and electric field strength.

6.2.2(a–d) Coulomb’s law, radial fields and comparison with gravitational fields.

Use $\varepsilon_0 = 8.85 \times 10^{-12}$ F m^{-1} and $k = 1/(4\pi\varepsilon_0) = 8.99 \times 10^{9}$ N m^2 C^{-2}.

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

1 Understand the calibration

An electrostatic sorter separates charged polymer fragments. Before use, an engineer tests uniformly charged insulating spheres. Assume the prescribed spherical charge distributions do not change. Small test charges do not disturb the source.

In Figure 1, A carries +8.0 nC and B carries −3.0 nC. Both radii are 8.0 mm. Unless a question states otherwise, use these charges.

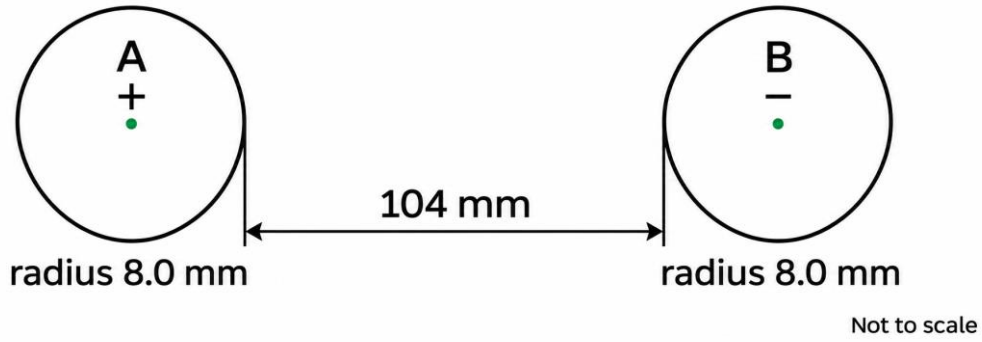


Figure 1 Calibration spheres

1(a) Define electric field strength at a point. Include how its direction is defined. **[2 marks]**

1(b) Figure 1 shows two calibration spheres. Calculate their centre-to-centre separation in metres and explain why this distance is used in the point-charge model. **[2 marks]**

2 Map the field

2(a) In the space below, draw at least six field lines outside an isolated positively charged sphere. Show the direction and the symmetry. **[2 marks]**

2(b) A small negative test charge is placed to the right of that positive sphere. State the directions of the field and the electric force on the test charge. **[1 mark]**

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2(c) Now consider equal and opposite point charges: positive on the left and negative on the right. Explain the direction of the resultant field at their midpoint. **[2 marks]**

2(d) Explain why the field line through a position does not necessarily show the trajectory of a particle launched through that position. **[2 marks]**

3 Predict the force

3(a) Calculate the magnitude of the electric force between the spheres in Figure 1. State whether the force is attractive or repulsive. **[2 marks]**

3(b) B is replaced by another negatively charged sphere. At the same centre separation, the force magnitude is 7.5×10^{-6} N. Determine the replacement sphere's charge. **[2 marks]**

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3(c) Return to the original charges and radii. The force must not exceed 5.0×10^{-6} N. Calculate the minimum centre separation and the corresponding clear surface gap. **[3 marks]**

3(d) The charge on B is doubled and the centre separation is tripled. Find the new force as a fraction of the original force. **[1 mark]**

4 Separate field from force

4(a) Sphere B is removed. Calculate the field strength 0.120 m from the centre of A. **[1 mark]**

4(b) A test charge of −2.0 pC is placed at this position. Calculate its force magnitude and state the direction relative to A. **[2 marks]**

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4(c) The test charge is replaced by −1.0 pC. Explain what happens to the field strength and to the force, assuming A is unchanged. **[2 marks]**

5 Combine fields along a line

5(a) Two point charges are now +8.0 nC at x = 0 and +2.0 nC at x = 0.300 m. Calculate the resultant field at x = 0.150 m. Show the direction of each contribution. **[2 marks]**

5(b) Find the zero-field point between these two positive charges. Let x be its distance from the +8.0 nC charge. **[3 marks]**

5(c) The charge at x = 0.300 m becomes −2.0 nC. Calculate the resultant field at the midpoint and explain why it cannot be zero anywhere between the charges. **[2 marks]**

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5(d) The two original interacting spheres exert equal and opposite forces on each other. Explain why these forces do not give zero resultant force on either individual sphere. **[2 marks]**

6 Test the inverse-square model

A field sensor tests a single positively charged source. The centre distances and field magnitudes are recorded below.

Table 1

r / m	E / N C^{-1}
0.100	7200
0.150	3200
0.200	1800
0.250	1150

6(a) Use at least two pairs of readings from Table 1 to test whether E is inversely proportional to r^2. Show your numerical test. **[2 marks]**

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6(b) State a pair of axes that should give a straight line through the origin. Sketch the expected line, then calculate its gradient from Table 1 and use it to infer Q. **[3 marks]**

6(c) Each E reading has a stated uncertainty of ±2%. Explain whether these data support the inverse-square model and whether they establish that every charged object can be treated as a point charge. **[2 marks]**

7 Make a calibration decision

7(a) The sorter must attract negatively charged fragments. Choose the collector polarity. For calibration, compare centre separations of 0.200 m and 0.225 m using Q = +8.0 nC and |q| = 3.3 nC, the largest permitted test charge. The force limit is 5.0×10^{-6} N. Choose a separation and justify it numerically. **[3 marks]**

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7(b) Give one similarity and one difference between the field of a point electric charge and the gravitational field of a point mass. Make each comparison explicit. **[2 marks]**

7(c) Explain two conditions that make the calibration spheres and test charge suitable for the model used in this worksheet. **[2 marks]**

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