The nuclear atom

Scattering, nuclear size and a target-film analyser

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

OCR A H556 | A-level physics | Module 6 | 36 marks

Specification points covered

6.4.1(a–d) Alpha scattering, nuclear structure, relative sizes, nuclide notation and isotopes.

6.4.1(e–g) Strong nuclear force, $R = r_0A^{1/3}$, and mean atomic/nuclear density.

Prior electric-potential, energy and graph skills are applied to an explicitly stated head-on model.

Use $e = 1.60 \times 10^{-19}$ C, $k = 1/(4\pi\varepsilon_0) = 8.99 \times 10^9$ N m^2 C^{-2}, $r_0 = 1.20$ fm and nucleon mass $= 1.67 \times 10^{-27}$ kg. 1 fm $= 10^{-15}$ m; 1 MeV $= 1.60 \times 10^{-13}$ J.

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

1 Prepare the target record

A materials-analysis centre is commissioning an alpha-beam instrument for ultrathin target films. It uses the beam counts to test an atomic model, then compares estimates of nuclear size.

Figure 1 is a plan view. The detector can be moved around the foil while keeping its distance and counting time fixed. An alpha particle has charge +2e. All diagrams are schematic; numerical work uses the supplied data.

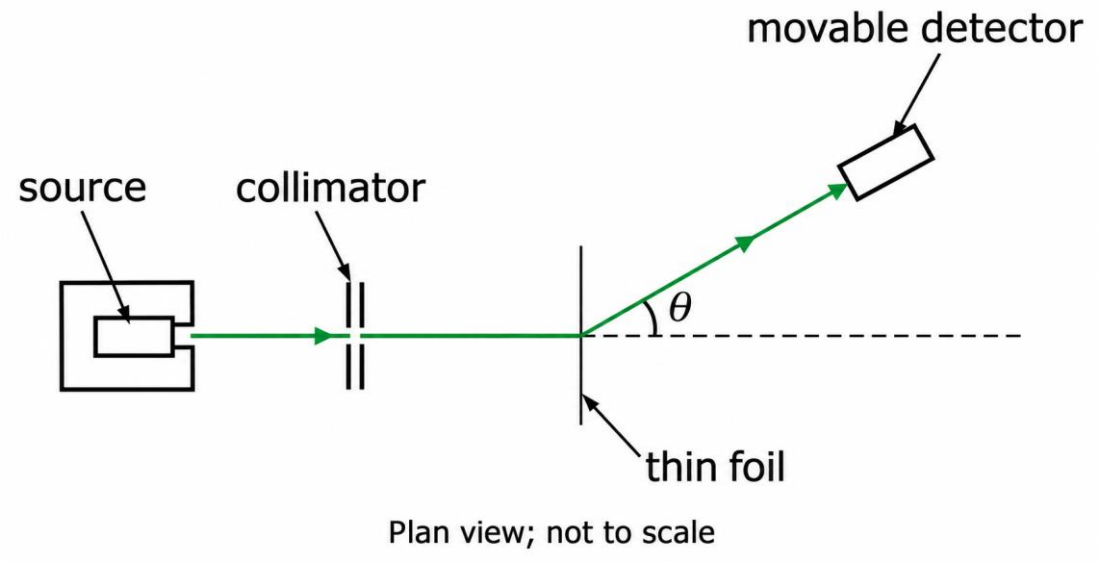


Figure 1 Alpha-beam target analyser

1(a) The analyser uses neutral tin-120 atoms, with proton number Z = 50. State the numbers of protons, neutrons and electrons in one atom, then represent its nucleus using A/Z nuclear notation. Use Sn for tin. **[2 marks]**

1(b) A second film contains tin-118. Explain why it is an isotope of tin-120 and state how its neutron count differs. **[1 mark]**

2 Connect observations to the model

2(a) For equal counting times, the mean detector counts at 30° and 150° are 2400 and 12. Calculate their ratio, N_{30}/N_{150}. **[1 mark]**

Continue your physics journey
Videos, practice and support for your next step
www.physicsuk.co.uk

2(b) A calibrated forward counter records about 96% of the incident particles within a narrow cone around the original beam direction. Separate measurements show a very small fraction scattered backwards. Explain what these observations support about atomic structure. **[3 marks]**

2(c) Can the two counts in 2(a) alone establish the percentage of all particles scattered through angles greater than 90°? Explain. **[1 mark]**

2(d) Explain why the target should be very thin and why the detector distance and counting time should be kept fixed when angular counts are compared. **[2 marks]**

3 Test a head-on approach model

This is a separate idealised head-on calculation. It does not describe every particle in the angular-count measurements.

3(a) A 5.00 MeV alpha particle approaches a stationary tin nucleus directly. Convert its initial kinetic energy to joules. **[1 mark]**

Continue your physics journey
Videos, practice and support for your next step
www.physicsuk.co.uk

3(b) Neglect recoil of the heavy target and all non-electrostatic effects. Take electric potential energy as zero at infinite separation. Calculate the distance of closest approach for a tin nucleus of charge +50e. **[2 marks]**

3(c) If the incident kinetic energy is doubled, what happens to this closest-approach distance? Explain using the model. **[1 mark]**

3(d) A technician reports the 28.8 fm result as an exact measurement of nuclear radius. Explain why this is not justified. **[2 marks]**

4 Use a nuclear-size relationship

4(a) Use $R = r_0A^{1/3}$ to estimate the radius of a tin-120 nucleus. Give the result in fm and in m. **[1 mark]**

Continue your physics journey
Videos, practice and support for your next step
www.physicsuk.co.uk

4(b) In the same model, a nucleus has radius 6.00 fm. Infer its nucleon number. **[1 mark]**

4(c) Compare the radii of nuclei with A = 216 and A = 27. State the ratio R_{216}/R_{27}. **[1 mark]**

4(d) The spherical mean-atom model uses radius 1.50×10^{-10} m for a tin atom. Calculate the ratio of atomic radius to nuclear radius for tin-120 and explain what this indicates about relative sizes. **[2 marks]**

5 Check the density model

Table 1 Rounded candidate radius records

A	R / fm
27	3.60
64	4.80
125	6.00

Continue your physics journey
Videos, practice and support for your next step
www.physicsuk.co.uk

5(a) Treat the tin-120 nucleus as a sphere and its mass as A times the given nucleon mass. Calculate its mean density. **[3 marks]**

5(b) Use $R = r_0 A^{1/3}$ and $M \approx Am_n$ to show why the simple model predicts approximately the same mean nuclear density for different A. **[2 marks]**

5(c) The rounded radius records in Table 1 are to be compared with $R \propto A^{1/3}$, rather than $R \propto A$. Choose straight-line graph axes and calculate the expected gradient from the table. **[2 marks]**

5(d) A radius reading is 2.0% too large while the assumed mass is correct. Calculate the factor by which the density inferred from that reading differs from the correct density. **[2 marks]**

Continue your physics journey
Videos, practice and support for your next step
www.physicsuk.co.uk

6 Interpret the model limits

6(a) Describe the strong nuclear force between two nucleons at separations of about 1 fm and below about 0.5 fm. State its approximate attractive range. **[2 marks]**

6(b) Using the same tin-120 mass and the stated mean-atom radius, calculate the mean density of the spherical atom model. Compare it with the nuclear density and interpret the difference. **[2 marks]**

6(c) Correct both claims in the instrument report: “Closest approach proves a sharp nuclear radius” and “A nearly constant mean density proves the density is identical at every point inside and outside a nucleus.” **[2 marks]**

Continue your physics journey
Videos, practice and support for your next step
www.physicsuk.co.uk