Rutherford questions

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1. Read the following passage, taken from a lecture given by Lord Rutherford in 1936, and answer the questions which follow.

   > In the early days, Dr Geiger found the majority of α particles passed through undeflected when fired at thin gold foil only a few atoms thick; only a small number diverged slightly off course. One day Geiger suggested that we set young Marsden to see if any α particles could be deflected through a large angle. I did not believe they would be, since we knew that the α particle was very fast and massive with lots of energy and unlikely, therefore, to suffer large deflections in uniform matter. Then, two or three days later, Geiger came to me in great excitement saying 'we have consistently seen some α particles (about 1 in 20 000) coming backwards'. It was quite the most incredible event that has ever happened to me in my life. It was almost as incredible as if you fired a 15 inch shell at a piece of tissue paper and it came back and hit you.

   (a) What is an α particle?

   (b) Why did most of the α particles pass through the foil undeflected?

   (c) Why were some deflected slightly?

   (d) What is the largest angle through which a particle is scattered? How does this come about?

   (e) Why do bound electrons, in orbitals around the gold nucleus, have a negligible influence on the α particle trajectories?

2. Beams of electrons, protons and neutrons, each having the same velocity, are passed separately in a vacuum between two metal plates of positive and negative electrical charge.

   (a) Which of the three types of particle is deflected the most by the electric field between the charged plates? Give a reason for your answer and state the direction this type of particle is deflected.

   (b) Which of the three types of particle has the greatest penetration through a sheet of metal? Give a reason for your answer.

3. Draw a simple diagram to outline Chadwick's experiment in which the neutron was first discovered. How did Chadwick actually detect the effect of the neutrons?

4. Give the names of the three isotopes of hydrogen. Find out about the uses of the two heavier isotopes.

5. Consider a head-on collision of a fast moving α particle and a nucleus of atomic number Z.

   (a) Show that, if the initial kinetic energy of the α particle is E_k, then the distance of closest approach of the α particle to the nucleus d is given by:

   $$d = \frac{1}{4\pi\varepsilon_0}\frac{2Ze^2}{E_k}.$$

(b) The actual value now taken for the radius of the gold nucleus ($Z = 79$) is 7×10^{-15} m or 7 fm. Compare the value obtained from the equation for an α particle of $E_k = 7.68$ MeV to this value, and comment on any discrepancy.

6. As the number of nucleons A in the nucleus increases, so too does the nuclear radius R. We might guess that the volume of the nucleus would be directly proportional to the number of nucleons, and the volume is also proportional to the cube of the radius, i.e. $R^3 \propto A$, or

$$R = r_0 A^{\frac{1}{3}}.$$

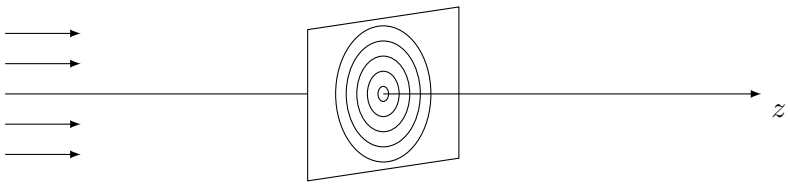
Use the information in the table below about nuclear radii to plot a **suitable graph** (i.e. it will turn out to be a straight line!) to find out if this relationship is true, and use it to estimate the radius of a proton.

A	$R/10^{-15}$ m
12	3.16
28	3.93
56	4.85
120	5.99
197	7.01
208	7.16

Extension

This bit is optional, but not for people who did well in the olympiad!

7. A uniform parallel beam of α particles, of number per unit volume ρ and velocity u, travels along the z-axis. Consider a plane perpendicular to the z-axis consisting of concentric circles, centres on the z-axis, with radii nt, where the constant t is the radial distance between adjacent circles and n is an integer $(0, 1, 2, 3 \ldots)$:



(a) Determine the number N of α particles per second that pass through an annulus (ring) between the nth and $(n + 1)$th circle.

(b) Sketch a graph of N against n.

8. In this question, assume the masses of the neutron and proton are both equal to m.

(a) Determine the distance of closest approach, r_1, of an α particle to a gold nucleus comprising 79 protons and 118 neutrons, in terms of its initial velocity v.

(b) If the gold nucleus is free to move and initially at rest, what is the velocity of an α particle *relative* to the gold nucleus at the distance of closest approach, r_2? Determine r_2 in this case.

[These last two questions are adapted from the British Physics Olympiad Paper 2, 2006]