**Rutherford: The gold foil experiment simulation - Answer Key**

**(© Eric Hanson 2015)**

**3) If you changed the variables below, how would the number of hits change? Why?**

a) If marbles were smaller, there would be fewer hits: the target would be smaller.

b) If marbles were further apart, there would be fewer hits: more empty space.

c) If number of trials were increased, there would be more hits: more chances to hit.

d) If the marble was thrown from further away, there would be fewer hits: more chance for the

rolling marble to veer away from the line of marbles.

**4) Explain what each part of the model represents:**

a) Marble that was rolled: Radioactive helium nucleus or alpha particle

b) Marbles on the 60-centimeter line: Gold atom nuclei

c) The 60-centimeter line: A row of gold atoms

**5) Name some differences between our simulation and the original experiment.**

i) The gold foil experiment was conducted in a vacuum. ii) The alpha particles (rolled marble) were smaller than the gold nuclei (row of marbles). iii) There was a zinc sulphide screen for detecting the alpha particles. iv) There was a lead box which held radiation source for the alpha particles.

**6) What did Rutherford expect when he first did the gold foil experiment? Explain.**

Rutherford expected all of the bullets would go through the gold foil. The model of the atom at that time was J.J. Thompson's "plum pudding model", in which single protons were suspended in the center. Based on this model, Rutherford thought that the alpha particles were travelling at a high speed and were heavier than a proton and so would not bounce back or be deflected.

**7) How did the actual results of the gold foil experiment surprise Rutherford? How did he**

**explain these unexpected results?**

Some alpha particles deviated from their path and some bounced back. There must be a very tiny and very heavy or dense central region (the nucleus) that has all the protons and all the mass of the atom

**8) Name two scientists who worked with Rutherford on the gold foil experiment.**

**Hans Geiger** Rutherford found that a narrow beam of -particles was broadened when it passed through a thin film of mica or metal. He therefore had Geiger measure the angle through which these alpha particles were scattered by a thin piece of foil. Because it is unusually ductile, gold can be made into a foil that is only 0.00004 cm thick. When this foil was bombarded with alpha particles, Geiger found that the scattering was small, on the order of one degree.

These results were consistent with Rutherford's expectations. He knew that the alpha particle had a considerable mass and moved quite rapidly. He therefore anticipated that virtually all of the alpha particles would be able to penetrate the gold foil, although they would be scattered slightly by collisions with the atoms through which they passed. In other words, Rutherford expected the alpha particles to pass through the gold foil the way a rifle bullet would penetrate a bag of sand.

**Ernest Marsden** One day, Geiger suggested that a research project should be given to Ernest Marsden, who was working in Rutherford's laboratory. Rutherford responded, "Why not let him see whether any alpha particles can be scattered through a large angle?" When this experiment was done, Marsden found that a small fraction (perhaps 1 in 20,000) of the alpha particles were scattered through angles larger than 90**°**. Many years later, reflecting on his reaction to these results, Rutherford said: "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."

Rutherford concluded that there was only one way to explain these results. He assumed that the positive charge and the mass of an atom are concentrated in a small fraction of the total volume and then derived mathematical equations for the scattering that would occur. These equations predicted that the number of alpha particles scattered through a given angle should be proportional to the thickness of the foil and the square of the charge on the nucleus, and inversely proportional to the velocity with which the alpha particles moved raised to the fourth power. In a series of experiments, Geiger and Marsden verified each of these predictions. When he published the results of these experiments in 1911, Rutherford proposed a model for the structure of the atom that is still accepted today. He concluded that all of the positive charge and essentially all of the mass of the atom is concentrated in an infinitesimally small fraction of the total volume of the atom, which he called the nucleus (from the Latin for little nut).

Most of the alpha particles were able to pass through the gold foil without encountering anything large enough to significantly deflect their path. A small fraction of the alpha particles came close to the nucleus of a gold atom as they passed through the foil. When this happened, the force of repulsion between the positively charged alpha particle and the nucleus deflected the alpha particle by a small angle. Occasionally, an alpha particle traveled along a path that would eventually lead to a direct collision with the nucleus of one of the 2000 or so atoms it had to pass through. When this happened, repulsion between the nucleus and the alpha particle deflected the alpha particle through an angle of 90**°** or more.

By carefully measuring the fraction of the alpha particles deflected through large angles, Rutherford was able to estimate the size of the nucleus. According to his calculations, the radius of the nucleus is at least 10,000 times smaller than the radius of the atom. The vast majority of the volume of an atom is therefore empty space.

**9) Bonus: How is the formula derived? Explain why it works.**

**Sources of Error**

i) If students aim at the targets, the number of hits increases and the size of the nucleus appears larger than it should, ii) If some targets are larger than others, the number of hits increases and the size of the nucleus appears larger than it should. iii) If the rolling marble is larger than the targets, the number of hits increases and the nucleus appears larger than it should.