

Atomic Target Practice

Rutherford Scattering and the Nuclear Atom

Introduction

It is one of the most famous experiments of all time. More than 25 years after conducting the experiment, Ernest Rutherford described the results this way:

“It was about as credible as if you had fired a 15-inch shell at a piece of tissue paper and it came back and hit you.”

The experiment itself was actually the culmination of a series of experiments, carried out over a five-year period, dealing with the scattering of high-energy alpha particles by various substances. What is “Rutherford scattering” and why was it so important?

Concepts

- Atomic structure
- Atomic mass
- Nucleus
- Nuclear charge

Background

Ernest Rutherford received the Nobel Prize in Chemistry in 1908 for his investigations into the disintegrations of the elements as a result of radioactive decay. Among the products of the radioactive decay of elements are alpha particles—small, positively charged, high-energy particles. In trying to learn more about the nature of alpha particles, Rutherford and his co-workers, Hans Geiger and Ernest Marsden, began studying what happened when a narrow beam of alpha particles was directed at a thin piece of metal foil. Alpha particles are a type of nuclear radiation, traveling at about 1/10 the speed of light. As expected for such high-energy particles, most of the particles penetrated the thin metal foil and were detected on the other side. What was unexpected was that a few—a very few, to be sure—of the alpha particles were actually reflected back toward the source, having been “scattered” or bent due to their encounters with the metal atoms in the foil target. The number of alpha particles that were reflected back depended on the atomic mass of the metal. Gold atoms, having the highest atomic mass of the metals studied, gave the largest amount of so-called “back scattering.”

Rutherford’s scattering experiments have been described as a “black box” experiment. The properties of the alpha particles, their mass, charge, speed, etc., were at least partially understood. The atoms making up the target, however, presented Rutherford with a kind of black box—the structure of the atom was not known at the time. In order to explain the results of the scattering experiments, Rutherford had to unlock the black box, that is, he had to solve the structure of the atom. In 1911 Rutherford proposed the following model for the structure of the atom:

- Most of the mass of the atom is concentrated in a very small, dense central area, later called the nucleus, which is about 1/100,000 the diameter of the atom.
- The rest of the atom is apparently “empty space.” (*Most of the alpha particles traveled straight through the metal foil, as if nothing were in their path.*)

- The central, dense core of the atom is positively charged, with the nuclear charge equal to about one-half the atomic mass. (*As alpha particles randomly struck the gold target, a few approached the nucleus of an atom head on. The positively charged alpha particles were strongly repelled by the nuclear charge and “recoiled” or bounced back to the source.*)

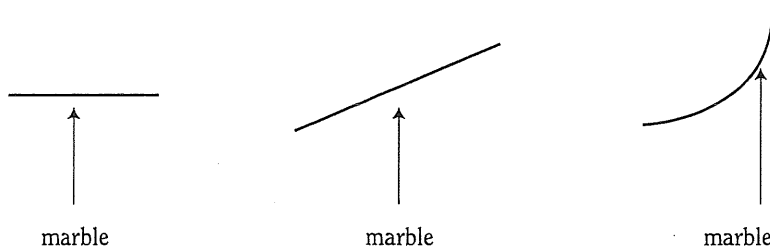
It is not practical to recreate Rutherford’s original scattering experiments in the high school laboratory. Some idea of the challenge that faced Rutherford and his co-workers can be gained from the following “black box” activity using marbles and an unseen, unknown target.

Experiment Overview

The purpose of this activity is to discover by indirect means the size and shape of an unknown object, which is hidden underneath the middle of a large board. The board is raised about 2 cm, leaving just enough space to roll or shoot a marble at the object. By observing and tracing the path the marble takes after striking the unknown target from a variety of angles, it should be possible to estimate the general size and shape of the unknown target.

Pre-Lab Questions

1. This activity is a simulation of Rutherford’s scattering experiments. Read the entire procedure and compare the components used in this simulation (the marbles, the board, the unseen object, and the traced path of the marbles) to Rutherford’s original experiments. What role is played by each component?
2. It is important to trace the apparent path of each marble roll, even when the marble rolls straight through without striking the unknown target. What general information about the target can be inferred based on where the marble rolls in one end and out the other?
3. The key skills in this activity, as in Rutherford’s experiments, are the ability to make careful observations and to draw reasonable hypotheses. Assume that the marble strikes the following sides of a possible target. Sketch the path the marble might be expected to take in each case.



Materials

“Black box,” consisting of a square, 18” × 18” cardboard or pegboard cover and a hidden, unknown object underneath

Marbles or small steel balls

Pencil

Paper, white, 8½ × 11 in, 2 sheets

Tape

Safety Precautions

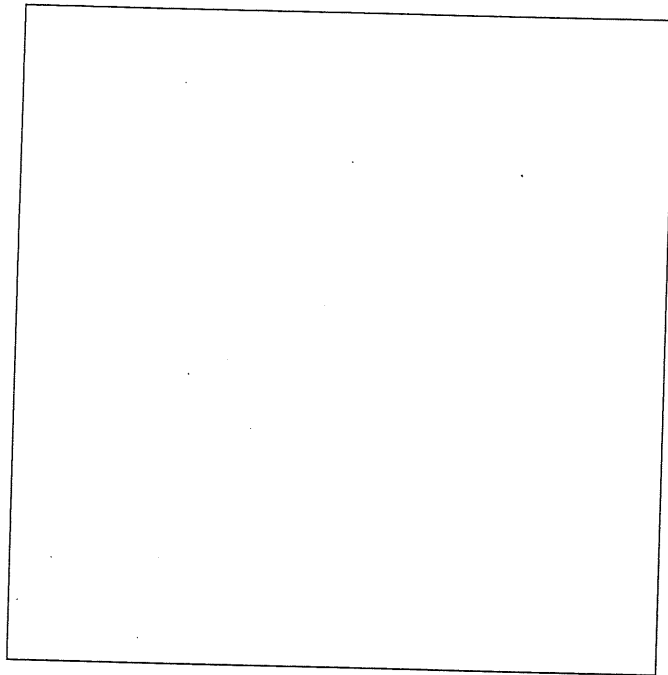
Although the materials in this activity are considered nonhazardous, please observe all normal laboratory safety guidelines.

Procedure

1. Form a working group with two or three other students, depending on the number of unknown “black boxes” available to the class.
2. Tape two pieces of standard size white paper together to form an 11"-square sheet.
3. Center the paper on top of a black box and tape it down to keep it in place. If there is a code letter for the black box, write the code on the sheet of white paper. Do not look underneath the “black box”!
4. Roll the marble with a moderate amount of force under one side of the black box. Observe where the marble comes out and trace the approximate path of the marble on the white paper. For example, if the marble rolls straight through, draw a straight line from one end of the sheet to the other.
5. Working from all four sides of the black box, continue to roll the marble under the board, making observations and tracing the rebound path for each marble roll. Roll the marble at least 20 times from each side of the box. Vary the angles at which the marble is rolled into the box.
6. After sketching the apparent path of the marble from all sides and angles, the general size and shape of the unknown target should emerge “in the negative” from the area where there are no lines (where the marble does not penetrate).
7. Form a working hypothesis concerning the structure of the unknown target. Based on this hypothesis, repeat as many “targeted” marble rolls as necessary to either confirm or revise the structure.
8. Check your final results with your teacher. Do not look inside the “black box” until the teacher verifies your results.
9. If time permits, switch black boxes with another group of students and conduct a second investigation.

Post-Lab Questions

1. Draw the general size and shape of the target to approximate scale in the square below. What characteristics of the target were easiest to determine? What characteristics of the target's shape were difficult to determine? Explain.



2. The speed of the marble rolls was an uncontrolled variable in this activity. How would the outcome of the scattering test have been different if the marble speed had been faster or slower?
3. Compare the overall size of the target with the size of the marble used to probe its structure. How would the outcome of the scattering test have been different if different size marbles had been used? Explain.
4. In what ways did this activity simulate Rutherford's efforts to determine the structure of the atom? In what ways was it different? Be specific—consider the size, speed, and charge of both the particles and the target.