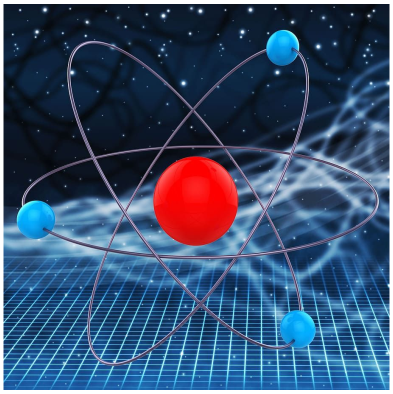
Finding the Space in an Atom



Objective:

Students will use inference and interpretation of indirect observations to create a model of an object that they cannot see.

Background

"...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..."

This is how Ernest Rutherford described his most famous experiment 25 years later. Really a culmination of a series of experiments carried out over a five-year period, Rutherford analyzed how high-energy **alpha particles** were scattered by different substances. In 1908, Rutherford received the Nobel Prize in Chemistry for investigating how elements disintegrate due to exposure to radioactive decay. One of 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, Hans Geiger and Ernest Marsden, studied the behaviors of a narrow beam of alpha particles projected at a thin piece of metal foil.

Alpha particles travel at about 1/10 the speed of light (10% of 300,000m/s = 30,000m/s). Because they are high-energy, most alpha particles penetrate thin metal foil. Rutherford's team were able to design devices that detected the alpha particle on the other side of the foil. What surprised them was that a few of the alpha particles reflected back toward the source, having been "scattered" or had their paths 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 by the early 1900s. The atoms making up the target, however, presented Rutherford with a kind of black box as 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; 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 lab. 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.

Objective: Discover by indirect means the size and shape of an unknown object.

Safety: Use marbles as they are intended to be used!
Materials: Whiteboard, marker, marbles, camera, paper, pen/pencil

Procedure:

1. Get into groups of 3-4 students
2. A whiteboard will be placed on top of an object. DO NOT:
    a. Peek under the board
    b. Tilt the board
    c. Feel under the board
3. Roll the marble with a moderate amount of force under one side of the board. Observe where the marble comes out and trace the approximate path of the marble on the whiteboard.
4. Working from all four sides of the board, 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 board. Be sure to vary the angles at which the marble is rolled. You may use the rulers as a launching platform.
5. After sketching the apparent path from all sides and angles, the general size and shape of the unknown target should emerge.
6. Form a working hypothesis concerning the structure of the unknown target. Based on this hypothesis, repeat as many “targeted” marble rolls as necessary to confirm or revise the structure.
7. Draw the general size and shape of the target
8. Check your answer with your teacher.
9. DO NOT peek under the board.
10. EACH PERSON should take a picture of your white board to attach to your individual reports.

Finding the Space in an Atom

Name______________________________

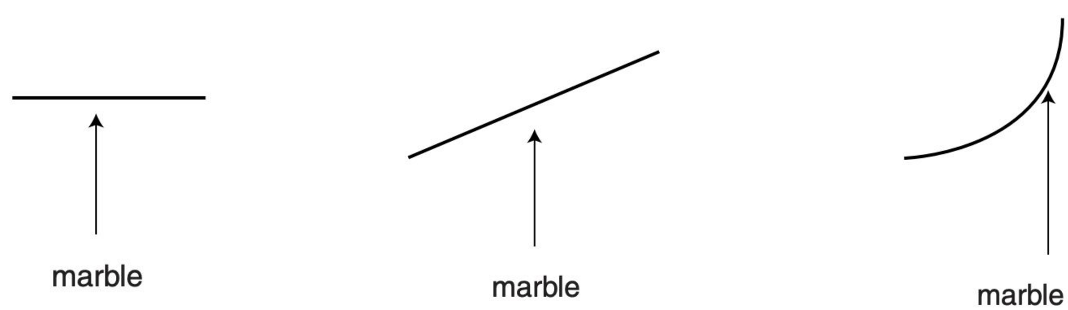
Period _____ **Date** ___________________

Pre-lab:

1. This activity is a simulation of Rutherford's scattering experiments. Read the entire procedure and background. Compare 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. On your paper, sketch the path the marble might be expected to take in each case.



4. Use information presented in the textbook to draw a picture of the Rutherford model of the atom.

Conclusions (complete individually)

1. 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?

2. 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.

3. 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.

4. What was the most difficult part of this experiment?