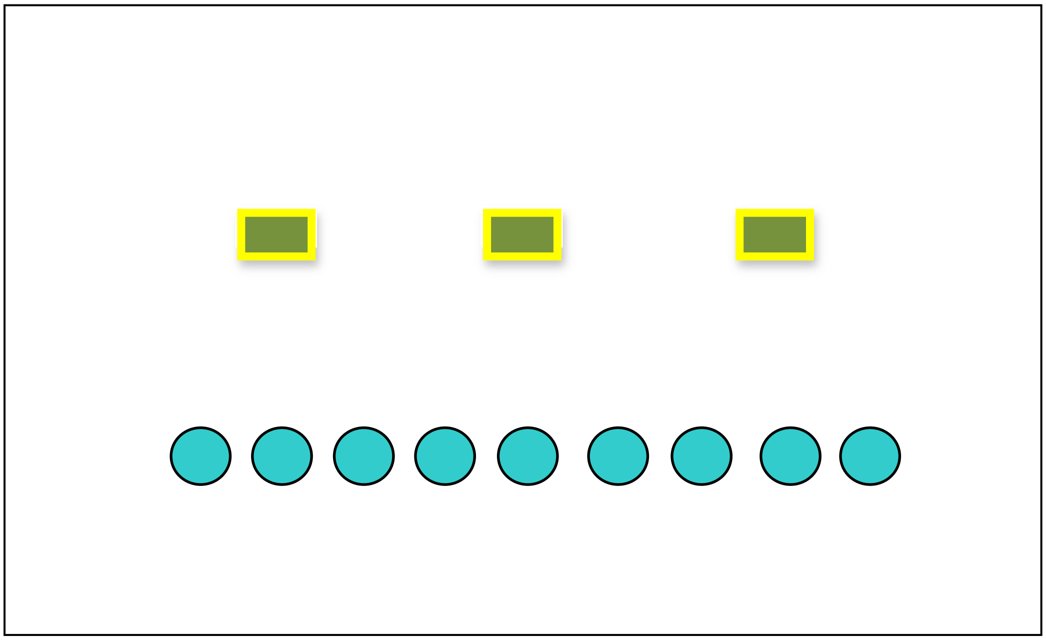
Rutherford Atomic Model: Hidden Obstacles
Student Advanced Version

This lab demonstrates the techniques that scientists used over a century ago to determine the basic structure of the atom. By rolling marbles past hidden obstacles and observing their trajectories, students will be able to make inferences on the shape and size of the obstacles.

Key Concepts:
- Most of the mass of the atom is concentrated in a very small, dense central area, called the **nucleus**, which is about 1/100,000 the diameter of the atom.
- The rest of the atom is apparently "empty space".
- The nucleus of the atom is positively charged, with the strength of this charge equal to the **atomic number**.
- Electrons occupy the bulk of the empty space in an atom and orbit the nucleus at a greater distance compared to the size of the nucleus.

Pre-Lab Questions:
Q1. This activity is a simulation of Rutherford's scattering experiment. Discuss this lab's procedure with the teacher, and compare the components used in this simulation to Rutherford's original experiment:
- *The first part of the lab requires you to shoot marbles through a row of equally spaced barriers, and observe the amount of marbles that cleanly pass through vs. the amount that bounce off the barriers. What aspect of Rutherford's experiment do the marbles represent?*
- *What aspect of Rutherford's experiment do the barriers represent?*

Q2. The key skills in this activity, as in Rutherford's experiment, is the ability to make careful observations to draw reasonable hypotheses, and the ability to determine the shape of an unknown object through indirect means. In the box below, marbles (blue circles) are in one direction (up the page) toward a row of equally spaced barriers (in green/yellow). Sketch the paths the marbles will likely take and the rebound trajectories if contact is made with the targets.



Q3. Discuss what information can be inferred if the marble rolls straight through without striking the unknown target.

Part I: Wall of Barriers

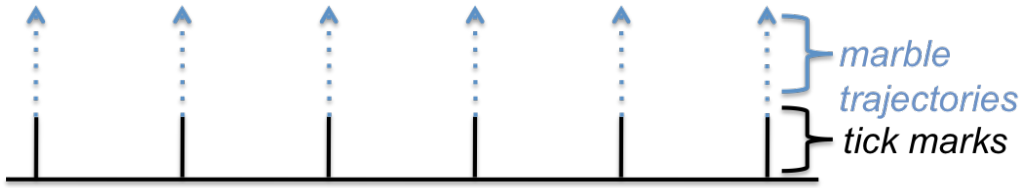
Procedure:

1. Allow the teacher to construct a cardboard platform with a row of barriers attached. Do not peek under to see where the barriers are!

2. Lay the platform on the table so the barriers are underneath the cardboard. From above, it should look like an elevated cardboard square, with no visible objects underneath.

3. One student (the marble shooter) should stand along one side of the platform, so that he or she can shoot marbles perpendicular to the row of barriers. Another student should stand on the side across from him or her, ready to catch marbles.

4. Using a ruler, make a number of equally-spaced tick marks along the side of the board at which the marble shooter is standing, separated by 1 inch. You will use these tick marks to line up your marble shots into the wall of barriers, so that they can easily be counted as "hits" or "misses", as diagrammed in the figure below.



5. You are now ready to shoot the marbles through these barriers. The marble shooting student should start by aligning the paper towel tube with a tick mark on one end of the cardboard edge, pointed totally perpendicularly to this edge. By creating a ramp with this tube, shoot the marble underneath the board.

6. If the marble is observed to hit a barrier as it rolls underneath the cardboard, mark that tick mark with an "H", and if it passes through without hitting anything, mark the tick mark with an "M" to signify a miss.
7. Line up the paper towel tube with the next tick mark along the edge and repeat steps 5 and 6. Continue along shooting the marbles from different points along the cardboard edge at all tick marks.
8. After the marbles have been rolled from all points along the edge, the total fraction of space occupied by the barriers underneath can then be approximated. The barriers in this experiment are analogous to the atomic nuclei in Rutherford's experiment.

   Expected Total Space Fraction = # of marble hits ÷ total # of marble rolls

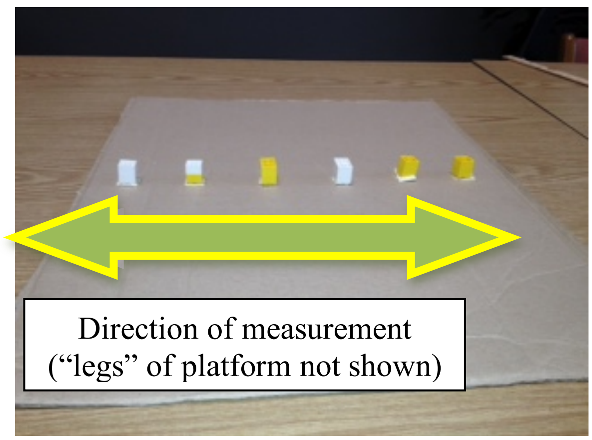
   = _______________ ÷ _________________=_________________

9. You can also observe the pattern of "hits" and "misses" across all tick marks to predict the number of Lego bricks concealed by the cardboard platform:

   Predicted Total number of bricks used = ________________________

10. After the expected total space fraction and the number of barriers are predicted, turn over the cardboard platform to calculate the actual space fraction.
11. Begin by measuring the length of the cardboard platform in the direction that the Lego bricks are arranged (see picture below). Subtract the length of the "legs" that you are using to stabilize the platform in the corners.

   Total Space Available = _____________ *cm*



12. Next, measure the length of one Lego brick in the same direction.

13. Measure the width of the marble you are using and add that to the length of a Lego brick to get the "single obstacle size".

   Single Obstacle Size = _____________ *cm*

14. Multiply the "single obstacle size" by the total number of Lego bricks used to get the "total obstacle size".

   Total Obstacle Size = *single obstacle size* × *number of Legos used* = _____________ *cm*

15. Calculate the actual space fraction of Lego bricks:

Actual Space Fraction = total obstacle size÷ total space available = _____________ *cm*

Questions:

Q4. Compare the expected space fraction and number of barriers that you predicted without seeing the barriers to their actual values. Were you close? What would account for any difference between the expected and actual values?

Q5. In Rutherford's experiment, he found that the nucleus of an atom was less than 1/1000th of the size of the rest of the atom, i.e. the space between barriers was more than 1000 times larger than the fraction of space that the barriers occupied. How does this compare to your experiment? Why do you think this experiment may be designed differently?

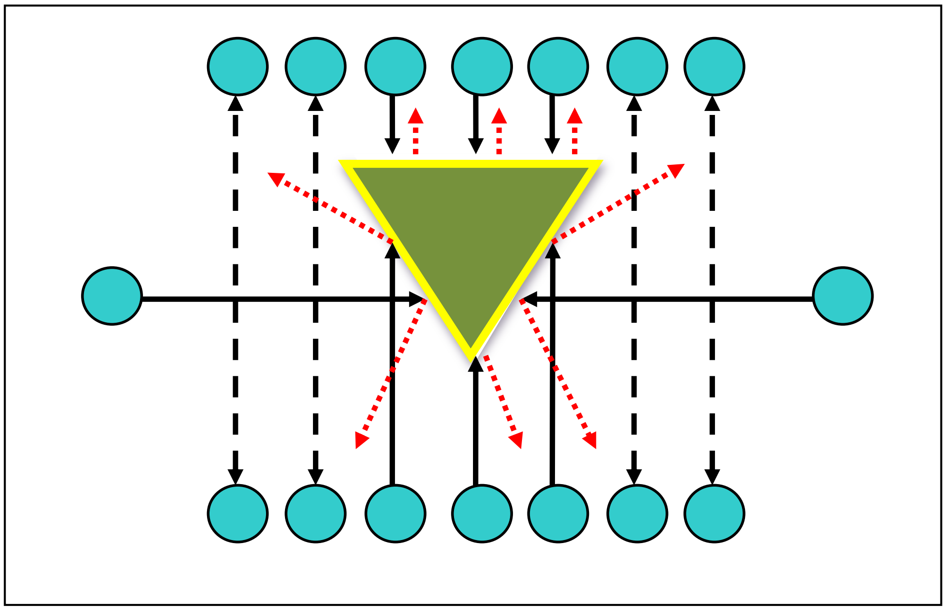
Q6. You were able to estimate the number of barriers under the cardboard. How were you able to do this? Do you think Rutherford was able to do this in his experiment?

Part II: Alternate Shapes

Procedure:

1. This time, an alternate object of unknown size and shape is placed under the cardboard platform, and a sheet of paper is taped on the opposite (upper) side by the teacher. Your job is to determine the size and shape of the object.

   Example: Your shape may be totally different than the one shown here. Based on the angles at which the marble is deflected away from under the board, the shape of the unknown object becomes clear.



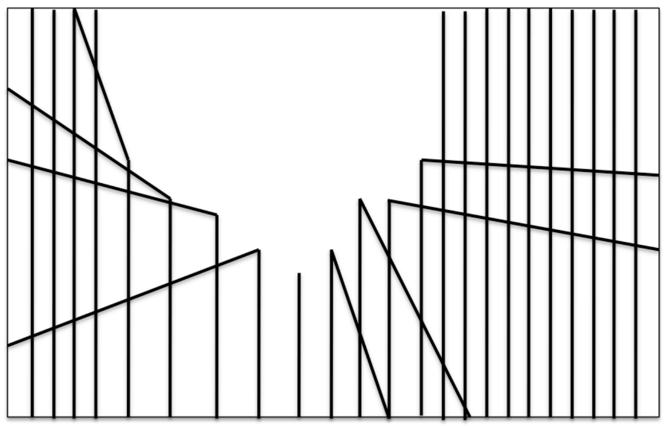
2. Again, students should stand on opposite sides of the cardboard platform while shooting and catching marbles.

3. As in Part 1, use the paper towel tubes to shoot marbles underneath the cardboard platform. The marbles should still be shot perpendicularly to the edge of the cardboard. Shots should also be started at one end and moved across the cardboard edge in increments, as in Part 1. **Closely observe the trajectory that the marble takes as it emerges from the cardboard.**

4. Trace the trajectory that the marble takes on the sheet of paper attached to the cardboard. It is important to track the emerging trajectory of the marble as closely as possible. By connecting the emerging trajectory line with that of the incoming marble trajectory, you can find the point of impact with the unknown object.

   - In the cases when the marble bounces straight back to the shooter, it is impossible to find the exact point of impact. However, those rolls do show where the unknown object has a face perpendicular to the marble trajectory.

5. Repeat rolling marble from one side of the board and tracing its path until the boundaries of the shape facing that side are roughly determined. It may be helpful to delineate the boundaries of the object by starting to shoot marbles near the edges of the cardboard and working inward. The page should contain a number of straight lines, joining at the points where the marbles impacted the unknown shape. An example that may or may not look like your paper depending on the unknown object, is shown below:



6. Rotate the board a quarter turn and repeat steps 5-7 until the marble has been rolled from each side of the board with corresponding paths traced from all sides. The paper should include many lines crossing over one another.

7. After sketching (on the sheet taped on the upper side of the cardboard) the apparent paths of the marble from all sides, the general size and shape of the unknown target should emerge. Draw the general shape of the unknown object to approximate scale in the square below:

Predicted Object

8. Turn the cardboard over and examine the actual object.

Questions:

Q7. How does the shape of the unknown object compare to the actual object? What may have caused any discrepancy?

Q8. 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?

Q9. Compare the overall size of the unknown object 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.

Q10. In Rutherford's experiment, he was able to determine the approximate size of an atom's nucleus. You were able to determine both an unseen object's shape and size. What key factor allowed you to make this prediction?