



Title:	2-D Scattering – An analog to Rutherford backscattering
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Appropriate Level:	Regents Physics or Chemistry
Abstract:	<p>This lab is a 2-D analog to the materials characterization technique of Rutherford backscattering (RBS). It introduces the concept of looking at the angular distribution of scattered particles to measure/characterize the scattering target. In RBS, the scattering targets are the atoms, and the scattered particles are alpha-particles. In this experiment, we instead use a metal target with ball-bearings that scatter. Students repeatedly launch the ball bearings down the grooves of a ramp to simulate a uniform flux of alpha particles. Students are guided through a series of exercises that introduces the basics of backscattering and leads them through a simple experimental investigation. The optional final section of the lab provides an opportunity for independent research using the apparatus.</p>
Time Required:	Two or three 40-minute periods
NY Standards Met:	<p>S3.1 Use various means of representing and organizing observations and insightfully interpret the organized data.</p> <p>S3.2 Apply statistical analysis techniques when appropriate to test if chance alone explains the result.</p> <p>S3.3 Assess correspondence between the predicted result contained in the hypothesis and the actual result, and reach a conclusion as to whether or not the explanation on which the prediction was based is supported.</p> <p>S3.4 Based on the results of the test and through public discussion, revise the explanation and contemplate additional research.</p>
Special Notes:	<p>Rutherford Scattering is a kit available from the CIPT Equipment Lending Library, www.cns.cornell.edu/cipt/ (cannot be shipped – must be picked up at Cornell, Ithaca, NY).</p>

Objectives:

- To explore alpha particle scattering and how it illuminates the structure of the atom.
- To provide students with an opportunity to derive hypotheses and to then design and conduct experimental tests of their hypotheses.
- To develop student ability in the organization, use, and analysis of experimental data.

Class Time required:

Two or three 40-minute periods, depending on how much of the lab is used.

Teacher preparation time:

10 to 20 minutes to set-up equipment.

Materials:

2-D Scattering kit from the Equipment Lending Library.

Assumed Prior Knowledge of Students:

Basic knowledge of atomic structure is essential. Previous exposure to Rutherford's work is helpful, but not essential.

Background Information for Teachers:

Rutherford back scattering (RBS) is a powerful materials characterization technique in which alpha particles (nuclei of helium) are fired at a target material that is being subjected to analysis. The energy and angular position of the scattered particles is analyzed to gain information about the atoms in the target. Ernest Rutherford first did this in 1911, when he fired alpha particles at gold foil. By studying the angular distribution of the scattered particles, Rutherford was able to determine the mass and size of the scattering agents in his target. To his great surprise, it was much smaller than the estimated size of the atom and thus he discovered the nucleus.

RBS is still used today as thin-film characterization technique. In modern implementations, data is collected as a function of energy at a fixed target angle. In addition, since most of the alphas are not scattered by any given lattice plane, they can probe significantly beyond the surface (up to microns deep) which allows the technique to be used for compositional analysis of thin-film multilayers.

In this experiment, we are exploring a 2-D analog of RBS. In place of alpha-particles, we use steel ball-bearings. The scatterer, rather than a lattice of nuclei, is a single, round, metal target, or an array of targets to simulate the nucleus.

The apparatus is very engaging for most students, so getting involvement is not usually a problem. The connection between this experiment and RBS techniques, while interesting and informative, is not the central point of the exercise. More importantly, the exercise is intended to encourage inquiry-based hypothesis derivation and testing.

General Tips for Teachers:

- Make sure students keep the center of the ramp aimed at the center of the table.
- Keeping the tables in reasonable balance is helpful, but not as essential as it might at first appear.
- The ramp works best at relatively low angles, approximately 20 to 30 degrees to the horizontal. When the ramps are set at too high of an angle, the balls have a tendency to bounce, sometimes high enough to bounce over the targets, particularly when the tacks are used for targets.
- The number of grooves per ramp varies from ramp to ramp.
- The nets are reasonably tough. Occasionally, one or more might need adjustment or a new staple hammered into the board to ensure that they stay in place.
- Lab groups should be a minimum of three. Up to six students can be kept profitably busy with just one apparatus; the work can be split into a number of different roles.
- The single rod can be screwed into or out of the table. Be careful to remove it when turning the table over or transporting it. Otherwise, damage can be done to the threads into which it is turned.
- Though it's important, usually, for students to use all the grooves in their studies so as to simulate 'random' alpha particle bombardment, don't let them get too focused on making sure of this! It's easy to lose track of which groove is next, but not absolutely essential with high enough sample sizes.
- Have extra data tables available for students to use, as needed, to record additional data.
- When using the tacks to represent nuclei, tape them with the head side down. Use two short pieces of Scotch tape in an 'X' so as make them stable.

Specific Directions for the Four Sections of the Laboratory:

Section I: The Apparatus

The intent in the section is to engage the students in the laboratory. Let them have a little bit of fun. The idea here is not to answer these questions in any detail, but just to open the questions up for them to explore. Don't worry about getting the answer 'right'!

Section II: Introduction to Rutherford Backscattering

This section contains enough background for students to complete it on their own. Here are the answers:

1. *That most of the atom consists of 'empty space'.*
2. *+2 e, nucleus, electrostatic or Coulomb force*
3. *Yes (probably). Yes (probably). Larger nuclei would have larger positive charges and would, therefore, exert more force on the incident helium nuclei.*
4. *Gold is very malleable and can be pounded very thin. If we want to study the internal structure of atoms, we want to get to as few atoms thick as is possible.*

Rutherford	Our Apparatus
Alpha Particles	<i>Balls (or marbles)</i>
Zinc Sulfide Screen	<i>Fish nets</i>
Energy of the Alphas	<i>Height of the ramp or speed of the balls</i>
Target Nuclei	<i>The obstacles</i>
Atomic Number of Target Nuclei	<i>The size of the obstacles</i>

Section III: First Experiment

Answers to the questions will vary enormously. Here are some suggestions for leading your students into a productive experience:

- Generally, the balls that fall into the nets that go into the 0 to 10 nets are non-scattered, but that's not always true. It's a good topic for discussion.
- One possibility for quantifying 'the proportion of balls that are scattered' is to calculate a percentage: number of balls scattered (in nets greater than 10 degrees) divided by the total number of balls multiplied by 100%.
- One possibility for quantifying average angle of scattering is to calculate the total number of degrees of scattering for all the balls in nets greater than 10 degrees divided by the total number of balls scattered. As an example, imagine that there are 27 balls in the 0 to 10 net, 4 balls in the 10 to 20 nets, and 3 balls in the 30 to 40 nets. The 27 balls are ignored (they aren't scattered), the 4 balls average 15 degrees each for a total of 60 degrees, and the 3 balls count for 35 degrees each for a total of 105 degrees. So, the average is $(60 + 105)/7$, which computes to an average angle of scattering of 23.6 degrees.
- As for data analysis, you can make graphing programs available if students chose to do a bar graph of their data.
- A large sample size of balls is great, but comes at the price of added time. You can talk about the trade-offs.
- Balls that do not go immediately into a net can be discarded or perhaps pushed into whatever net they were headed toward.
- It would make sense that balls that are 'ricocheting from one net to another should be counted in the net that they originally struck; after all, it's the ball's behavior before they hit the 'detector' that we are really interested in.
- Be sure students label their data tables!

Section IV: Original Investigation

Let students be ingenious! A few possible studies are listed. Other studies you might want to suggest include:

- The effect of sending more than one ball at a time.

- The effect of putting a magnet somewhere on the table.
- The proportionalities between target size and scattering rates.
- The effect of tack size or height on scattering.

References:

- <http://www.eaglabs.com/en-US/references/tutorial/rbsinst/cairinst.html>
A nice site summarizing RBS through a tutorial format.
- William H. Cropper, Great Physicists: The Life and Times of Leading Physicists from Galileo to Hawking. Oxford University Press: New York. 2004. The section on Rutherford is helpful to understand his work.

2-D SCATTERING

AN ANALOG TO RUTHERFORD BACKSCATTERING

Name _____

Section I: The Apparatus

Before you begin experimenting with the Rutherford Backscattering (RBS) apparatus, make sure that the center of the ramp is aimed straight at the obstacle in the center of the board. Make sure your apparatus is level. Slide the larger of the two 'donut' shaped obstacles over the center post. Roll some marbles down the ramp. Try a variety of grooves in the ramp.

1. Into which nets did the balls land if they missed the center obstacle?

2. Did any hit the obstacle? If so, what are the angles of the nets that they landed in?

3. When a ball hits the obstacle, do you think there are any particular angles that it is more likely to land in? Are there any angles at which it is unlikely to land?

4. Do you think very many will end up bouncing straight back, at an angle greater than 170° ? Did any of yours?

5. Try adjusting the ramp to different heights. Ask your teacher if you need help doing this. Did you find anything interesting?

6. Try shooting more than one ball at a time. What did you find?

7. Try shooting a larger ball at the obstacle. Any effect?

Section II: Introduction to Rutherford Backscattering

Ernest Rutherford was an early twentieth century physicist originally from New Zealand. He was one of the pioneers in research into radioactive decay. In 1911, he and his students conducted a celebrated experiment in which they bombarded alpha particles at a sheet of gold foil. They then used a screen of zinc sulfide that scintillates (flashes) when struck by an alpha particle. They found that most of the alpha particles went straight through the gold foil, un-deflected. Some were scattered to a small angle. A very few, one in every eight thousand, was deflected at an angle greater than 90 degrees.

Rutherford commented that this "...was quite the most incredible event that has ever happened to me in my life. It was almost as incredible as if you had fired a 15-inch shell at a piece of tissue paper and it came back and hit you."

1. What can we conclude about the atom from the fact that most of the alphas passed straight through?
2. An alpha particle is a helium nucleus. What is its charge in elementary charges?
_____ The scattered alpha particles were repelled by what part of the gold atom (which Rutherford discovered in this experiment)? _____ What is the force that causes this deflection? _____
3. If he had used an atom with a higher atomic number than gold, do you think a greater proportion of alpha particles would have been scattered? _____ Do you think they would have been scattered at a greater average angle? _____ Explain your answers below:
4. Why do you think Rutherford used gold? (Hint: gold is highly malleable.)

Rutherford backscattering is still used today as a technique in the study of materials. Experimental surfaces are bombarded with low mass ions and by measuring the direction, energy, and angle of the particles as they scatter off the surface, physicists can identify the chemical makeup of the surface and determine its structure.

In today's lab, our apparatus serves as a model (analogy) for Rutherford's experiment. As with any analogy, ours is not perfect. On the left are various features of the alpha particle scattering experiment. Fill in the column on the right with the analogous parts in our apparatus.

Rutherford	Our Apparatus
Alpha Particles	
Zinc Sulfide Screen	
Energy of the Alphas	
Target Nuclei	
Atomic Number of Target Nuclei	

Section III: First Experiment

You are now ready to design an experiment. Let's start with a simple one: the effect of target size on the scattering of the balls. You will be using three different targets: the bare post, the smaller donut, and the larger donut. With the help of your teacher and through the answers to the following questions, you will develop a hypothesis, an experimental plan (called a protocol), and a method of data analysis. Note the data tables on the next page that you can use to record your data.

1. First, let's develop a couple hypotheses. Use the following questions to formulate your hypotheses.
 - a. Will the size of the obstacle increase the proportion of balls that are scattered? Write your answer in the form of a testable hypothesis.

 - b. Considering just the balls that hit the target and are therefore scattered, will the size of the obstacle change the average angle of scattering? Write your answer in the form of a testable hypothesis.

2. After you've counted which nets the balls fall into, we need to plan what you do with the data.
 - a. Which nets will you identify as containing balls that are 'non-scattered'?

- b. How are you going to quantify the proportion of the balls that are scattered?

 - c. How are you going to quantify the 'average angle of scattering'?

 - d. Put below a summary of how you are going to use your data to test your hypotheses. Include a description of any graph you may want to create.
3. Which grooves are you going to use and in what order?
4. How many balls are you going to shoot?
5. What are you going to do about balls that do not go immediately into a net?
6. What are you doing to do with balls that go straight backwards to the ramp?
7. What are you going to do with balls that bounce off a net and then ricochet into a different net from the one they were headed toward?

Trial #1

Trial Description: _____

Angle (degrees)	Number of Balls
0-10	
10-20	
20-30	
30-40	
40-50	
50-60	
60-70	
70-80	
80-90	
90-100	
100-110	
110-120	
120-130	
130-140	
140-150	
150-160	
160-170	
170+	

Trial #2

Trial Description: _____

Angle (degrees)	Number of Balls
0-10	
10-20	
20-30	
30-40	
40-50	
50-60	
60-70	
70-80	
80-90	
90-100	
100-110	
110-120	
120-130	
130-140	
140-150	
150-160	
160-170	
170+	

Trial #3

Trial Description: _____

Angle (degrees)	Number of Balls
0-10	
10-20	
20-30	
30-40	
40-50	
50-60	
60-70	
70-80	
80-90	
90-100	
100-110	
110-120	
120-130	
130-140	
140-150	
150-160	
160-170	
170+	

8. From your data, what do you conclude about your hypotheses?

9. Take a look at the data from the other groups in your class. Does that change your conclusion?

Trial #1

Trial Description: _____

Angle (degrees)	Number of Balls
0-10	
10-20	
20-30	
30-40	
40-50	
50-60	
60-70	
70-80	
80-90	
90-100	
100-110	
110-120	
120-130	
130-140	
140-150	
150-160	
160-170	
170+	

Trial #2

Trial Description: _____

Angle (degrees)	Number of Balls
0-10	
10-20	
20-30	
30-40	
40-50	
50-60	
60-70	
70-80	
80-90	
90-100	
100-110	
110-120	
120-130	
130-140	
140-150	
150-160	
160-170	
170+	

Trial #3

Trial Description: _____

Angle (degrees)	Number of Balls
0-10	
10-20	
20-30	
30-40	
40-50	
50-60	
60-70	
70-80	
80-90	
90-100	
100-110	
110-120	
120-130	
130-140	
140-150	
150-160	
160-170	
170+	

Put a summary below: