Mini-Rutherford

Grade Level
5-12

Disciplinary Core Ideas (DCI, NGSS)
5-PS1-1, MS-PS1-1, MS-PS1-4, HS-PS1-8

Time for Teacher Preparation
40-60 minutes – To make the mini-Rutherford Boards
40-60 minutes – To prepare for the classroom

Activity Time:
40-60 minutes (1 Class Period)

Materials
• 5-10 blocks of various shapes 20 cm (8" x 10" x 3/4")
• 5-10 30.5 x 30.5 cm (12" x 12" x 1/8") masonite boards
• Pkg./30-1.9 cm (3/4") or (5/8") marbles
• Paper
• Pen, marker, or pencil
• Ruler

Safety
• Students should use care when handling marbles
• Students should not throw marbles
• Students should avoid stepping on marbles

Science and Engineering Practices (NGSS)
• Ask questions
• Define Problems
• Use Models
• Plan and Carry out investigation
• Analyze and interpret Data
• Construct Explanations
• Communicate Information

Cross Cutting Concepts (NGSS)
• Patterns
• Cause and Effect
• Scale, Proportion, and Quantity
• Systems and System Models

Objective
Students will try to determine the shape of an unknown object by using the scientific thought process of creating a hypothesis, then testing it through inference. It is based upon the Rutherford Gold Foil Experiment where scientists discovered that the structure of the atom includes the nucleus in the center surrounded by electrons in empty space.

It is a great introduction to the scientific process of deducing, forming scientific theories, and communicating with peers. It is also useful in the mathematics classroom by plotting the angles of incidence and reflection.

Background
From 1911 to 1913, British physicists Geiger and Marsden, working in the laboratory of Ernest Rutherford, conducted experiments with beams of positively charged, alpha particles to penetrate gold, silver, and copper atoms. They observed that most of the alpha particles went directly through the foil. However, some particles were deflected and others recoiled back toward the source. Rutherford systematically investigated the results Geiger and Marsden obtained with alpha particles; Rutherford concluded that most of the mass of an atom is concentrated in a small region in its center, now called the nucleus.

Fundamental Particles Detection
Light has a wavelength of $10^{-7}$ m. Light microscopes enable us to view parts of a cell as small as $10^{-6}$ m. Electron microscopes enable us to see an image with a wavelength as small as $10^{-9}$ m. With the help of scanning electron microscopes, we can see fuzzy images of atoms. To detect a smaller image, such as a fundamental particle, we need to produce particles with greater energy, and thus, a shorter wavelength. The smallest fundamental particle is less than $10^{-18}$ m in diameter!

Although scientists have not yet been able to actually see fundamental particles, they can infer the presence of these particles by observing events and applying conservation laws of energy, momentum, electric charges, etc.

One way to do this is with a particle accelerator. Essentially, a particle accelerator works by shooting particles at high speed toward a target. When these bullet particles hit a target, a detector records the information about the resulting event.
Necessary Components for Particle Detection

1. **Bullet Particles.** These can be either electrons, positrons (the anti-particle of an electron), or protons. The particles are collected as follows:

   • Electrons are collected the same way a TV picture tube collects them; a metal plate is heated and electrons are emitted.

   • To obtain positrons, a beam of electrons collides with a target, resulting in a photon. From the photon, electrons and positrons may be formed and are separated by their charges in a magnetic field.

   • Protons are obtained by ionizing hydrogen gas. Ionization requires collisions at energy great enough to strip electrons from hydrogen, leaving protons.

2. An **accelerator** increases the speed of bullet particles to greater energy levels. The particles are accelerated with an electric field by riding on traveling electromagnetic (EM) waves. The EM waves are created in devices called klystrons, which are large microwave generators.

3. The **steering device** directs the bullet particles to their target. Magnets are used to steer the particles around a circular accelerator and to focus the particles so they will hit the target. The same magnets make positive and negative particles traveling in the same direction bend in opposite directions.

4. A **target** can be any solid, liquid, or gas, or another beam of particles.

5. A **detector** interprets the paths of the resulting particles once the bullet particles have collided with their target. Modern detectors have several layers, to detect the many particles produced in a collision event. A detector can be up to three stories tall. An advanced computer system is used to reconstruct the many paths of the particles detected in the layers associated with a collision. By viewing particle paths through each layer of the detector, scientists can determine the results of an event. Charged particles leave a track in the inner (tracking) layer of the detector. The positive or negative charge of the resulting particle can be determined by the direction it curves in a magnetic field. A particle with great momentum (speed x mass) will have a less curved path compared to one with less momentum. After a collision, electrons and protons will leave showers of particles in certain detector layers. Photons and neutrons travel a little further through the layers before their collisions create a shower of particles. Muons (one type of a fundamental particle), however, can be detected in the outer layer of a detector. They travel right through the inner layers with little or no interaction.

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**Modeling Atoms**

**Modeling Atoms – Mini-Rutherford**

<table>
<thead>
<tr>
<th>Waveband</th>
<th>Wavelength (m)</th>
<th>Frequency (s⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radio Waves</td>
<td>3 x 10⁻³</td>
<td>3 x 10¹⁵</td>
</tr>
<tr>
<td>Microwaves</td>
<td>3 x 10⁻²</td>
<td>3 x 10¹³</td>
</tr>
<tr>
<td>Infrared</td>
<td>10⁻⁴</td>
<td>3 x 10¹⁴</td>
</tr>
<tr>
<td>Visible</td>
<td>0.5 x 10⁻⁴</td>
<td>3 x 10¹⁴</td>
</tr>
<tr>
<td>Ultraviolet</td>
<td>10⁻⁸</td>
<td>3 x 10⁻⁵</td>
</tr>
<tr>
<td>X-rays</td>
<td>10⁻¹⁸</td>
<td>3 x 10⁻¹⁰</td>
</tr>
<tr>
<td>Gamma-Rays</td>
<td>10⁻¹⁵</td>
<td>3 x 10⁻¹²</td>
</tr>
</tbody>
</table>

**Visible Light**

Low Energy: 3 x 10⁻³ m

High Energy: 3 x 10⁻⁸ m
Teacher Lesson Plan:

Traditional

To make Mini-Rutherford Boards:
Velcro, glue, or nail block shapes underneath the masonite boards. Note: Some hardware stores will cut shapes for you free of charge.

Potential Block Shapes:

Place the Mini-Rutherford boards on a large table or on the floor, obstructing the shapes from your students’ view. Place a piece of paper on top of each Mini-Rutherford board. Beware; your students may be tempted to peek.

The student activity, described in the accompanying worksheet, should take about five minutes to complete. The activity can be repeated several times during a class period, using different shapes and/or marbles each time. Some shapes are more difficult to detect than others.

NGSS Inquiry

Explain Rutherford’s experiment. Tell students that they will design their own experiment, using rolling marbles as alpha particles to discover the shape of a hidden geometric shape, which simulates the nucleus.

You might suggest that the students experiment with rolling a marble at different angles at a straight surface and seeing the different ways the marble deflects.

Student Procedure

Using the Mini-Rutherford boards:

Middle School

Part 1

1. Working in small groups, roll one of the marbles at the hidden object underneath the Mini-Rutherford board while one student draws the marble’s path in, and the deflected path out, on the piece of paper placed on the Mini-Rutherford board. Map the paths of the marbles that do not deflect or deflect slightly, as well. Make sure you roll the marble fast enough so that it makes a clean shot in and out.

2. Repeat Step 1 as many times as needed to define the outline of the hidden shape, using the same size marble each time. Make sure you roll the marble from many points on each side of the board.

Part 2

5. Have the instructor place a different block back under the Mini-Rutherford board (or switch boards if they are permanently attached). Place a clean sheet of paper on the top of the Mini-Rutherford board and repeat the procedure (Steps 1-4).

High School

Repeat steps 1-5 as per the Middle School procedure.

Place the Mini-Rutherford board on a large piece of butcher paper, and then have the students record the shapes on the large paper. Do not put the paper on the board so that students must infer the shape from the surrounding angles of incidence/reflection.

3. Once you are satisfied that you know the shape of the object under the Mini-Rutherford board, draw the shape onto the piece of paper. (You might want to trace the shape from the paper with the outline formed by the collision paths).

4. Before looking at the actual block shape, show your instructor the shape you have drawn. Then look at the block underneath the Mini-Rutherford board, and discuss any parts of the shape you have drawn that are ill-determined.
Data Collection
Attached Student Data Collection Sheet

Post Discussion/ETS
Questions provided on the Student Data Collection Sheet

Questions
1. Explain the necessity of drawing the pathways of the marbles that miss as well as those that hit.
   a. How can you find where the hits occurred?
2. Describe how varying the block shape can change the outcome of the event.
3. List two ways in which the Mini-Rutherford Activity is analogous to and two ways in which it is different from Rutherford’s scattering experiment.

Assessment Ideas
- Question the student about how this experiment is similar to Rutherford’s Gold Foil Experiment
- Test the students’ ability to determine an unknown geometric shape
- To better represent the presentation of scientific results, explain to the students that every time they guess the shape and get it wrong they will lose 10 points. This will emphasize that scientists do not “guess” at the answers until someone tells them that they are right. Scientists perform multiple experiments using different variables before they announce their results.

Differentiated Learning/Enrichment
Repeat experiment using more complicated shapes and equipment, i.e. mirrored surfaces and inexpensive lasers

Enrichment Questions
1. Compare the Mini-Rutherford Activity components to that of a particle detector. Describe the target, bullet, accelerator, steering device, and detector components of the Mini-Rutherford board.
2. Have students devise an experiment that would more closely simulate the Rutherford experiment using magnetic particles and a charged shape under the board.

Further Resources
For more information on Ernest Rutherford:
http://www.nobelprize.org/nobel_prizes/chemistry/laureates/1908/rutherford-bio.html
http://www.rutherford.org.nz/

For similar experiments:
http://www.lepp.cornell.edu/Education/Lessons.html

Adapted from:
Modeling Atoms
Mini-Rutherford

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It is a great introduction to the scientific process of deducing, forming scientific theories, and communicating with peers. It is also useful in the mathematics classroom by plotting the angles of incidence and reflection.

Procedure

Using the Mini-Rutherford Boards:

Part 1

1. Working in small groups, roll one of the marbles at the hidden object underneath the Mini-Rutherford board while one student draws the marble’s path in, and the deflected path out, on a piece of paper placed on the Mini-Rutherford board. Map the paths of the marbles that do not deflect or deflect slightly, as well. Make sure you roll the marble fast enough so that it makes a clean shot in and out.

2. Repeat Step 1 as many times as needed to define the outline of the hidden shape, using the same size marble each time. Make sure you roll the marble from many points on each side of the board.

3. Once you are satisfied that you know the shape of the object under the Mini-Rutherford board, draw the shape onto the provided piece of paper. (You might want to trace the shape from the paper with the outline formed by the collision paths of the marbles).

4. Before looking at the actual block shape, show your instructor the shape you have drawn. Then look at the block underneath the Mini-Rutherford board, and discuss any parts of the shape you have drawn that are ill-determined.

Part 2

5. Have the instructor place a different block back under the Mini-Rutherford board (or switch boards if they are permanently attached). Place a clean sheet of paper on the top of the Mini-Rutherford board and repeat the procedure (Steps 1-4).
Part 1 - Marble Test Sketch of Hidden Shape

Part 2 - Steel Ball/Different Size Marble Test: Sketch of Hidden Shape
Questions

1. Explain the necessity of drawing the pathways of the marbles that miss as well as those that hit.
   The marbles that miss denote empty space. The marbles that hit show an object.

   a. How can you find where the hits occurred?
   By measuring the angle of incidence and reflection, you can determine where they meet and the point where they hit the shape. The marbles come out at a different angle than where they went in.

2. Describe how varying the block shape can change the outcome of the event.
   If you use a shape that is non-symmetrical and not centered under the board, the students will have to overcome their bias that the outside of the object defines what is underneath.

3. List two ways in which the Mini-Rutherford Activity is analogous to and two ways in which it is different from Rutherford’s scattering experiment.

   Similarities: In this experiment we are shooting particles at an object and using angles of incidence and reflection to determine the shape. Another is that we are using the scientific principle of inference to identify an object that we cannot see.

   Differences: The particles and shapes are on a very large scale as compared to Rutherford’s experiment which dealt with atoms. The shape used in this laboratory is not magnetic, and does not attract or deflect the particles being directed toward it.

Enrichment Questions

1. Compare the Mini-Rutherford Activity components to that of a particle detector. Describe the target, bullet, accelerator, steering device, and detector components of the Mini-Rutherford board.

   The bullet particle is the marble. The accelerator is the student releasing the marble or shooting the marble under the board. The steering device can be a ruler that the students roll the marble down, or the student as they send it under the board. The target is the shape under the board. The detector is the student data collection sheet.

2. Devise an experiment that would more closely simulate the Rutherford experiment using magnetic particles.

   Using a magnet as the shape under the board and using metal balls or other magnets rather than marbles as the bullets.
Modeling Atoms

Mini-Rutherford
Student Data Collection Sheet

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2. Repeat Step 1 as many times as needed to define the outline of the hidden shape, using the same size marble each time. Make sure you roll the marble from many points on each side of the board.

3. Once you are satisfied that you know the shape of the object under the Rutherford board, draw the shape onto the provided piece of paper.

(You might want to trace the shape from the paper with the outline formed by the collision paths of the marbles).

4. Before looking at the actual block shape, show your instructor the shape you have drawn. Then look at the block underneath the Mini-Rutherford board, and discuss any parts of the shape you have drawn that are ill-determined.

Part 2

5. Have the instructor place a different block back under the Mini-Rutherford board (or switch boards if they are permanently attached). Place a clean sheet of paper on the top of the Mini-Rutherford board and repeat the procedure (Steps 1-4).
Part 1 - Marble Test: Sketch of Hidden Shape
Part 2 - Different Marble Test: Sketch of Hidden Shape
Modeling Atoms – Mini-Rutherford
Student Data Collection Sheet

Name: ____________________________________________
Date: _____________________________________________

Questions

1. Explain the necessity of drawing the pathways of the marbles that miss as well as those that hit.

   a. How can you find where the hits occurred?

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