

Indirect Measurement

Introduction:

Modern physics relies heavily on indirectly determining the physical characteristics of objects. The following activities will demonstrate to students that indirect determinations are important methods through which accurate measurements can be obtained. These activities can provide a platform for the introduction of the Rutherford model of an atom.

Objectives:

Students will:

- Draw conclusions from collected data
- Explain the importance of using direct measurement techniques to draw conclusions about objects that cannot be seen
- Explain why indirect measurement is important in particle physics

Standards Met:

Standard 1 – M1.1c

Standard 1 – S2.1, S3.2

Standard 4 – 3.3a

Lesson Components:

I. Introductory Question

II. Indirect Measurement of the Radius of an Atom Activity

- Indirectly determine the area of a target circle using proportions
→ Determine size of an “atom”

III. Rutherford’s Experiment Model – (Modeling Rutherford’s Scattering Experiment)

- Indirectly determine the shape of a mystery object using marble collisions
→ Determine shape of an “atom”

IV. Closure: The Invisible Soccer Ball story

- Connection to particle physics with soccer game analogy

V. Real World Application

Group question: How do scientists determine where to drill for oil?



Courtesy of the National Research Council

Tiny Rulers?

On January 1st, 1994 scientists at the National Research Council in Canada created the world's smallest ruler – each division measures the width of 18 atoms! The device was created in order to measure features designed on a computer chip that can be one-60th of a human hair wide. The calibrations are so minute that it gained entry in the Guinness Book of World Records.

In 1911, nearly 80 years before the creation of the NRC's ruler, Ernest Rutherford and his colleagues Hans Geiger and Ernest Marsden accurately measured the size of a single gold atom. How did they do this??

Indirectly Measuring the Radius of An Atom

(Adopted from the National Teachers Enhancement Network)

Time Required - 50 minutes

Grade Level: 6-12

Materials:

- Steel ball bearing
- A sheet of carbon paper
- A handout--one sheet paper containing a number of small, equal-size circles drawn uniformly on the paper (occupying ~ 2/3 of the paper) See attachment.
- Metric ruler

Purpose:

The students will indirectly measure the radius the diameter of a single circle contained in our target. This is analogous to measuring the radius of a single atomic nucleus in the gold foil of Rutherford's experiment.

The circles on a sheet are uniform in size. The circles fill the sheet, and are about 8mm in diameter for example. There are two different sheets, each with circles of different sizes. The circles that you and your partner have may be different from those of the pair beside you. A "circle hit" is defined as: "completely within a circle".

Background:

Modern physics deals with particles that cannot be directly observed and measured. In Rutherford's famous experiment, carried out by Geiger and Marsden, alpha particles were directed at a thin sheet of gold foil with the idea of measuring the deflection of the alpha particles. The experimenters unexpectedly found recoils of the particles, as well as deflections. This led to the concept of the atomic nucleus. From the data gathered,

Rutherford was able to draw conclusions about the size of the nucleus: i.e., he relied upon indirect measurement. We can learn about indirect measurement through this exercise.

Students will indirectly measure the radius of an "atom" (circle on the paper). The comparison of the indirect value to the value obtained by direct measurement should demonstrate the validity of the use of indirect evidence in science.

Procedure:

1. Students will work in pairs. Each pair is provided with a steel ball bearing, a sheet of carbon paper, and a sheet of paper with a large rectangle (~ 2/3 of the page) containing a number of small circles drawn onto it.
2. Place a sheet of carbon paper (with the carbon side up) on the floor. The sheet of circles should be placed on the carbon paper, circle side down. If necessary, it can be held in place with a couple of pieces of tape.
3. Drop the ball bearing from a height of ~ 3 feet onto the sheet of paper, so that it lands somewhere within the rectangle. Try some preliminary shots on a plain piece of paper, to practice your aim and technique. The impact will cause the carbon paper to make a mark on the circle sheet, so that at the end of the exercise (100 drops later) you will be able to tell whether the ball hit within the rectangle, and whether it hit within a circle.
 - * The "dropper" has to ensure that the ball bearing hits within the rectangle, but not in the same place each time. We want a random but good coverage of the entire rectangle, because we are trying to sample its contents -- the circles -- without knowing precisely where they are located. (That's indicative of a vital difference between direct and indirect measurements.)
 - * The "catcher" has to ensure that the ball bearing does not bounce a second time on the paper and cause a false reading.
4. Each pair takes turns dropping the ball (25 drops each). When not dropping the ball, the other partner should be the catcher. Drop the ball from waist high. Remember: At least one hundred drops, as evenly distributed as possible over the **whole area** of the rectangle.
5. After 100 drops, count the total number of impact marks within the rectangle ("hits") and the total number of marks that are completely within circles ("circle hits"). Remember: A "circle hit" is defined as "completely within a circle". Record in the Results and Analysis section.
6. Count the number of circles on the page:
7. Measure the dimensions of the rectangle in millimeters and calculate its area: We know that the circles are of uniform size, and that the distribution of drops was random, so that let's make an assumption in the form of an equation:

Results/Analysis:

Step 1: We know that the circles are of uniform size and that the distribution of drops was random, so an assumption can be made in the form of a proportion using the equation:

$$\frac{\# \text{ circle hits}}{\# \text{ of hits}} = \frac{\text{total area of all circles}}{\text{area of the rectangle}}$$

Step 2: From that, you can calculate the total area of all the circles:

$$\text{Total area of all the circles} = \frac{\text{Total area of (circle hits)(area of rectangle)}}{\# \text{ of hits}}$$

Step 3: Now you can then calculate the area of a single circle:

$$\text{Area of one circle} = \frac{\text{Area of total area of all circles}}{\text{total number of circles}}$$

Step 4: After the above calculations, then calculate the radius of the circle.
Remember: Area of circle = $\pi (\text{radius})^2$

Step 5: Finally, compare the radius you have found by indirect measurement with a direct measurement of the radius of one of the circles with your ruler.

Step 6: Find the percent error by: $[(\text{direct measure}-\text{indirect measure})/\text{direct measure}]*100$. Show your calculations below.

Sources/References:

The National Teacher Enhancement Network. "Indirect Measurement" Contributors: Bruce Harper, Eugene McGraw, David Hayes.

<http://www.scienceteacher.org/k12resources/lessons/lessonK26.htm>

Fermi National Accelerator Laboratory. "A Laboratory Exercise in Direct Measurement".

<http://www-ed.fnal.gov/samplers/hsphys/activities/idmeas.html>

Conclusion:

The radius of the circle, determined by indirect method, compared to the radius of the circle using direct measurement and calculation. These two measurements should be close (5% error -15% error).

Assessment Questions:

- What would the result be if all your drops were circle hits?
- Is there an optimum percentage of circle hits that will give the optimum accuracy of indirect measurement? (Explain.)
- Would you expect the percentage of circle hits to be significantly different if you used a slightly smaller or larger ball bearing? (Explain.)
- How would the accuracy of this method of indirect measurement be affected if the rectangle contained fewer circles (i.e., circles of the same size as the ones in this exercise, but fewer of them)?
- Suppose that this laboratory exercise was a model of an experiment in a particle accelerator, using high-energy particles to study a sample of the alleged alien material from the Roswell incident. What would the rectangle represent? What would the circles and ball bearing represent?
- Explain how this activity compares to how Rutherford indirectly determined the size of the nucleus.

Modeling Rutherford's Scattering Experiment

(Adopted from the University of Virginia Physics Department)

Background Information:

Often we can look at or touch an object to learn about it. Sometimes, however, objects are too small or too large for us to learn about them this way. When this happens, we need to use indirect measurement techniques. Ernest Rutherford realized that atoms, which are the building blocks of nature, are much too small to be measured directly. Rutherford and his colleagues designed an experiment to measure the characteristics of atoms indirectly. The scientists used a thin piece of gold foil at which they directed alpha particles, which were like very small bullets. Though they could not see the atoms in the gold foil, they knew that if they watched where the alpha particles went after hitting the gold foil, they could draw conclusions about the gold atoms. Alpha particles are very small, but they are heavy. They also travel quickly, and they have a positive electrical charge. When the alpha particles collide with a specially designed screen that Rutherford placed around the gold foil experiment, the screen would light up at the point of the collision.

Imagine a stream of water from a garden hose directed at a brick wall. What would happen to the water as it impacted the wall? Rutherford thought alpha particles against the gold foil would behave much like water against the wall, but he was very surprised to find most of the alpha particles went straight through the foil. Imagine how you would feel if the water from the hose went straight through the wall! This experiment led Rutherford to conclude that an atom is actually mostly empty space with a small, dense, positively charged nucleus in its center.

Materials

- Small wooden block (approximately 6 inches across) cut into a triangular, circular or rectangular shape. Other shapes can be used as well.
- Large piece of plywood (or large, collapsed cardboard box like those in which refrigerators are delivered) which is much larger than the block and can be placed over the block so that the block cannot be seen (approximately 4'x 6')
- Marble or steel ball bearing (a ping pong ball or golf ball will also work)
- Supports for the corners of the plywood (spools work well)
- Blackboard or another surface to record data
- Tape, ruler and marker
- Hard, level floor

Procedure

1. On a level, hard floor set up the plywood or large box as shown. Center the wooden block to be used as the "unknown object" under the plywood so it is not

- visible to the students. (You may want to tape the small block in place so it will not shift when struck with the marble during the experiment.)
2. Marking off 3 inch increments on all edges of the board will aid in students identification of exit points.
 3. Each group of students (~ 4 students/group) forms a circle around the plywood.
 4. Draw a sketch of the plywood set-up on the board. Include on it the dimensions of the plywood and the approximate positions of the students around it. You may want to mark the positions on the floor for the students to sit to ensure that they remain properly spaced around the set-up. (This will increase the accuracy of the experiment.)
 5. One student at a time will be the "Launcher" and will roll the marble under the plywood on the floor. An area on one edge should be designated as the "Launch Area" so that all trials start from the same general location. The other students must be ready to catch the marble when it comes out from under the board. The marble should be launched fast enough it will roll straight through the set-up unless it collides with the center object.
 6. Record the path of the marble on a sketch of the set-up on the blackboard. The path should include the entrance and exit point from under the plywood and the position where the marble was caught. This helps visualize the angle of deflection for the marble. Additionally, point out to the students that the only way for the marble to be deflected is through collision with the small object in the middle. Assume the marble's path is straight line until it collides with the center object. Following the collision, the path is again straight.
 7. Students can rotate through the launching position so each has a chance to launch the marble. As students move to the launch position, have other students move around the set-up to ensure each position remains filled.
 8. After everyone has rotated through the launch position or after sufficient data are collected, examine the recorded paths followed by the marble. As a group, try to conclude the approximate size and shape of the wooden block.

Recommended "Rules"

1. *If the marble collides with one of the supports, do not use the trial. Re-launch the marble.*
2. *If the marble fails to exit from under the plywood, do not use the trial. Re-launch the marble.*
3. *When recording the paths of the marble, indicate trials where it collides with the unknown objects differently than those where it does not collide (different colored chalk, for example.)*

Assessment

1. Students identify examples from everyday life where objects are analyzed in a manner similar to the Rutherford Gold Foil experiment.

2. Students place themselves in the position of Ernest Rutherford following his gold foil experiment and write a short paper explaining their feelings about the outcome of the experiment along with their conclusions.

Sources/References:

University of Virginia Physics Department. "Indirect Measurement II".
<http://www.phys.virginia.edu/Education/outreach/8thgradesol/IndirectMeasure2.htm>