ROLLING WITH RUTHERFORD
TEACHER NOTES

DESCRIPTION
Students will perform an experiment similar to Rutherford's: they will fire a probe at a target and observe how often the path of the probe changes. In this case, the "probe" and the "target" are balls and the "firing" is replaced with "rolling." They will use their data to calculate the diameter of the ball. The activity allows the students to use indirect measurements to determine a parameter; it also allows the students to see how Rutherford made his influential discovery. That discovery yielded today's model of the atom.

STANDARDS ADDRESSED
Next Generation Science Standards

- Science and Engineering Practices
    - 4. Analyzing and interpreting data
    - 5. Using mathematics and computational thinking
    - 6. Constructing explanations
- Crosscutting Concepts
    - 4. Systems and system models

Common Core Literacy Standards

- Reading
    - 9-12.4 Determine the meaning of symbols, key terms . . .
    - 9-12.7 Translate quantitative or technical information . . .

Common Core Mathematics Standards

- MP1. Make sense of problems and persevere in solving them.
- MP2. Reason abstractly and quantitatively.
- MP4. Model with mathematics.

ENDURING UNDERSTANDING
- Indirect evidence provides data to study particles too small and fleeting to see.

LEARNING OBJECTIVES
Students will know and be able to:
- Describe the process that Ernest Rutherford used to determine the size of the nucleus.
- Apply simple probability to experimental data.
- Use indirect measurement to determine properties difficult (or impossible) to determine otherwise.
- Create and interpret a histogram. [optional]

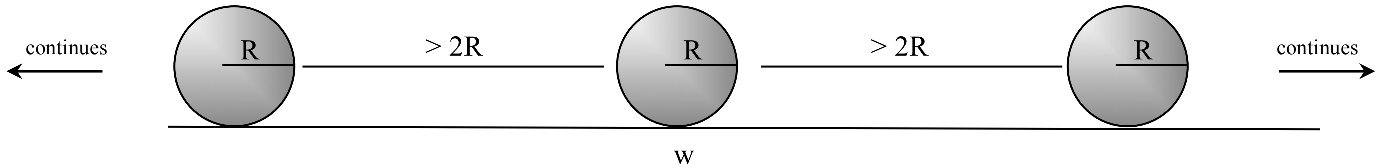
PRIOR KNOWLEDGE
Students must be able to keep careful records of observations and divide one integer into another.

BACKGROUND MATERIAL
Ernest Rutherford (1871-1937) is credited with the first measurements of the distribution of the positive charges in the atom. He showed us that the atomic charge is concentrated in a small nucleus. That model of the atom survives to this day.

Rutherford learned this by firing alpha particles at gold foil and observed the deflection in the alpha particle's path. This is an enduring example of *indirect measurement*. Rutherford used the data to determine the diameter of the nucleus.

Scientists often use indirect measurement in their work. For example, indirect evidence tells us all that we know about atoms, confirms the existence of black holes, and suggests the need for dark energy and dark matter.

IMPLEMENTATION
This activity uses no student handouts. We provide detail here for the teacher to use at his or her discretion when setting up the experiment for the class.



The cartoon on this page shows the simple setup. The “target” is a row of balls (or marbles) with spacing of at least one diameter between them. The “probe” is another ball rolled towards the row from the perpendicular. The roller shouldn’t attempt to aim the rolling ball. (A cardboard screen helps eliminate “aiming.”) You can use as many balls as you wish in the target. Pairs of students can work together to roll a marble many times and count the number of hits. A class can collect many hundreds of data points in one class period.

We set up the calculation in two steps. First, we work out the probability of the probe hitting one of the target balls. You may see that they will hit when their centers are closer than the sum of their radii. The probability of this happening is the ratio of the width of the target area “covered” by the target balls to the total width (w) of the target area. This probability increases directly as the number (n) of target balls present.

In symbols, this is $p = \dfrac{4n\sqrt{r_t r_i}}{w - 2r_i}$.

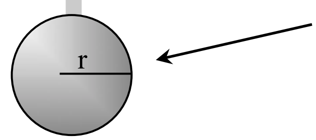
When the incident and target balls have the same radius, this simplifies to $p = \dfrac{4nr}{w - 2r}$.

Second, we recognize that students can *measure* this probability by rolling the probe at the target area (many, many times (t)) and counting the number of hits (h):

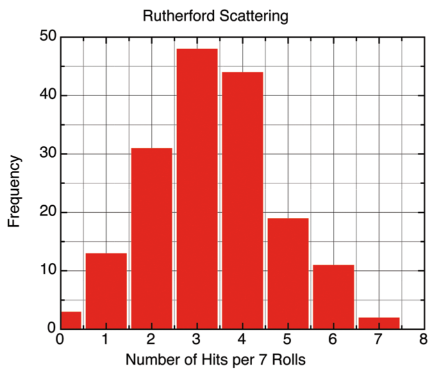
$$p = \frac{h}{t}$$

These two terms for *p* can be set equal and solved for the target radius r_t. There are two ways to simplify this equation. One (as noted above) is to use incident and target balls of the same radius. Another is to assume that $2r_i$ is negligibly small compared to *l*. All four solutions are below. Depending on their level, students should be encouraged to derive the solutions (which require algebra and simple geometry).

	$2r_i << l$ **not** assumed	$2r_i << l$ assumed	*w* is the width of the target area. *n* is the number of target balls. *h* is the number of hits. *t* is the number of times the probe was rolled.
Different Radii	$r_t = \left[\dfrac{h(w-2r_i)}{4nt\sqrt{r_i}}\right]^2$	$r_t = \dfrac{h^2 w^2}{16 n^2 t^2 r_i}$	
Equal Radii	$r = \dfrac{w}{\frac{4nt}{h} + 2}$	$r = \dfrac{hw}{4nt}$	



Probe – Roll towards the screened target a large number of times. Keep track of the hits and total number of trials.



The class can also learn about (or practice making) histograms with this activity. They must divide their work into consistent "runs"; a run contains a certain number of rolls (e.g., 7). Students count the number of hits in each run. Each data point then becomes "the number of hits in this particular run." (This will be some integer less than 8.) Doing so allows the class to create a group histogram of their data. Make a table that allows students to contribute their own runs to the class set.

The plot to the left shows the distribution of 150–200 runs of seven rolls each. Most runs had three or four hits; very few runs had seven. Plotting the histogram allows the students to see the data from another perspective. While it is impossible to directly use the plot to determine the ball's diameter, the students can use it to quickly determine how many rolls involved a hit and how many did not. We describe this ratio on the page that outlines the calculations: $p = \frac{h}{t}$.

ASSESSMENT

You might consider asking the students questions like:

(Some of these questions might be useful in small—or large—group discussions.)

- Would you expect more or fewer hits if you increased the number of balls in the target area? Why?
- Is the relationship between radius and the number of hits direct or indirect? Why is that?
- How many hits occurred in the runs that appear at the peak of the histogram?
- Look at the histogram and determine which is more likely to occur: 2 hits out of 10 or 6 hits out of 10.
- What is the diameter of the ball? How do you know this?
- Draw a simple sketch of the experiment that Rutherford used to measure the size of the nucleus.
- Contrast the activity that you did today with Rutherford's experiment.