# Alpha Scattering, Marbles, and Indirect Measurement

**Objectives:** To gain insight into scattering experiments and indirect measurement.

**Equipment:** One scattering box and one marble.

## Discussion

In this exercise you will learn how data acquired in scattering experiments can be used to gain information about systems that cannot be observed directly. Many systems of interest to physicists cannot be observed directly without great difficulty. Information about these systems such as their size and structure must be gained by indirect methods. Information about the nucleus of an atom, for instance, is generally gained by one of two methods. The first involves exciting the nucleus and measuring the radiation it emits. The second involves scattering beams of particles off the nucleus, counting the scattered particles, and measuring the patterns that result.

An example of the latter is a famous experiment by Rutherford, Geiger and Marsden in 1911 on the scattering of alpha (α) particles by gold nuclei. An α particle is a Helium atom with its two electrons stripped away ( i.e., the nucleus of a He atom) and a residual charge of +2*e*. Alpha particles are emitted during certain types of radioactive decay. In this experiment, Geiger and Marsden directed a narrow stream of α particles from a radioactive source to a thin gold foil by placing the source behind a lead shield with a small hole in it and placing the gold foil in the path of the beam on the other side of the shield. A zinc-sulfide screen, which gives off a flash of light when struck with an α particle, was placed on the other side of the gold foil (Figure 1). It was expected that α particles would pass through the gold foil with very little deflection. What Geiger and Marsden observed was that although most of the α particles passed through the foil undeflected, some were deflected through large angles and some were even scattered backwards. This experiment led the way to the concept of a nuclear atom. In this model, the atom consists of a small, positively charged nucleus where most of the mass of the atom is concentrated. The nucleus is surrounded by relatively distant electrons. Since the volume of an atom is composed largely of empty space it is easy to see why most of the α particles should pass through the foil undeflected. When, however, an α particle (+2*e*) comes near the positively charged nucleus the repulsive effect of the Coulomb force between the two results in scattering through various angles. The electrons surrounding the gold nuclei, being about 1/7000 as massive as the α particles have negligible effect on the scattering process.

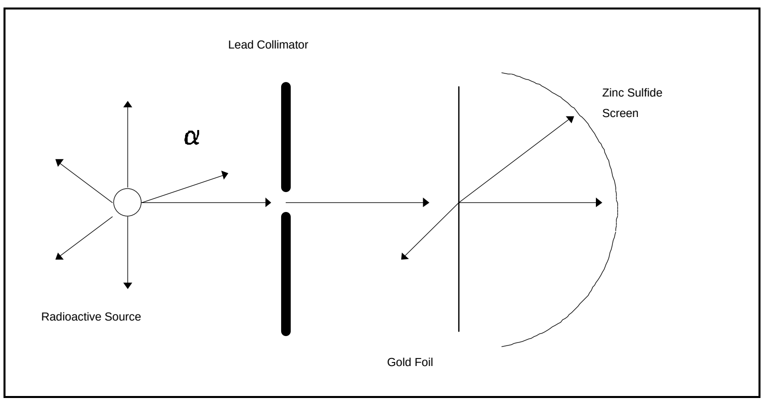

**Figure 1. The Rutherford Scattering Experiment.**

## Procedure

In this exercise you will attempt to determine the size of a hidden target by scattering marbles from a group of evenly-spaced pegs in a box (Fig. 2).

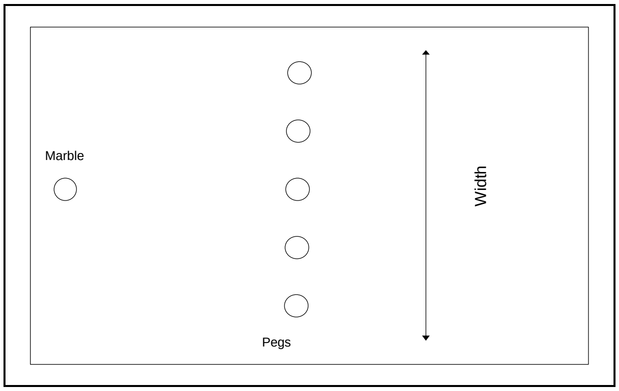


**Figure 2. Alpha Marble Scattering Apparatus.**

To emulate a particle beam, you will roll a marble many times *parallel* to the sides of the box. The purpose of rolling the marble parallel to the sides of the box is to produce a *collimated* beam, i.e., one in which all of the particles move in the same direction. You should not attempt to aim your marble at any particular peg. Rather, you should choose random points along the uphill end of the box from which to release the marble.

We are using five identical wooden pegs as targets. The probability of a collision between the marble and a peg depends upon the both the size of the pegs and the size of the bombarding marble. In this exercise we will not attempt to determine any pattern to the scattering data other than hit or miss. The number of hits for a given number of attempts will be used to determine the size of the unknown pegs. A roll in which the marble reaches the downhill end of the box without hitting a peg will be counted as a miss. A roll in which the marble collides with any number of pegs will be counted as a single hit.

In order for a hit to occur, the marble must come within a distance of the center of the peg equal to the sum of the radius of the peg (R) and the radius of the marble (r), i.e., (R + r). As indicated in Figure 3, the width blocked by one peg is D + d. The total width blocked by all of the

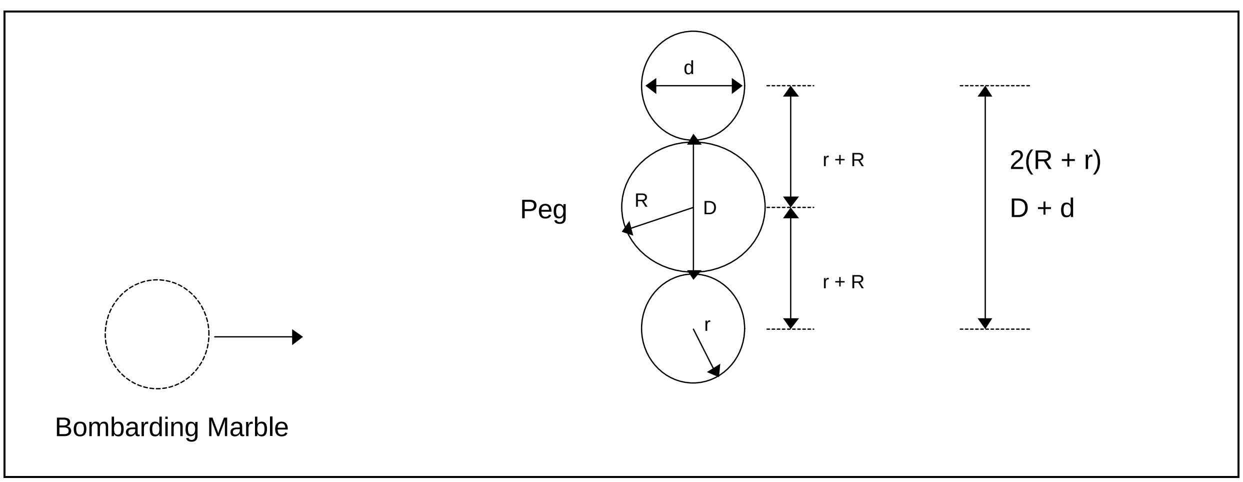


**Figure 3. The area blocked by each peg depends upon both the peg size and the marble size.**

pegs is simply the number of pegs times this quantity, i.e., N(D + d). When this expression is divided by the width of the box, the resulting expression yields the probability of hitting a peg with a random roll:

$$P = \frac{total\ width\ blocked}{total\ width} = N\frac{(D + d)}{W}$$

If the marble is rolled enough times, and the number of hits is divided by the number of rolls, this also yields the probability of hitting a peg with a single roll:

$$P = N\frac{(D + d)}{W} = \frac{hits}{rolls} = \frac{H}{R}$$

In these terms, we can solve for the diameter of a single peg, D:

$$D = \frac{WH}{NR} - d$$

Roll your marble 200 times. Remember to allow the marble to roll parallel to the sides of the box but from random locations along the top end of the box. Do not attempt to aim the marble. Keep an accurate record each roll as either a hit or a miss. Remember that if the marble collides with more than one peg it still counts as a single hit. The width of the box and the number of pegs has been provided for you. Measure the diameter of your marble (several times). You should be able to use this data to compute the diameter of the peg.

Your lab instructor will ask each group to report on their peg diameter. Calculate and record the class average and standard deviation. Remove the cover from the boxes and measure the peg diameters directly (an option the Rutherford, et al, did not have). How does this measurement correspond to the data collected by your class?

## Exercises

**1.** Compare/contrast this exercise with the Rutherford scattering experiment.

**2.** This procedure closely parallels experiments done with particle beam accelerators at I.S.U. What are the similarities between rolling a marble down a ramp at a target and accelerating a proton towards a target in a beam line in a linear accelerator?