97 Nuclear Marbles

Purpose

To determine the diameter of a marble by indirect measurement.

Required Equipment/Supplies

7 to 10 marbles
3 metersticks

Discussion

People sometimes have to resort to something besides their sense of sight to determine the shape and size of things, especially for things smaller than the wavelength of light. One way to do this is to fire particles at the object to be investigated, and to study the paths of the particles that are deflected by the object. Physicists do this with particle accelerators. Ernest Rutherford discovered the tiny atomic nucleus in his gold-foil experiment. In this activity, you will try a simpler but similar method with marbles.

You are not allowed to use a ruler or meterstick to measure the marbles directly. Instead, you will roll other marbles at the target "nuclear" marbles and, from the percentage of rolls that lead to collisions, determine their size. This is a little bit like throwing snowballs at a tree trunk while blindfolded. If only a few of your throws result in hits, you can infer that the trunk is small.

First, use a bit of reasoning to arrive at a formula for the diameter of the nuclear marbles (NM). Then, at the end of the experiment, you can measure the marbles directly and compare your results.

When you roll a marble toward a nuclear marble, you have a certain probability of a hit between the rolling marble (RM) and the nuclear marble (NM). One expression of the probability P of a hit is the ratio of the path width required for a hit to the width L of the target area (see Figure A). The path width is equal to two RM radii plus the diameter of the NM, as shown in Figure B. The probability P that a rolling marble will hit a lone nuclear marble in the target area is

$$P = \frac{\text{path width}}{\text{target width}}$$

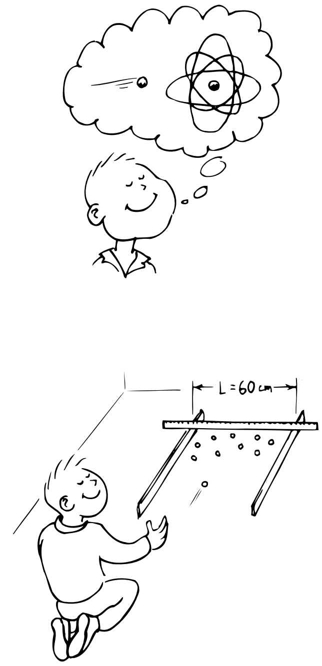

Fig. A

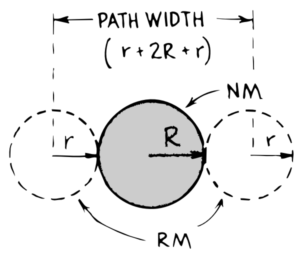

Fig. B

Activity

$$= \frac{2R + 2r}{L} = \frac{2(R + r)}{L}$$

where R = the radius of the NM

r = the radius of the RM

$R + r$ = the distance between the centers of an RM and an NM that are touching

and L = the width of the target area.

If the number of nuclear marbles is increased to N, the probability of a hit is increased by a factor of N (provided N is small enough that the probability of multiple collisions is small). Thus, the probability that the rolling marble will hit one of the N widely spaced nuclear marbles is

$$P = \frac{2N(R + r)}{L}$$

The probability of a hit can also be determined experimentally by the ratio of the number of hits to the number of trials.

$$P = \frac{H}{T}$$

where H = the number of hits

and T = the number of trials.

You now have two expressions for the probability of a hit. These two expressions may be equated. If the radii of the rolling marble and nuclear marble are equal, then $R + r = d$, where d is the diameter of any of the marbles. Combine the last two equations for P, and write an expression for d in terms of H, T, N, and L.

marble diameter d = _______________

This is the formula you are now going to test.

Procedure

Set up nuclear targets.

Step 1: Place 6 to 9 marbles in an area 60 cm wide (L = 60 cm), as in Figure A. Roll additional marbles randomly, one at a time, toward the whole target area from the release point. If a rolling marble hits two nuclear marbles, count just one hit. If a rolling marble goes outside the 60-cm-wide area, do not count that trial. A significant number of trials—more than 200—need to be made before the results become statistically significant. Record your total number of hits H and total number of trials T.

H = ___________

T = ___________

Step 2: Use your formula from the Discussion to find the diameter of the marble. Show your work.

computed diameter = ____________

Step 3: Measure the diameter of one marble.

measured diameter = ____________

Analysis

1. Compare your results for the diameter determined indirectly in the collision experiment and directly by measurement. What is the percentage difference in these two ways of measuring the diameter?

2. State a conclusion you can draw from this experiment.