45 The Nucleus

Nuclear Marbles

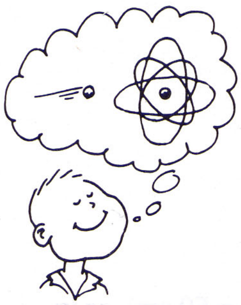
Purpose

To determine the diameter of a marble by indirect measurement.

Required Equipment and Supplies

6–10 marbles
3 metersticks
"Nuclear Marbles" simulation (optional)
Apple II Series computer (optional)

Discussion



People sometimes have to resort to something besides their sense of sight to determine the shape and size of things, especially when those things are smaller than the wavelength of light. One way to do this is to fire particles at the object to be investigated and study the path of the particles that deflect off the object. Physicists do this with particle accelerators. Ernest Rutherford inferred the size of the nucleus of a gold atom by studying how alpha particles were deflected by the nuclei of gold foil. In this experiment you will try a simpler but similar method with marbles.

You are not allowed to use the meterstick across the marble to measure it directly. Instead, you will roll other marbles at the target marble (or "nucleus") and, from the ratio of collisions to trials, determine their size. This is a little bit like throwing snowballs at a car while blindfolded. If you score very few hits compared to the number of throws, then you sense that the car is small.

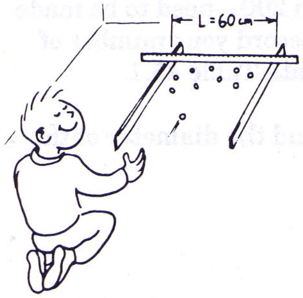


Figure 45.1

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

When you roll a marble toward a nuclear marble, there is 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 target width, L, of the target area (see Figure 45.1). The path width is equal to two RM radii plus the diameter of the NM, as shown in Figure 45. 2. The probability, P, that a rolling marble will hit a lone nuclear marble in the target area is

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

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

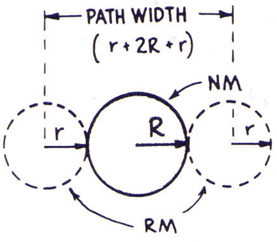


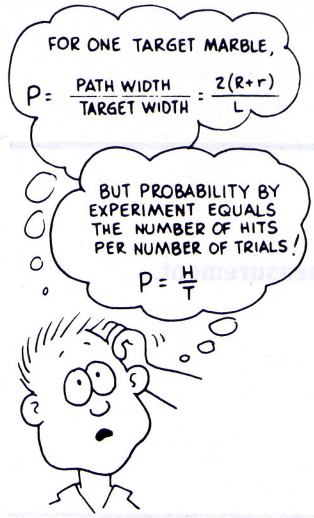
Figure 45.2

where R = the radius of NM

r = the radius of RM

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

L = the width of the target area



If the number of target marbles is increased to N, the probability of a hit is increased by a factor of N. Thus,

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

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

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

where H is the number of hits and T is the number of trials.

You now have two expressions for the probability of a hit. Assume that both of the expressions are equivalent. 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

Step 1. Place 6 to 9 marbles in an area 60 cm wide (L = 60 cm), as in Figure 45.1. Roll additional marbles toward the whole target area from the release point. If a rolling marble hits two nuclear marbles, it counts as just one hit. If an 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 number of hits, H, as you increase the number of trials, T, in Data Table 45.1.

Data Table 45.1

T(#)	d (cm)
10	
25	
50	
75	
100	
125	
150	
175	
200	
300	

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

diameter = ________

Step 3. Measure the diameter of one marble.

measured diameter = ________

Analysis

1. Compare your result for the computed diameter with your direct measurement of the marble's diameter. What percentage variation did you get between the computed diameter and the measured values?

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

Going Further

Compare your results to that of the computer using the "Nuclear Marbles" program, if it is available. Record the simulated value for the diameter of the marble for each of the number of trials in Data Table 45.2. How does the value for the diameter vary as the number of trials, N, increases? Compare these results with the measured diameter of the marble in Step 3 as well as the indirect measurement made in Step 2. How would you explain any differences between the three methods?

Data Table 45.2

T (#)	d (cm)
10	
25	
50	
75	
100	
125	
150	
175	
200	
300	