24 Conserving Your Momentum

Purpose

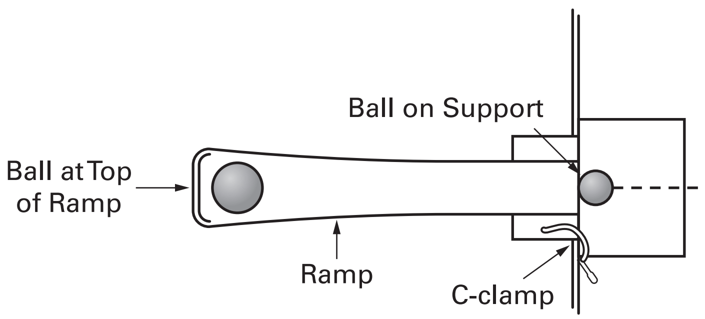
To investigate the momentum changes when two balls collide

Required Equipment/Supplies

collision in two dimensions apparatus or equivalent
one half-inch steel ball
one half-inch glass marble
plumb bob with string
C-clamp
carbon paper
blank paper, tape
meterstick
balance, preferably electronic
protractor
graph paper

Discussion

When you're playing pool, you strike the cue ball to hit the 8-ball. The cue ball comes to a stop and the 8-ball moves with the same speed and momentum the cue ball had. When a bowling ball strikes the pins, the ball slows down and the pins go flying. When one atom collides with a stationary one, the incoming atom bounces off in one direction while the target atom bounces in another direction. All these collisions have *changes of momentum*. A quantity is conserved when the amount before equals the amount after. In this experiment, you're going to investigate the momentum (mv) of two balls: one that rolls down a ramp and collides with the other, a stationary "target" ball. To keep things simple at first, you'll adjust the apparatus so that the collisions are along a straight line (one dimension). Then if time permits, you'll investigate what happens when the balls collide and fly off in different directions (two dimensions).



In this experiment, you're going to use similar techniques to those you learned in the lab Bull's Eye. You will compute the speeds of the first ball. In Bull's Eye you measured the horizontal speed of a ball to figure out its horizontal range (where it would land). In this lab, you're going to backtrack and use the horizontal range where the ball lands and the time of fall to figure out the speed of the ball as it leaves the ramp. Since the horizontal and vertical motions are independent of each other, the ball's horizontal speed does not change (at these low velocities air friction can be ignored). As in Bull's Eye, the time it takes the ball to fall is found by measuring the vertical distance, equating it to $\frac{1}{2}gt^2$, and solving for t. Therefore, the horizontal speed of the ball is simply the horizontal distance divided by the time it takes the ball to fall, (v_x/t).

Part A: Collisions in One Dimension

Procedure

Step 1: Clamp the ramp so that the lower end hangs just off the lab table. Make sure the ramp is horizontal at the table edge where the ball leaves the ramp. Arrange the apparatus as shown in Figure A. Notice that the set-screw at the bottom of the ramp has a depression at its top. This is the resting place for the target ball for each collision. Position the set-screw directly in front of the ramp and about one ball-radius away from the groove.

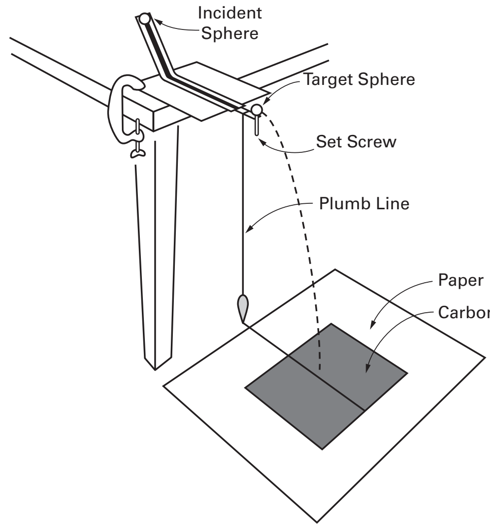


Fig. A

Step 2: Adjust the set-screw so that, when a ball is released from the ramp, it *just* misses it.

Step 3: Measure the height h the ball falls to the floor in centimeters. Solve for the free-fall time t it takes the ball to hit the floor when dropped from this height. Keep in mind that the time it takes for the ball to fall to the floor is *the same whether the ball is dropped from the ramp from rest or whether it rolls from the ramp*.

$h =$ ________ cm

$$h = \frac{1}{2}gt^2$$

Since your measurements for h are in centimeters, use $g = 980\ \text{cm/s}^2$, so that the cm units cancel. Show your calculations.

$t =$ _______ s

Step 4: As accurately as you can, measure the mass of the steel ball, m_b, and the glass marble, m_m.

$m_b =$ ________ g $m_m =$ ________ g

Step 5: Use the plumb bob to find the point right on the floor directly underneath the end of the ramp. Hold the string against the end of the ramp so that the weight on the end of the string just touches the floor. Tape a piece of paper on the floor and then mark a small "X" on the paper directly underneath the end of the ramp. All your distance measurements will be made from this point on the paper.

Step 6: You're almost ready to start taking data. First, make certain that the balls move horizontally after leaving the ramp. You can tell if the bottom portion of the ramp is level if the ball doesn't tend to roll when placed there. It may be necessary to adjust the set-screw slightly so that the glass marble is not too high or too low.

Step 7: Now, place the steel ball on the top of the ramp. Release it and observe where it lands. Tape another piece of paper to the floor so that the ball lands near the middle of the paper. Place a piece of carbon paper on top of the paper (carbon side down). Release the ball several times. Remove the carbon paper and mark the average position where the ball lands on the paper. Measure the distance in centimeters from the plumb bob mark to the average landing point. Record your measurement.

$d_{ball} =$ _______ cm

Step 8: Use the time you calculated in Step 3 and the distance you measured in Step 7 to calculate the horizontal speed of the ball as it left the ramp.

$v_x =$ _______ cm/s

Step 9: Calculate the momentum of the ball as it left the ramp.

$mv_x =$ _______ g·cm/s

Step 10: Place the glass marble on the set-screw so that its center is along the path of the center of the steel ball as the ball rolls down the ramp. Release the steel ball from the top of the ramp as you did in Step 8. The objective is to cause both the steel ball and the marble to move along the same line after they collide. It may take several trials to adjust the height and position of the marble to accomplish this. Once you're certain the balls land in a straight line, tape a piece of paper where each ball lands. Get ready to take data. As you did in Step 7, place a piece of carbon paper (carbon side down) on top of the sheets of paper to mark your landing points.

Step 11: Place the glass marble on the set-screw. Release the ball from the top of the ramp as you did in Step 8, allowing the ball and the marble to collide and land on the floor. Make certain that the ball and the marble always move along a straight line. Remove the carbon paper and mark the average landing point of the ball and the marble. Measure the distances, and then calculate the speeds and corresponding momenta as you did in Steps 8 and 9. Show your calculations.

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d_{ball} = ________ cm d_{marble} = ________ cm

v_{ball} = ________ cm/s v_{marble} = ________ cm/s

Analysis

1. What was the momentum of the steel ball as it left the ramp?

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2. What was the momentum of the steel ball after the collision with the marble?

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3. What was the momentum of the marble after the collision with the steel ball?

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4. How does the sum of the momenta of the steel ball and the marble compare to the steel ball before it left the ramp? Calculate the percent difference between them.

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5. Write down the equation for momentum conservation for the collision. Label what each variable represents in your equation.

equation: ______________________________

variables: ______________________________

Going Further

Choose an appropriate scale and draw a momentum vector to represent the momentum of the ball as it leaves the ramp. Appropriate means that the vector is at least half a page long or more.

Now draw momentum vectors for the steel ball and marble after the collision.

Part B: Collisions in Two Dimensions

Procedure

In Part A, we took great care to assure the balls moved in a straight line after the collision. The motivation for doing this was to keep the calculations relatively simple: the momentum of the steel ball as it left the ramp was simply the sum of the momentum of the steel ball and the marble after the collision.

$$m_x v_x = m_b v_b + m_m v_m$$

This time we will modify the experiment so the marble is off-center with the path of the steel ball. When they collide, they will move at different angles relative to the straight line after the collision. Let's call the direction parallel to the ramp the *x*-direction, and perpendicular to the ramp will be the *y*-direction.

Before proceeding, remember that momentum is a *vector* quantity. That means, *the sum of the components* equals *the resultant momentum vector.*

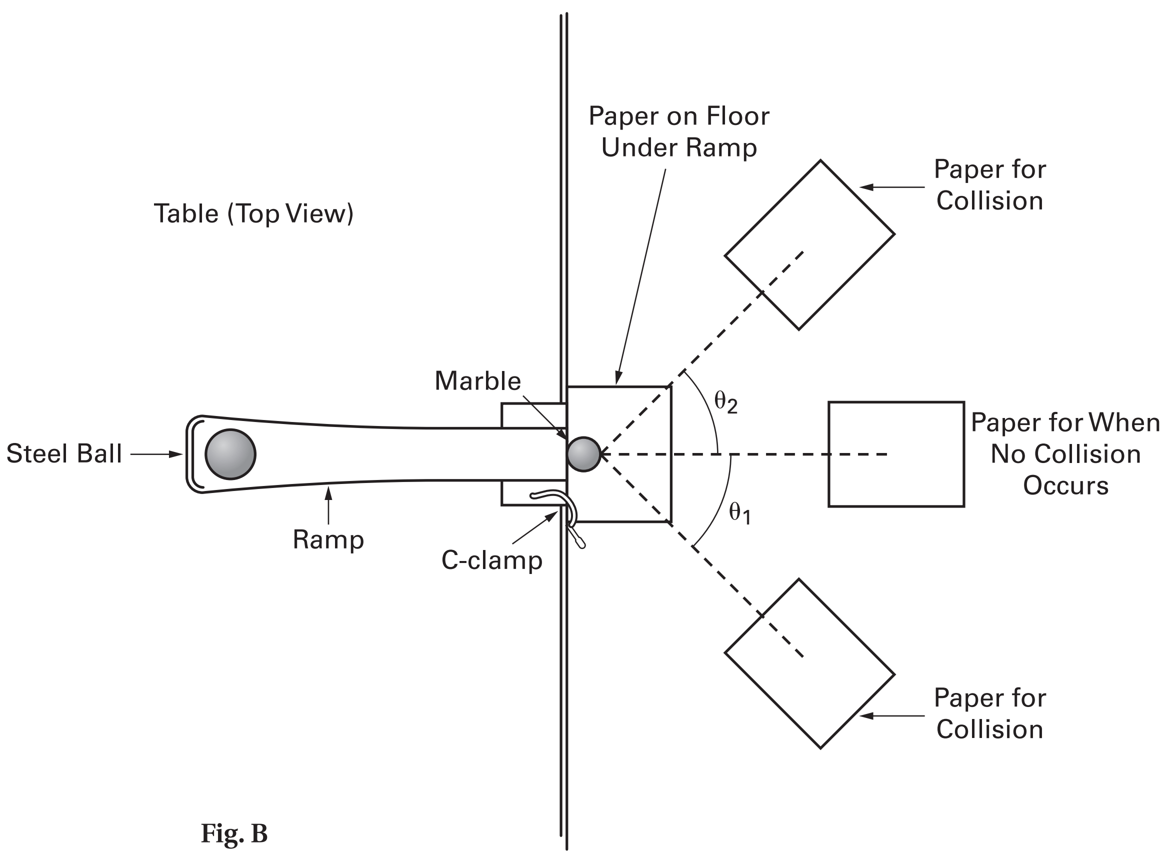

Fig. B

Since the steel ball and marble have no momentum in the *y*-direction before the collision, the momentum in the *y*-direction must also be zero after the collision in order to conserve momentum. Therefore, the *y*-component of the steel ball has the same magnitude (or length) as the *y*-component of the marble after the collision.

Employ the same procedure as in Part A except this time adjust the setscrew so that the steel ball and marble collide so that they move at an angle relative to the straight line the steel ball had by itself. Be sure to release the steel ball from the same position each time. Tape pieces of paper where the steel ball and the marble land. Place a piece of carbon paper on top of each paper. Release the ball several times and mark the average landing point. Measure the distances and the angles where the steel ball and marble land relative to the straight line the steel ball had alone. Calculate their corresponding velocities and momenta.

d_{ball} = ________ cm d_{marble} = ______ cm

θ_{ball} = ________ degrees θ_{marble} = _________degrees

v_{ball} = _________cm/s v_{marble} = _________ cm/s

mv_{ball} = ________ g·cm/s mv_{marble} = ________ g·cm/s

Analysis

Draw vectors on a piece of graph paper to represent the momentum of the steel ball after the collision. Resolve the momentum vector into *x*-components and *y*-components. If you're unsure how to do this, ask your teacher for assistance.

Now repeat the same procedure for the marble after the collision.

6. How does the sum of the *x*-components of the momenta of the steel ball and marble compare to the momentum of the steel ball alone? Calculate the difference between them.

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7. What is the sum of the *y*-components of the momenta of the steel ball and marble? Do your results support the conservation of energy?

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8. Identify sources of error.

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