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COLLISION IN TWO DIMENSIONS

CAT NO. PH0349CTD

Instruction Manual

INTRODUCTION:

Linear momentum is a vector quantity and therefore has both magnitude and direction. In the absence of external forces, linear momentum is conserved and the initial and final moment a must be equal *for each direction independently*. In this experiment, students can measure the momentum of a simple system of two spheres colliding elastically at the edge of a table. Students can vary the initial energy and momentum of the system and also the angle of collision by sending a steel ball down a ramp where another steel ball sits at rest on a rotatable platform. The initial and final velocities in each direction are determined by simple kinematic equations.

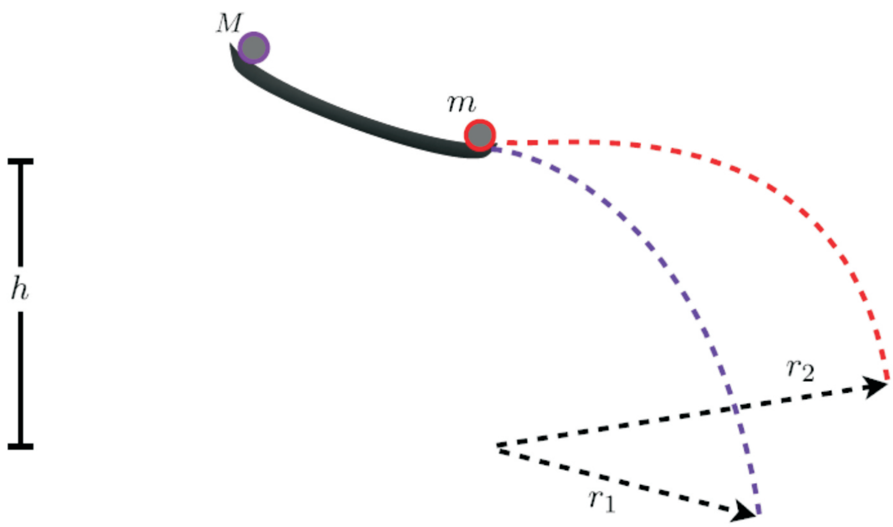
COMPONENTS:

Included Equipment:
Metal ramp with small rotatable platform
(2) Metal Balls
(1) Glass Ball
Plumb bob

Required Equipment not included:
Clamp (to attach ramp to table)
Carbon paper
Scale for obtaining masses
Protractor
Meter stick

GENERAL THEORY:

In this simple experiment, a short ramp sits at the edge of a table. A steel ball, *m*, is placed on a rotatable platform at the base of the ramp partially blocking the path. Another ball is sent down the ramp, an elastic collision occurs, and both balls then fly off the table at different angles. Students can measure the final location of each ball and apply kinematic equations to find what their velocity (and momentum) in each direction must have been immediately after the collision.

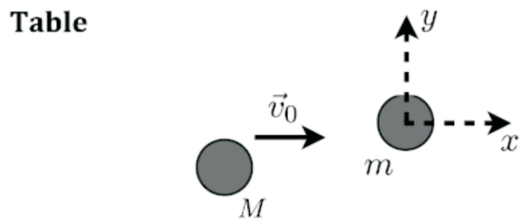


We will define the *x* direction as the one along the direction of the ramp and the *y* direction as the one perpendicular to it, as shown in the figures below.

Before Collision

Top-Down View

$$\vec{P}_i = M\vec{v}_0$$

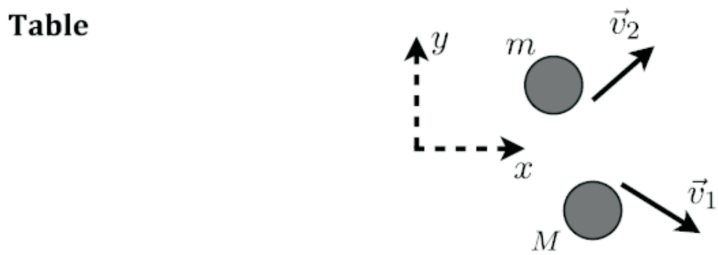


Just before the collision, all the momentum comes from the mass *M* and is solely in the *x*-direction.

After Collision

Top-Down View

$$\vec{P}_f = M\vec{v}_1 + m\vec{v}_2$$



After the glancing collision, each ball has momentum in the *x* and *y* directions and the total momentum is the vector sum of each. The momentum is conserved in each directly independently and we therefore find:

$$Mv_0 = Mv_{1_x} + mv_{2_x}$$

$$0 = Mv_{1_y} + mv_{2_y}$$

Notice that since there was no momentum in the *y* direction initially, the final momenta in the *y* direction must exactly cancel (have equal magnitude and be in opposite directions).Students can compare the momentum before and after the collision to see how closely the conservation law holds in this experiment. If the masses are equal then they cancel out of the equations above, and the conservation of momentum leads directly to the following relationship between the velocities:

$$v_0 = v_{1_x} + v_{2_x}$$

$$0 = v_{1_y} + v_{2_y}$$

(Equal masses)

By measuring where the balls land, students can infer what the velocities must have been when they left the table. After the balls leave the table they are in freefall and there is no acceleration in the *x* or *y* directions. The distance the balls will travel is simply given by:

$$x = v_x t$$

$$y = v_y t$$

The time of flight, *t*, can be found by measuring the height the balls fall, *h* (the height of the table plus the small distance to the center of the ball on the ramp) and using the kinematic equation:

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

where *g* is the acceleration due to gravity. Solving for *t,* we find:

$$t = \sqrt{\frac{2h}{g}}$$

Students will use the time of flight and measured distances to calculate the velocity of the balls in each direction immediately after collision:

$$v_{1_x} = x_1/t \qquad v_{2_x} = x_2/t$$

$$v_{1_y} = y_1/t \qquad v_{2_y} = y_2/t$$

To find the initial velocity of the moving ball *M* before the collision, students can repeat the procedure above without the second ball *m.* They can let *M* slide down the ramp and off the table and measure the distance it falls x_0. The time of flight remains the same and the velocity is therefore:

$$v_0 = x_0/t$$

Sample Procedure:

- Set up apparatus on a table, using a clamp to secure (position the end of the ramp at the edge of the table)
- Mark the location of the end of the ramp on the floor
- Tape paper to the floor with carbon paper on top in front of the ramp where the balls are expected to land
- Rotate the platform and record the angle it makes with the ramp
- Put a ball on top of the platform
- Release another ball from the top of the ramp
- Measure the distance where the balls lands
- Repeat, rotating the platform until the balls no longer collide

Sample Calculations:

- Compute the velocity of ball leaving ramp in non-collisional case. Compare the Kinetic Energy of the ball at the bottom of the ramp to the Potential Energy of the ball at the top of the ramp. *Advanced students can take into account rotational Kinetic Energy (=1/5Mv_o^2).*
- Compute the Kinetic Energy of the ball at the bottom of the ramp before collision. Compare to the Kinetic Energy of the system just after collision.
- Compute the momentum of the ball at the bottom of the ramp before collision. Compute the momentum of each ball just after collision. Compare to the momentum of the system just after collision. *Remember momentum is a vector quantity.*

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