Conservation of Momentum: Marble Collisions
Student Advanced Version

In this lab you will roll a marble down a ramp, and at the bottom of the ramp the marble will collide with another marble. You will measure the speed of each marble before and after the collision to determine whether momentum is conserved in this system for collisions between marbles of varying relative masses.

Key Concepts:

- ***Velocity*** is the rate of change of an object's position over time.
- ***Momentum*** is the quantity of motion an object has, given by the product of an object's mass and velocity. The momentum of a system is conserved in a collision.
- ***Kinetic energy*** is the energy an object in motion has.
- An ***elastic collision*** is a collision between at least two objects in which the total kinetic energy is conserved.
- In an ***inelastic collision***, on the other hand, some kinetic energy is lost to other forms of energy or processes but the total momentum is still conserved.

Part 1 – Equal Masses

In this first part, you will determine whether momentum is conserved for a collision between two marbles of equal masses.

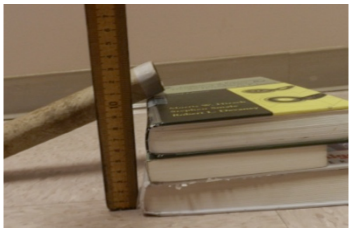
1. Measure the mass of one marble using an electronic scale.

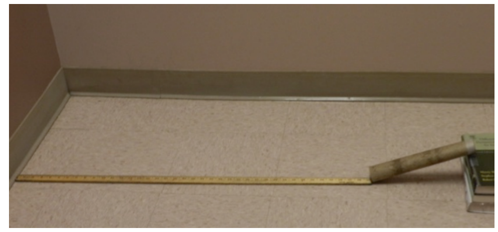
Note: For this situation of the lab, we'll be working with the marbles that are the same size, so in the table below, the mass of top marble should equal the mass of bottom marble.

Marble	Mass (g)
Top	
Bottom	

2. Place textbooks (or other props) on a smooth, flat surface, such as a floor or table, approximately 1 m away from wall. With a meter stick, **give them a height of 5 cm.**

3. **Lean a grooved ruler or paper towel tube against the textbooks (or other props) so that the top end is at the 5 cm height while the other end is touching the floor.** The ramp should be positioned so that the marble rolled down the ramp will roll across the floor and collide with the wall.

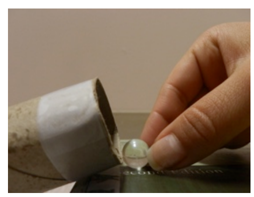


4. Tape down the top of the ramp onto the textbooks/props (if needed).

5. Place Top Marble at the top of the paper towel tube ramp.

6. Place the other Marble at the bottom of the ramp, directly in the path of where the first marble will roll.

7. **Measure the distance (in meters) from Bottom Marble** to the wall that it will eventually hit.

   Distance to wall: ___________________ (m)

8. **Calculate and record the initial velocity of each marble** in the table below using the laws of conservation of energy (the velocity of the stationary Bottom Marble is 0 m/s).

   a. Due to gravitational potential energy (GPE), all unsupported objects fall downward with a "gravitational acceleration" of 9.8 m/s^2. The total GPE is a product of mass m, gravitational acceleration g, and height h:

   $$\text{GPE} = mgh$$

   b. Conservation of energy states that the marble's kinetic energy at the bottom of the ramp is equal to its GPE at the top of the ramp.

   c. To find the velocity v of the rolling marble, set the two equations equal to each other and solve for the unknown variable v.

   Kinetic Energy = Gravitational Potential Energy

   $$(\tfrac{1}{2})mv^2 = mgh$$

** By rearranging the above equation, v(initial) = $\sqrt{[2gh]}$ **
** To convert height in cm to height in m, multiply the height in cm by 0.01 **

Marble	g (acceleration)	Height (m)	Initial Velocity (m/s)
Top	9.8 m/s^2		
Bottom	9.8 m/s^2		

Q1. If momentum is conserved, what do you think will happen when the two marbles make contact with each other?

Q2. Assume this will be an elastic collision, meaning that the velocity of the Top Marble is transferred to the Bottom Marble. Calculate the time it will take marble 2 to cross the 1 m distance to the wall.

9. **Calculate and record the initial momentum of each marble** using the formula: p = mv, where p is momentum, m is mass and v is velocity. Add the two individual momentums to get the total initial momentum.

** p = mv **

Marble	Mass (g)	Velocity (m/s)	Initial Momentum (g·m/s)
Top		1 m/s	
Bottom			

Total initial momentum (g·m/s) =

10. Have one student prepare to start recording on Audacity as soon as the Top Marble is rolled down the paper towel ramp.

11. **Start Audacity, wait a few seconds, then roll the Top Marble** by simply releasing it at the top of the ramp without pushing it down at all.

12. **Observe the collision and make sure that the collision sound recorded on Audacity.** If not, redo the procedure or adjust the microphone until a peak in the sound recording appears at the moment of the collision.

13. **Redo steps 17 and 18, this time having one student focusing on Top Marble and stopping its motion as soon as Bottom Marble hits the wall.**

14. Stop recording on Audacity after Bottom Marble hits the wall (there should also be a sound peak at the moment of collision with the wall).

15. **Measure and record the distance traveled by Top Marble after the collision.**

16. **Measure the time difference between the two collision sound peaks on Audacity.** This corresponds to the time spent rolling after the collision by both Top Marble and Bottom Marble. Record this time below and use it to **calculate the velocity of each marble.**

** v = distance / time **

Marble	Distance (m)	Time (s)	Final Velocity (m/s)
Top			
Bottom			

17. **Calculate the final momentum of each marble** and add the two individual momentums to get the total final momentum.

** p = mv **

Marble	Mass (g)	Velocity (m/s)	Final Momentum (g·m/s)
Top			
Bottom			

Total final momentum (g·m/s) =

Q3. Do the marbles' final momentums add up to the total initial momentum? If not, what are some sources of error in your procedure?

Q4. Was this experiment an example of an elastic collision or an inelastic collision? How do you know?

Part 2 – Different Masses

In this part, you will determine whether momentum is conserved if the mass of the marble at the top of the ramp is less than that of the marble at the bottom of the ramp.

1. Exchange one of the marbles for a marble with a different mass.

2. **Measure the mass of the marbles** using an electronic scale.

Marble	Mass (g)
Top (small)	
Bottom (large)	

Q5. How do you think the Top Marble's lower mass will affect the momentum and velocity of the larger Bottom Marble after the collision? Explain.

3. Place the smaller marble at the top of the ramp; place the larger marble at the bottom of the ramp, directly in the path of where the first marble will roll.

4. **Calculate and record each marble's initial velocity**, referring to step 8 of part 1.

Marble	g (acceleration)	Height (m)	Initial Velocity (m/s)
Top (small)	9.8 m/s^2		
Bottom (large)	9.8 m/s^2		

Q6. Assume this will be an elastic collision, meaning that the velocity of the Top Marble is transferred to the Bottom Marble. Calculate the time it will take the Bottom Marble to cross the 1 m distance to the wall.

5. **Calculate the initial momentum of each marble.** Add the two individual momentums to get the total initial momentum, referring to step 9 of part 1.

** p = mv **

Marble	Mass (g)	Velocity (m/s)	Initial Momentum (g·m/s)
Top (small)			
Bottom (large)			

Total initial momentum (g·m/s) =

6. Have one student prepare to start recording on Audacity just before the Top Marble is rolled down the paper towel ramp.

7. **Start Audacity, wait a few seconds, then roll Top Marble** by simply releasing it at the top of the ramp without pushing it down at all.

8. **Observe the collision and make sure that the collision sound recorded on Audacity.** If not, redo the procedure or adjust the microphone until a peak in the sound recording appears at the moment of the collision.

9. **Redo steps 7 and 8 this time having one student focusing on Top Marble and stopping its motion as soon as Bottom Marble hits the wall.**

10. Stop recording on Audacity after Bottom Marble hits the wall (there should also be a sound peak at the moment of collision with the wall).

11. **Measure and record the distance traveled by the Top Marble after the collision.**

12. **Measure the time difference between the two collision sound peaks on Audacity.** This corresponds to the time spent rolling after the collision by both marbles. Record this time below and use it to **calculate the velocity of each** marble, referring to step 16 of part 1.

Marble	Distance (m)	Time (s)	Final Velocity (m/s)
Top (small)			
Bottom (large)			

13. **Calculate the final momentum of each marble** and add the two individual momentums to get the total final momentum, referring to step 17 of part 1.

Marble	Mass (g)	Velocity (m/s)	Final Momentum (g·m/s)
Top (small)			
Bottom (large)			

Total final momentum (g·m/s) =

Q7. Did the fact that Bottom Marble had a larger mass have an effect on the velocity of either marble after the collision?

Q8. Do the marbles' final momentums add up to the total initial momentum?

Part 3 – Switch!

In this part, you will determine whether momentum is conserved if the mass of the marble at the top of the ramp is greater than that of the marble at the bottom of the ramp.

1. This time, **place the larger marble (at the top of the ramp; place the small marble at the bottom of the ramp, directly in the path of where the first marble will roll.**

2. **Calculate and record the initial velocity of each marble**, referring to step 8 of part 1.

Marble	g (acceleration)	Height (m)	Initial Velocity (m/s)
Top (large)	9.8 m/s^2		
Bottom (small)	9.8 m/s^2		

Q9. Assume this will be an elastic collision, meaning that the velocity of the Top Marble is transferred to the Bottom Marble. Calculate the time it will take the Bottom Marble to cross the 1 m distance to the wall.

3. **Calculate the initial momentum of each marble.** Add the two individual momentums to get the total initial momentum, referring to step 9 of part 1.

** p = mv **

Marble	Mass (g)	Velocity (m/s)	Initial Momentum (g·m/s)
Top (large)			
Bottom (small)			

Total initial momentum (g·m/s) =

4. Repeat steps 6-10 from part 2.

5. **Measure and record the distance traveled by Top Marble after the collision.**

6. Record the time each marble spent rolling after the collision and use this time to **calculate the velocity of each marble,** referring to step 16 of part 1.

Marble	Distance (m)	Time (s)	Final Velocity (m/s)
Top (large)			
Bottom (small)			

7. **Calculate the final momentum of each marble** and add the two individual momentums to get the total final momentum, referring to step 17 of part 1.

Marble	Mass (g)	Velocity (m/s)	Final Momentum (g·m/s)
Top (large)			
Bottom (small)			

Total final momentum (g·m/s) =

Concept Questions

Q10. *What do your observations from part 2 and the results of this section tell you about the relationship between mass and momentum?*

Q11. *Based on your response to the previous question, what are some ways an object can increase its momentum?*

Q12. *Who do you think would have a greater momentum, a 25 kg person running at 10 mph, or a 40 kg person running at 5 mph?*