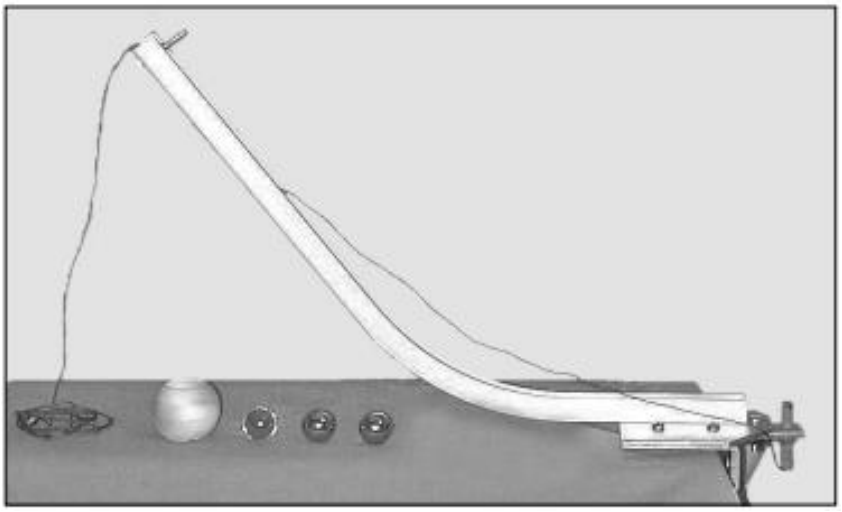
ARBOR SCIENTIFIC

Name(s) > ______________________________

Collisions! → Law of Conservation of Momentum

In this lab, you will use the ***Collision in Two Dimensions Apparatus*** to investigate the concept of **Conservation of Momentum and Energy** during collisions. A metal curved ramp is attached by a table clamp with an adjustable target support and a plumb line attached to the bottom of the target support. (See diagram below)
The kit includes two identical steel balls, a glass ball of the same diameter, and a larger hollow wooden ball. Elastic, inelastic, and partially elastic collisions will be determined using a combination of the steel, glass and wood balls from your experiments.

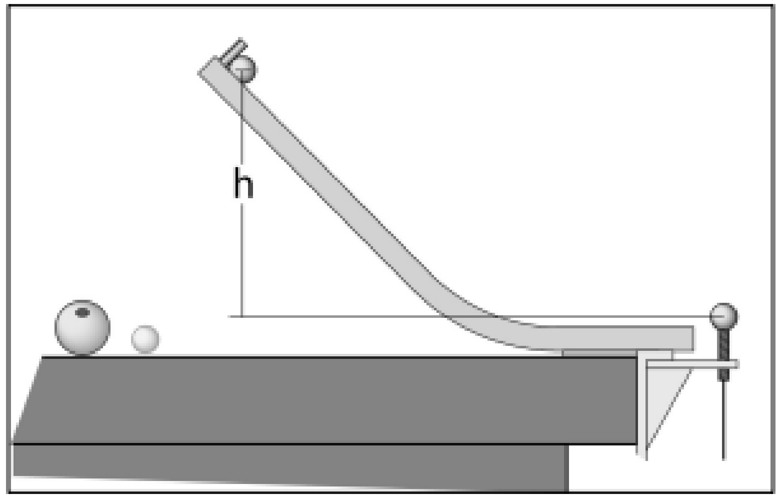


Lab Concepts and Objective

A target ball will be placed on the target support, and a second ball is placed on the track at the top of the inclined ramp, resting against the "starting" peg. When the upper ball is released, it will run down the ramp and strike the target ball, which will follow a parabolic trajectory and land on the floor. The **Distances** of both balls will be measured from the plumb line point (directly below the impact/target holder) to the impact points for each ball. From those experiments, you will be able to calculate Conservation of Momentum and Energy for each trial in this lab. Example calculations will be illustrated below.

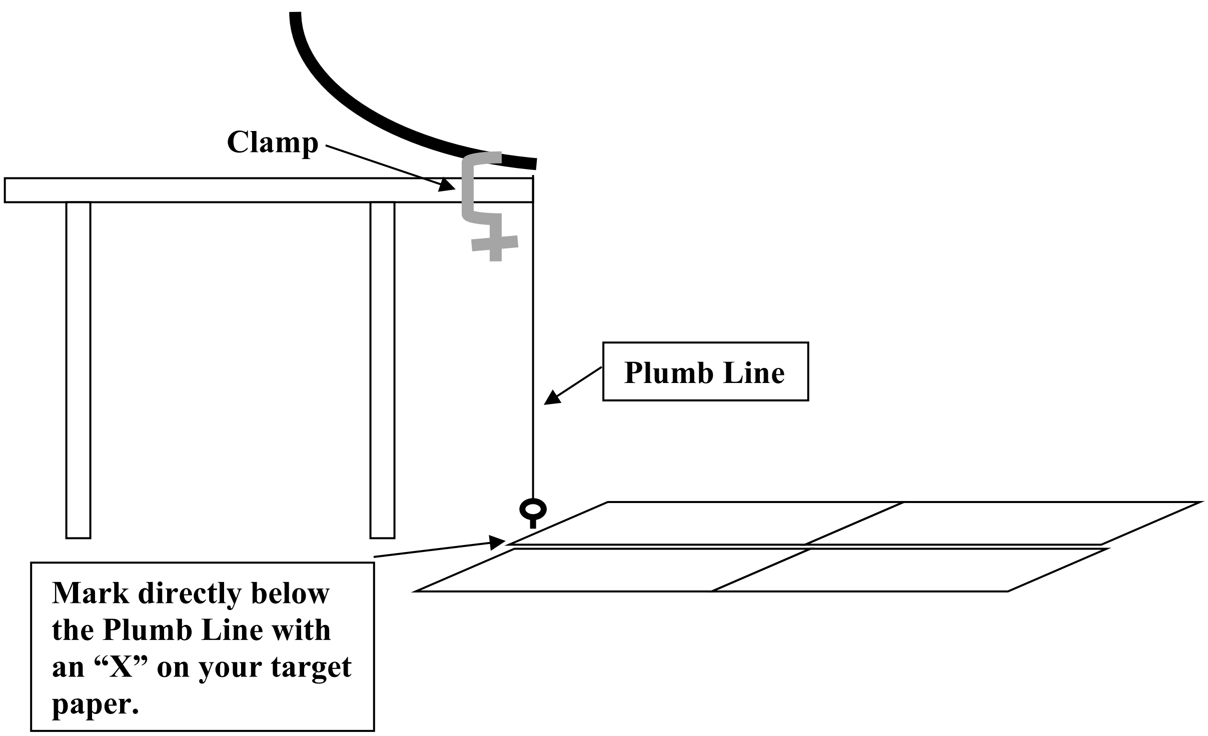
Materials

- *Collision in Two Dimensions Apparatus*
- Steel/Glass/*Hollow* Wood ball
- Metric measuring tape/meter stick
- Plain white paper
- Scotch or Masking tape
- Graphite Transfer Paper
…formally Carbon paper)
- Electronic Digital Balance



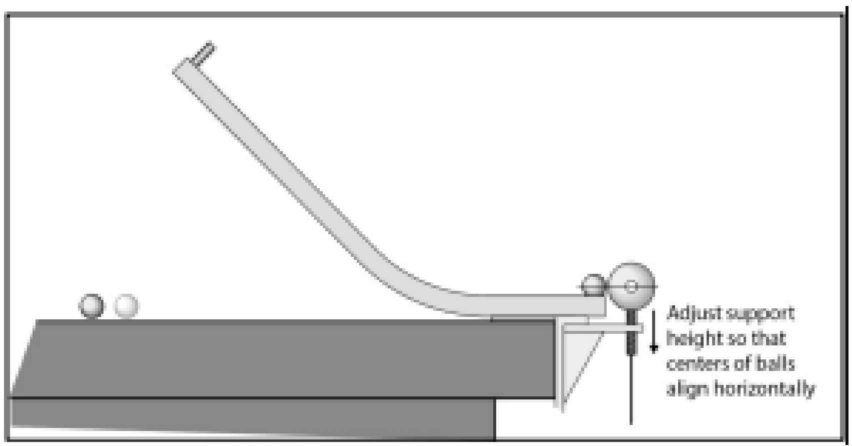
Set-Up

1. Set up the ramp and clamp to the lab table as shown in the diagram (Page #1).
2. Take **4 sheets of paper** and tape them together as shown. Secure them to the floor with a piece of tape. (…as shown in the schematic shown below). This is your **Target Paper**.
3. Be certain that the **plumb line** is directly over the paper and mark its position on the paper as shown in the diagram. You will need to do this for **EACH** trial. There are **Three Trials** so you will need to this set-up **three separate times**!



Experiment

1. Set the **Steel Ball** on the **Target Support** and place the other **Steel Ball** at the end of the track NEXT to the Target Ball to make sure that their centers are at the same height. Adjust the height of the Target Support if necessary.
   You will not have to change the Target Support height using the Glass Ball but when using the Wood Ball, you MUST make a height adjustment because the Wood Ball is much larger. For each experiment, it is always vital that each Steel-to-Steel/Steel-to-Glass/Steel-to-Wood Ball collisions, occur at the **Centers of each ball**.



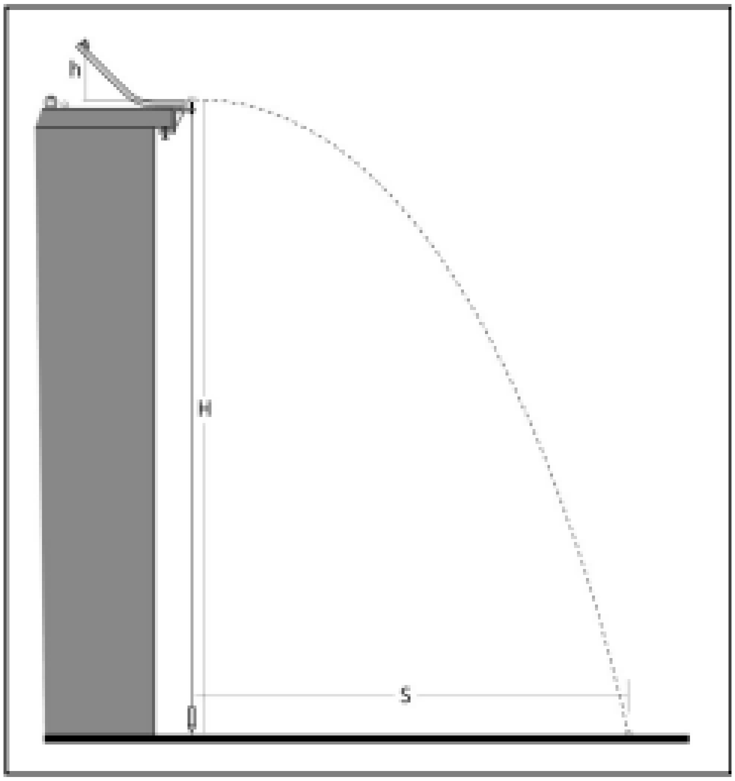
2. Place a piece of **Graphite Transfer Paper** over your Target Paper and place a **Steel Ball** at the Starting Peg and a Steel Ball should be resting on the Target Support.
3. Mark an **"X"** directly below the plumb bob on the paper (…as shown on page 2). This will be used later in the experiment when you do your measurements.
4. Release the Steel Ball and allow the collision to occur, making certain that the Target ball lands on the **Graphite Transfer Paper** and that the Target Ball makes a "mark" on the paper. If the Target Ball does not hit the Graphite paper, then adjust the paper and repeat the experiment.
5. Remove the Target papers and **label** them as **"Trial #1-Steel/Steel collision".**
6. **Repeat the experiment** with the **Glass Ball** as the Target Ball. Remember to mark the point below the plumb bob on the Target Paper and label as **"Trial #2-Steel/Glass collision".**
7. **Repeat the experiment again** with the **Wood Ball** as the Target Ball. Remember to mark the point below the plumb bob on the Target Paper and label as **"Trial #3-Steel/Wood collision".**

Measurements and Calculations

1. Using the diagram below, make the following measurements and record them in **Table A**.

Table A

Height (h)	Height (H)	Distance (S)	Mass of Steel Ball (kg)	Mass of Glass Ball (kg)	Mass of Wood Ball (kg)



2. The **Target Ball has an Initial Velocity = to "0"**. You must find the **__Initial Velocity__** of the rolling Steel Ball at the moment of impact. Knowing the Initial Velocities and Masses of the two balls, you will be able to calculate the **Total Momentum of the System before the collision**.

2A. Using **PE = mgh**, Calculate the **PE (Potential Energy)** of the Steel ball (Rolled) at the Starting Peg Height.

- h = (Starting) Height of Steel Ball (meters)
- m = Mass of Steel Ball (kg)
- g = Acceleration due to Gravity (9.81 m/s^2)

PE (steel ball at the Starting Peg) = ________ **Joules**

2B. The **Law of Conservation of Energy** states that the **PE** of the Steel Ball at the top of the ramp will **__equal__** the **KE (Kinetic Energy)** at the bottom of the ramp (…BEFORE the collision).

KE (steel ball at the bottom of the ramp) = ________ **Joules**

2C. Using **KE = $\frac{1}{2}$mv^2**, Calculate the **Velocity** of the Steel ball at the moment of impact.

- KE = Energy (Joules)
- m = Mass of Steel Ball (kg)

Velocity (BEFORE the collision) = **m/s** Enter the value into **Table B.**

2D. You will need to find the **Velocity of the Target Ball AFTER the Collision**. Using the **Height (H)** to find the **Time (t)** of flight of the Target Ball and the **Distance (S)** the Target Ball travelled, you can calculate the **Velocity of the Target Ball AFTER the collision**. Remember that the Vertical Time of fall will <u>EQUAL</u> the Horizontal Time of flight since the Vertical and Horizontal Velocities are <u>INDEPENDENT</u> of each other.

Using **H = $\frac{1}{2}$ gt^2**, find the **<u>Time of Flight</u>** for the Target Ball.

- H = Height of Target Ball (meters)
- t = Time of Vertical Fall (seconds)
- g = Acceleration due to Gravity (9.81 m/s^2)
-

Time (Flight time Target ball) = **seconds**

Measure the **Distance (S)** where the Target Ball landed from the plumb bob marked spot. Using **V = *S/t***, find the **Velocity of the Target ball AFTER the collision**.

- S = Distance of Target Ball AFTER the collision (meters)
- t = Time of Flight-SAME Time as the Time of Vertical fall (seconds)
- V = Velocity of Target Ball AFTER the collision (m/s)

Velocity (Target ball AFTER the collision) = **seconds**

Enter the value into **Table B.**

The Law of Conservation of Momentum states that the **Total Momentum of the System before the collision will = the Total Momentum of the System after the collision**.
Therefore, for each experiment, use the relationship:

$$m_1v_1 + m_2v_2 = m_1v_1 + m_2v_2$$

Table B – Steel/Steel Collision

Mass of "rolled" Steel Ball (kg)	Velocity of "rolled" Steel Ball BEFORE the collision (m/s)	Mass of "target" Steel Ball (kg)	Velocity of "target" Steel Ball BEFORE the collision (m/s)	Momentum of System BEFORE the collision (kg·m/sec)

Mass of "rolled" Steel Ball (kg)	**Velocity of "rolled" Steel Ball AFTER the collision (m/s)**	**Mass of "target" Steel Ball (kg)**	**Velocity of "target" Steel Ball AFTER the collision (m/s)**	**Momentum of System AFTER the collision (kg·m/sec)**

4. Keeping the **<u>SAME</u>** experimental procedure, now use the **<u>Glass Ball</u>** as the Target Ball. Be certain to find the **<u>Mass</u>** of the Glass Ball and use the identical method in calculating the **<u>Momentum of the Steel/Glass Ball System</u>** just as you did in the previous experiment.

<u>IMPORTANT!</u> **It IS possible that Velocity of the rolled Steel ball AFTER the collision is NOT "zero". In that case, you will employ the SAME calculations in finding the Velocity AFTER the collision for BOTH balls.** Record all value(s) in **Table C.**

Table C – Steel/Glass Collision

Mass of "rolled" Steel Ball (kg)	Velocity of "rolled" Steel Ball BEFORE the collision (m/s)	Mass of "target" Glass Ball (kg)	Velocity of "target" Steel Ball BEFORE the collision (m/s)	Momentum of System BEFORE the collision (kg·m/sec)
Mass of "rolled" Steel Ball (kg)	**Velocity of "rolled" Steel Ball AFTER the collision (m/s)**	**Mass of "target" Glass Ball (kg)**	**Velocity of "target" Glass Ball AFTER the collision (m/s)**	**Momentum of System AFTER the collision (kg·m/sec)**

5. Keeping the **SAME** experimental procedure, this time use the **HOLLOW Wood Ball** as the Target Ball. Be certain to find the **Mass** of the Wood Ball and use the identical method in calculating the **Momentum of the Steel/Wood Ball System** just as you did in the previous experiment.

5A. Before rolling the steel ball down the ramp, take a small piece of masking tape and cover one end of the Hollow Wood Ball with the tape.

5B. Place the Wood Ball on the Target peg with the hole opening lined up, facing and in-line with the ramp. When the steel ball is released, it will enter the hole, stick inside the Hollow Wood Ball and BOTH will travel down and strike the target paper.

IMPORTANT! This collision is different than the previous 2 experiments because the two balls fall as one!
However, you will employ the SAME calculations in finding the Velocity AFTER the collision for BOTH balls. Record all value(s) in **Table D.**

Table D – Steel/Wood Collision

Mass of "rolled" Steel Ball (kg)	**Velocity of "rolled" Steel Ball BEFORE the collision (m/s)**	**Mass of "target" HOLLOW Wood Ball (kg)**	**Velocity of "target" HOLLOW Wood Ball BEFORE the collision (m/s)**	**Momentum of System BEFORE the collision (kg·m/sec)**
Combined Mass of "Steel/Wood" Ball (kg)	**Velocity of "rolled" "Steel/Wood" Ball AFTER the collision (m/s)**	**Mass of "target" HOLLOW Wood Ball (kg)**	**Velocity of "target" HOLLOW Wood Ball AFTER the collision (m/s)**	**Momentum of System AFTER the collision (kg·m/sec)**

Analysis and Conclusions

Compare the Momentum of EACH system Before and After the Collisions.
Determine whether or not **Momentum was Conserved** in EACH case.

For the Steel/Steel collision…

Momentum of System BEFORE the collision (kg·m/sec)	Momentum of System AFTER the collision (kg·m/sec)

1a. Was Momentum **Conserved** for the Steel/Steel Ball collision experiment?

1b. What might have been the sources of **error** in your experiment?

1c. All of the balls *MAY* have lost *some* momentum during the experiment, what happens to the momentum that was lost?

For the Steel/Glass collision…

Momentum of System BEFORE the collision (kg·m/sec)	Momentum of System AFTER the collision (kg·m/sec)

2a. Was Momentum **Conserved** for the Steel/Glass Ball collision experiment?

2b. What might have been the sources of **error** in your experiment?

For the Steel/Wood collision…

Momentum of System BEFORE the collision (kg·m/sec)	Momentum of System AFTER the collision (kg·m/sec)

3a. Was Momentum **Conserved** for the Steel/Wood Ball collision experiment?

3b. What might have been the sources of **error** in your experiment?

Lab Extension

Engineers study collisions between balls and bats, golf balls colliding with golf clubs, tennis balls with racquets and consider the bounces of basketballs.

- The **Coefficient of Restitution (COR),** is the ***Ratio*** (between two objects) of their Velocity ***after*** the collision to the Velocity ***before*** the collision. It ranges from **0 to 1** where 1 would be a perfectly **Elastic** collision and 0 would equal a perfectly **Inelastic** collision.
- **Elastic collisions** occur when Momentum is conserved. (COR over 50%)
- **Inelastic collisions** occur when Momentum is NOT conserved. (COR under 50%)

Find the **Coefficient of Restitution (COR)** for each collision system and determine whether each trial was Elastic, Inelastic, or a partially Elastic/Inelastic collision.

Using the Conservation of Momentum relationship (re-written) below, **calculate the COR** for each trial.

$$m_{1B}v_{1B} + m_{2B}v_{2B} = m_{1A}v_{1A} + m_{2A}v_{2A} \rightarrow \text{COR} = (v_{1A} - v_{2A})/(v_{1B} - v_{2B})$$

Enter your values into **Table E.**

Table E –Coefficient of Restitution (COR)

Collision	ΔV (After Collision) $(v_{1A} - v_{2A})$	ΔV (Before Collision) $(v_{1A} - v_{2A})$	Coefficient of Restitution (COR) $(v_{1A} - v_{2A})/(v_{1B} - v_{2B})$	Is the Collision Elastic or Inelastic?
Steel/Steel				
Steel/Glass				
Steel/Wood				

Momentum Lab Extension Questions

1. On a snow-covered road, a car with a mass of 1.1×10^3 kilograms collides head-on with a van having a mass of 2.5×10^3 kilograms traveling at 8.0 meters per second. As a result of the collision, the vehicles lock together and immediately come to rest. Calculate the speed of the car immediately before the collision. [Neglect friction.] [Show all work, including the equation and substitution with units.]