THE CONSERVATION OF LINEAR MOMENTUM

Introduction

In this experiment you will test the validity of the Law of Conservation of Linear Momentum in one dimension utilizing elastic and inelastic collisions on an air track.

Apparatus

Computer with Logger Pro software	Air Track Accessory kit - bumpers for the elastic collision	Right angle clamps (2) or integral photogate clamps
Vernier Lab Pro box	Air Track Gliders (2)	Laboratory Balance
Pasco Air Track	Vernier Photogate (2)	
Air supply	Ring Stands (2)	

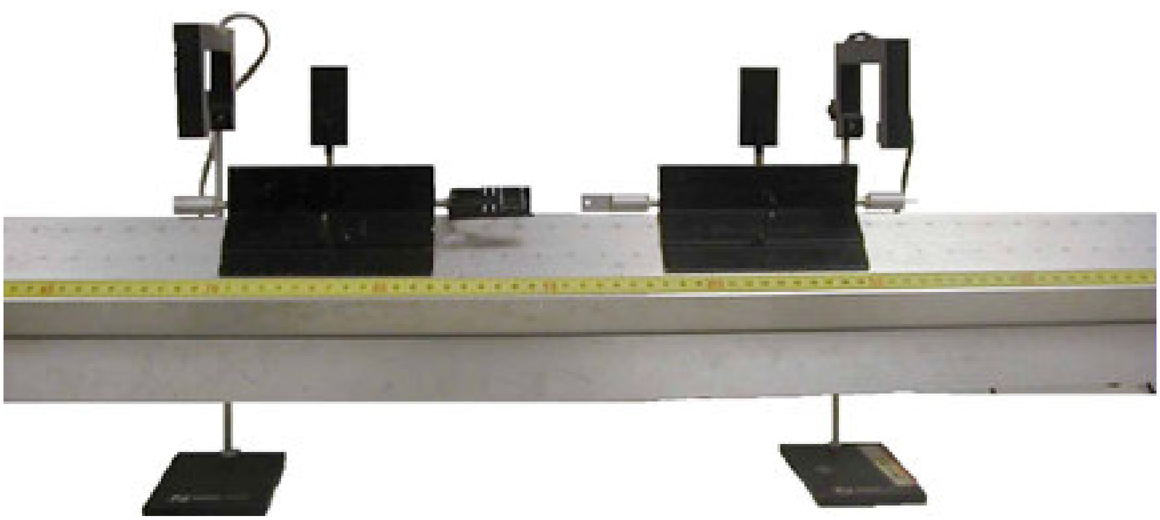


Figure 0: Elastic Near Collision

Theory

If two objects collide, and are subject to no net external forces, then it can be shown by application of Newton's 2nd and 3rd Laws that the total linear momentum of the system of masses will not be altered by the collision. The linear momentum of an object of mass m_1 and velocity v_1 is given by $p_1 = m_1v_1$. In a system consisting of two objects of momentum p_1 and p_2, the total linear momentum is the vector sum of their individual momenta:

$$\mathbf{p}_1 + \mathbf{p}_2 = m_1\mathbf{v}_1 + m_2\mathbf{v}_2$$

The total linear momentum ***before*** collision is $m_1\mathbf{v_1} + m_2\mathbf{v_2}$

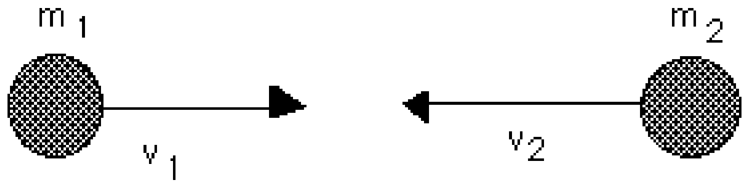


Figure 1 (Before the collision)

If the two masses collide, in general, their velocities will be altered to v_1' and v_2', respectively.

The total linear momentum ***after*** collision is $m_1\mathbf{v'}_1 + m_2\mathbf{v'}_2$

Figure 2 (After the collision)

According to the conservation of linear momentum principle, the total linear momentum will not be altered by the collision, or

$$\mathbf{p}_1 + \mathbf{p}_2 = \mathbf{p}_1' + \mathbf{p}_2' \qquad (1)$$

that is: $$m_1\mathbf{v}_1 + m_2\mathbf{v}_2 = m_1\mathbf{v'}_1 + m_2\mathbf{v'}_2 \qquad (2)$$

Procedure

Conventions: Glider #2 is always the glider that is launched. **Glider #1** is always the glider that starts out at rest between the two photogates. Ensure that the photogate that **Glider #2** initially passes through is labeled **Photogate #2** and that it is plugged into **Digital Input #2** in the Vernier Lab Pro box. Ensure that the photogate that **Glider #1** passes through is labeled **Photogate #1** and that it is plugged into **Digital Input #1** in the Vernier Lab Pro box.

1. Start the computer.

2. Turn on the air supply and increase the flow volume until the gliders are floating on a cushion of air. Level the air track by placing a glider in the center of the track and adjusting the leveling screws until the glider will remain at rest.

3. Clearly label the **Gliders** as **#1** and **#2** using a small piece of masking tape.

4. Plug the photogate timers into the Digital Inputs #**1** and #**2** in the Vernier Lab Pro box according to the convention above. Place the photogates symmetrically about the center of the track, leaving about 70 cm of open space between them.

5. Place one of the unused cylindrical track accessories on the top of each glider. These will be used as “flags.” Adjust height of photogates so that the flags will interrupt the beams when the gliders pass through the photogates. (Test to see if photogate timers work properly – when the beam is blocked the Red LED will light up.)

6. Open the **Collision Timer** file**:** Under the **File** menu click on the **Open** menu item. The **Experiments** folder will open, double click on the **Probes and Sensors** folder, double click on the **Photogates** folder and then double click on the **Collisions Timer** file.

7. Enter "**Flag Lengths" - one for each photogate (to 4 significant figures).** Measure the diameter of the flags using the calipers in the laboratory. To enter the numbers into the computer: Click on the **Experiment** menu and click on the **Set Up Sensors** menu item. Then select **Show All Interfaces**. Click on the first **Photogate** icon and select **"Set Distance or Length."** Then enter **"Flag Length"** or **"Photogate Distance"** and click OK. Repeat for the second photogate.

PART 1: Elastic Collision

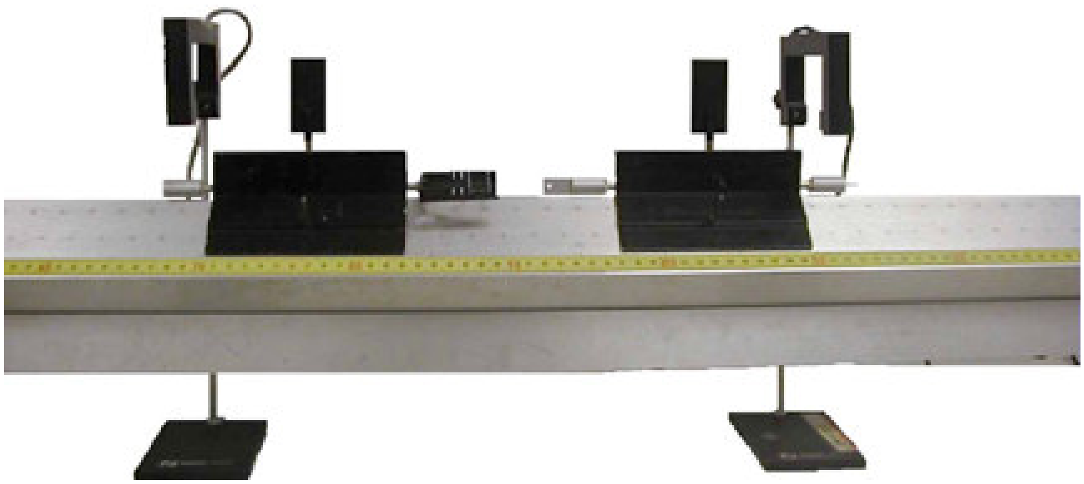


Figure 3: Elastic Near Collision

1. Affix a spring bumper to **Glider** #1 and a knife-edge to **Glider** #2. <u>These must go in the lower holes - center of mass</u>. Balance the gliders with another fixture on the other end. All parts weigh about the same. Weigh both gliders (with the bumpers and flags). Enter the masses of each glider and the width of the flags in Table 1.

2. Place **Glider** #1 between the two gates and carefully bring it to rest. Start the timer by clicking on the **Collect** button and launch **Glider** #2 toward **Glider** #1. If the two gliders are of identical mass then **Glider** #1 should move in the same direction as the incident **Glider** #2 at the same initial velocity of **Glider** #2 and **Glider** #2 would be at rest. In this case all the momentum was transferred from **Glider** #2 to **Glider** #1. If **Glider** #1 is more massive than **Glider** #2 then **Glider** #2 will rebound. If **Glider** #1 is less massive than **Glider** #2 then **Glider** #2 will not come to rest but will follow **Glider** #1.
Catch the glider before it bounces off the end air track bumper.

3. The computer records all times and calculates velocities. Record these velocities (to 4 significant figures) in Table 1 Calculate the momentum and enter the results in Table 1. Compare total momentum prior to the collision to total momentum after. [Don't forget that momentum is a *vector* quantity! It has a *direction* (+ or – in this case) as well as a magnitude. Calculate % difference – the quantity $(\mathbf{P_T' - P_T})$ divided by $\mathbf{P_T}$ and then multiplied by 100. **<u>Repeat 3 more times</u>** for a total of 4 data sets.

PART 2: Inelastic Collision

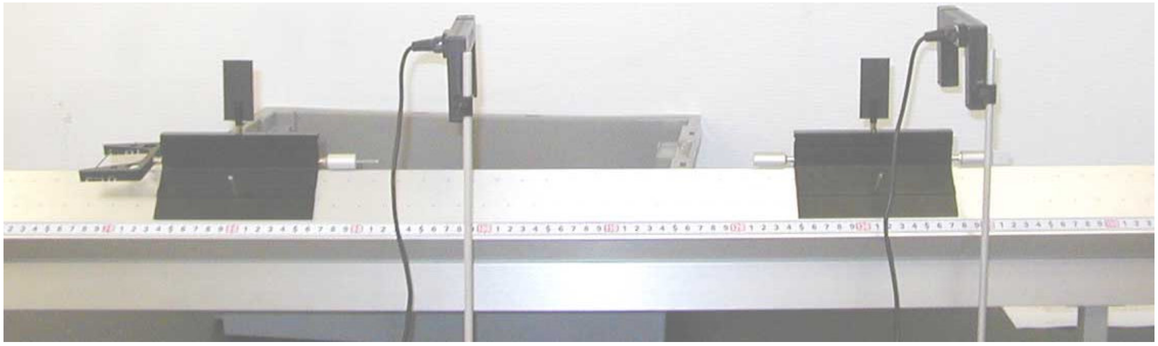


Figure 4: Inelastic at launch

4. Rotate the gliders by 180^o so that the straight pin and a clay cup will be facing each other. Remove the safety cork from the straight pin. *NOTE: It is essential that the clay in the clay cup be repacked after each run to fill in the hole.*

5. Weigh both gliders and enter the data in Table 2. Ensure that the masses are the same to within 1.0 gram. If necessary, add a couple 1.0 gram disks to the lighter glider to make them as close to equal, in mass, as possible.

6. Place **Glider** #1 between the two gates, and bring it to rest. Start the timer by clicking on the **Collect** button, and launch **Glider** #2 toward **Glider** #1.

7. Go to step #3 and repeat that Procedure.

8. You have finished taking data. In Part 3, you will use the data that was taken in Part 1 and Part 2, for the Kinetic Energy calculations.

PART 3: Energy Calculations

1. In the *elastic cases* the value of the total kinetic energy should be the same after the collision as it was before the collision.
   - Compare the kinetic energies in each of your elastic trials. $\mathbf{KE = (1/2)\ m\ v^2}$
   - For the elastic case: $\mathbf{KE_f = KE_i}$
   - Express the % difference between them.

$$\mathbf{(\ KE_f - KE_i\ )*100/\ KE_i}$$

2. In the *completely inelastic cases*, where the objects stick together after the collision, a substantial amount of kinetic energy is "lost" in the collision.
   - Measure the change in kinetic energy observed in the inelastic cases. Compare the measured differences between before and after to the anticipated differences.
   - For the inelastic case: $\mathbf{KE_f^{Calc}}$ should be equal to $\mathbf{(m_2/(m_1 + m_2))KE_i}$
   - Express the % difference between them.

$$\mathbf{(\ KE_f - KE_f^{Calc}\ )*100/\ KE_f^{Calc}}$$

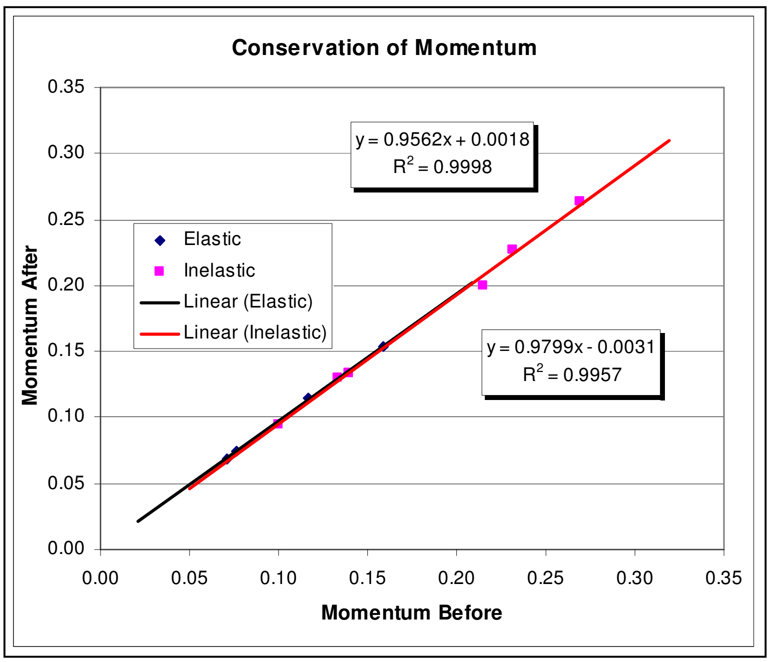
Graphical Analysis

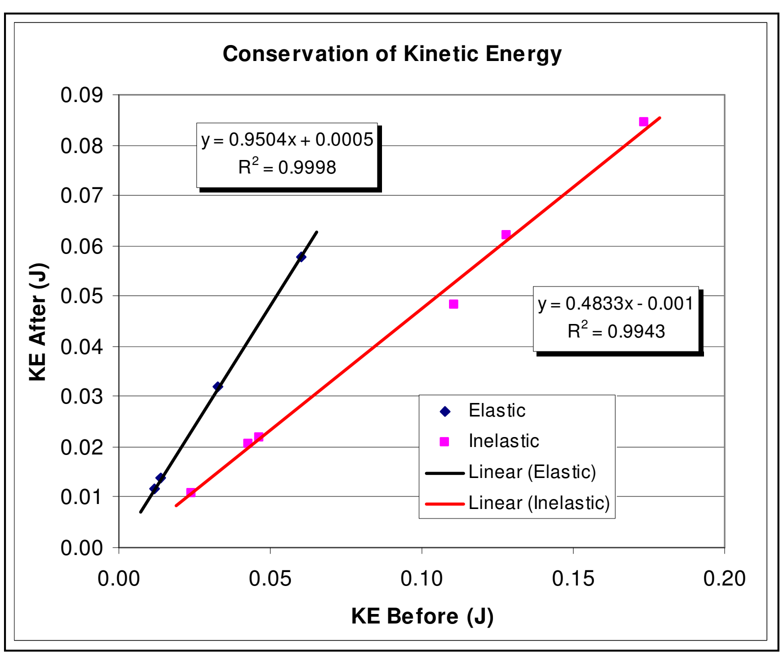
The velocity of each experimental run is not easily repeatable. At the same time comparing before and after momentum in each independent case is not the best use of the data to determine if Linear Momentum is conserved. There is however a graphical analysis technique that will use all the data together and provide a statistical based answer to the conservation question.

- Two X-Y Scatter charts: (1) Momentum After vs Momentum Before and (2) KE After vs KE Before. (As shown below)
- Also do the LINEST analysis of the slope values. This analysis will determine the answer to the conservation question.

Lab Report

Your report should follow the instructions in the document "Format for Formal Lab Reports."





Data Tables

Flag Length 1_____________(m) Flag Length 2_____________(m) (4 significant figures)

Table 1 ELASTIC COLLISION													
Before Collision								After Collision					
Trial	m_1	m_2	v_1	v_2	p_1	p_2	p_{tot}	v_1'	v_2'	p_1'	p_2'	p_{tot}'	% Diff
1													
2													
3													
4													

Table 1A - Energy Calculations - Elastic							
Trial	KE_{1B}	KE_{2B}	$KE_{Total\ B}$	KE_{1A}	KE_{2A}	$KE_{Total\ A}$	% Diff
1							
2							
3							
4							

Table 2 INELASTIC COLLISION												
Before Collision								After Collision				
Trial	m_1	m_2	v_1	v_2	p_1	p_2	p_{tot}	(m_1+m_2)	v_1'; v_2'	$(v_1'+v_2')/2$	p_{tot}'	% Diff
1												
2												
3												
4												

Table 2A - Energy Calculations - Inelastic							
Trial	KE_{1B}	KE_{2B}	$KE_{Total\ B}$		$KE_{Total\ A}$	% Difference	
1							
2							
3							
4							