Collisions

Purpose:
To investigate conservation of momentum and kinetic energy in elastic and inelastic collisions in one dimension.

Introduction:
When two masses collide with each other, the total momentum of both masses is conserved, regardless of the type of collision, whereas the total kinetic energy is only conserved in an elastic collision. The purpose of this experiment is to investigate the motion before and after a collision in order to test the conservation of momentum and the conservation of kinetic energy.

The linear momentum of an object is the product of its mass times its velocity, \( \vec{p} = m\vec{v} \). The law of conservation of linear momentum states that the total momentum of a system remains constant if there is no net external force. For a one dimensional collision between two masses, \( m_1 \) and \( m_2 \), this is expressed as the following equation

\[
m_1\vec{v}_1 + m_2\vec{v}_2 = m_1\vec{v}_1' + m_2\vec{v}_2'
\]

where \( v_1 \), \( v_2 \) and \( v_1', v_2' \) are the velocities of the masses before and after the collision, respectively.

The kinetic energy of an object is \( KE = \frac{1}{2}mv^2 \). The law of conservation of energy states that the total energy of a system is always conserved. This does not mean that kinetic energy is always conserved, for in some instances (like inelastic collisions, where two objects stick together) kinetic energy is converted into energy of another form. In elastic collisions, there are no energy transformations, and the total kinetic energy of the system is conserved. For a collision between two masses this is expressed as

\[
\frac{1}{2}m_1v_1^2 + \frac{1}{2}m_2v_2^2 = \frac{1}{2}m_1v_1'^2 + \frac{1}{2}m_2v_2'^2
\]

This equation holds true for elastic collisions only. Kinetic energy will not be conserved in an inelastic collision (kinetic energy is converted into other forms of energy).

Laboratory Procedure

Part I - Taking Direct Measurements

We will be using an air track apparatus, two photogates, and the aid of a Smart Timer or computer to calculate the velocities of two gliders before and after they collide. From the measured velocities and masses of the gliders we can test equations 1 and 2 for different types of collisions.

Determining the Effects of Friction

1. Measure and record the masses of the gliders.
2. Determine and record \( \delta m \) for each glider.
3. Determine and record the fractional uncertainty \( (\delta m/m) \) for each glider
4. Level the air track by setting a cart in the middle of the track, turning on the air, and seeing which way the cart glides. Adjust the leveling screw at the end of the track to raise or lower that end until the cart remains at rest.
5. Position the two photogates just far enough apart so the collision can take place between the photogates. Adjust the height of the photogates so the 1 cm flag on the picket fence will block the photogate beams.
6. Open the Collisions software by double clicking the icon (square with the symbol \( \vec{p} \)) on the desktop.
7. When the program is open, you will see 4 tabs with the headings Collision 1, Collision 2, Collision 3, and Determining Friction. In each, there are slots that will give a reading of velocity in \( \frac{m}{s} \). Select the tab for the collision you are performing.
8. When you are ready to record velocities click on the run arrow at the top of the screen. The run arrow will turn black indicating the apparatus is ready to take measurements. **NOTE:** If the photogates do not detect the correct number of passes (depends on which collision you are doing), the program will not complete the timing cycle and velocities will not display automatically. This likely means that you are performing the collision incorrectly. Stop the program, reread the instructions and try again.

9. By far the largest source of error in the experiment is in the final velocity after the collision. This is because while the carts are in contact with each other, there are small vertical forces which increase the frictional force and cause losses of both momentum and kinetic energy. We would therefore be underestimating our uncertainty in velocity if we just relied on the precision of the timer.

10. To estimate the uncertainty in the final velocities (we will not determine uncertainties for initial values), do the following measurement:

   (a) Select the *Determining Friction* tab.

   (b) Take one of the carts and send it along the entire length of the track passing both photogates, then let it bounce off the end of the track and rebound all the way back. If the collision at the end of the track were perfect (and there were no friction), the initial and final speeds would be identical. The extent to which they are not identical gives a measure of the uncertainty in final velocities.

   (c) Record the initial and final velocities. Determine the **fractional uncertainty** in the velocity by taking the difference in initial and final speeds divided by the initial speed.

\[
\frac{\delta v}{v} = \frac{v_i - v_f}{v_i}
\]

(d) Repeat this for a total of 3 times with each of the 3 carts (you will have 9 results).

(e) Calculate the average of these fractional uncertainties and use that as your final fractional uncertainty in velocity.

(f) Confirm the fractional uncertainty in the velocity is larger than the fractional uncertainty in your masses.

**Performing the Collisions**

Perform each of the following collisions and record all initial and final velocities for both carts. For #1 and #2, make sure the gliders collide on the sides without velcro strips. Since all the collisions are one dimensional remember to record the direction (+ or -) in terms of velocity.
Collision Type #1: Elastic with Stationary Target.
Place cart 2 at rest between the photogates, \( v_2 = 0 \). Give cart 1 an initial velocity fast enough to collide with cart 2.
(a) Case 1: \( m_1 = m_2 \)
(b) Case 2: \( m_1 > m_2 \) (target mass is small cart)

Collision Type #2: Elastic with Moving Target.
Place carts 1 and 2 outside the photogates on the same side of the air track so that the carts will be traveling in the same direction. Give cart 2 an initial velocity then give cart 1 a velocity such that the carts collide in between the photogates.
(a) Case 1: \( m_1 = m_2 \)
(b) Case 2: \( m_1 > m_2 \) (target mass is small cart)

Collision Type #3: Inelastic with Stationary Target.
Place cart 2 at rest between the photogates, \( v_2 = 0 \), so that its velcro is facing cart 1. Give cart 1 an initial velocity fast enough to collide with cart 2 so that its velcro strip will connect with that of cart 2. They will stick together in a completely inelastic collision.
(a) Case 1: \( m_1 = m_2 \)
(b) Case 2: \( m_1 > m_2 \)

Calculate \( p_i, p_f, \delta p_f, KE_i, KE_f, \delta KE_f \) for each collision.

Part II - Determining Uncertainties in Your Final Values

In the results section of your notebook, state the results of all your experimental final values in the form \( p_f \pm \delta p_f \) and \( KE_f \pm \delta KE_f \). Note, \( \delta p_f \) and \( \delta KE_f \) should be equal to the fractional uncertainty you obtained for velocity multiplied by your final value of \( KE_f \) and \( p_f \).

\[
\delta KE_f = KE_f \ast \left( \frac{\delta v}{v} \right)_{\text{average}}, \delta p_f = p_f \ast \left( \frac{\delta v}{v} \right)_{\text{average}}
\]

You should also address the following questions:

1. Do your results for the final values agree within their uncertainties to the initial values?
2. Are momentum and kinetic energy conserved in each collision?