Lab 5: Measuring Momentum

Goals: Improve communication, teamwork capacities, observational skills, and record-keeping**;** Explore momentum conservation.

Equipment: 2 meter track + feet + end stops + etc (should be set up); low friction carts: one blue plastic & one red plastic or 4 metal; masses: 2 silver for plastic carts or 2 black for metal carts. Computer.

Groups & Lab Notebook: Groups of 3 for observations and analysis. Update Table of Contents. General Lab Notes guidelines.

Part 1: Sticking Collisions Observations.

In this series, two carts on low friction tracks will collide and stick together. These kinds of sticking collisions are also called *perfectly inelastic*. This will be achieved by having the Velcro ends of the carts oriented towards each other so that after any interaction, they stick together. **Don't have any collisions be very violent – gentle collisions are best**. When directed to have carts move at about same speeds, this doesn't have to be exact, but they should move towards each other with roughly similar speeds. Practice a few times, and repeat as needed.

For each Scenario, below, draw before and after pictures for this scenario, including labels for the carts, masses, and vectors. <u>For each Scenario, draw the relative lengths of the velocity vectors to be qualitatively accurate</u> (in other words, longer arrows mean moving faster, shorter arrows mean moving slower).

<u>**Scenario A: Equal masses, one cart stationary, sticking collision**</u>. Place the red cart (mass m) so that it is stationary on the track. Gently push and release the blue cart (mass m) so that it moves to the right at speed v_i and collides with the stationary red cart. The blue cart and red cart should stick together and move together after the collision at some speed v_f. **In your before and after pictures, label the carts and indicate m, v_i, and v_f.**

<u>**Scenario B: Unequal masses, more massive cart stationary, sticking collision**</u>. Add mass to the red cart so that its mass is 3m. Place the red cart with extra mass so that is stationary on the track. Gently push and release the blue cart (mass m) so that it moves to the right at speed v_i and collides with the stationary red cart (note: this v_i should be about the same as before, but doesn't need to be exact). The blue cart and red cart should stick together and move together after the collision at some speed v_f (not necessarily the same as in the previous scenario). **In your before and after pictures, label the carts and indicate m, 3m, v_i, and v_f.**

<u>**Scenario C: Unequal masses, more massive cart moving, sticking collision**</u>. Add mass to the blue cart so that its mass is 3m. Place the red cart (mass m) so that is stationary on the track. Gently push and release the blue cart with extra mass so that it moves to the right at speed v_i and collides with the stationary red cart (note: this v_i should be about the same as before, but doesn't need to be exact). The blue cart and red cart should stick together and move together after the collision at speed v_f (not necessarily the same as the previous scenario). **In your before and after pictures, label the carts and indicate m, 3m, v_i, and v_f.**

<u>**Scenario D: Unequal masses, both carts moving about same speed, sticking collision**</u>. Add mass to the blue cart so that its mass is 3m. Gently push and release the blue cart (mass 3m) so that it moves to the right at speed v_i and collides with the red cart (mass m) moving to the left at **about the same speed** v_i. The blue cart and red cart should stick together and move together after the collision at some speed v_f. **In your before and after pictures, label the carts and indicate m, 3m, v_i, v_i, and v_f.**

<u>**Scenario E: Equal masses, both carts moving at different speeds, sticking collision**</u>. Gently push and release the blue cart (mass m) so that it moves to the right at speed $v_{B,i}$ and collides with the red cart (mass m) moving to the left at speed $v_{R,I}$; have the **blue cart move faster** than the red cart. The blue cart and red cart should stick together and move together after the collision at some speed v_f. **In your before and after pictures, label the carts and indicate m, $v_{B,i}$, $v_{R,i}$, and v_f.**

<u>**Scenario F: Unequal masses, both carts moving with massive car moving faster, sticking collision**</u>. Add mass to the red cart so that its mass is 3m. Gently push and release the blue cart (mass m) so that it moves to the right at speed $v_{B,i}$ and collides with the red cart (mass 3m) moving to the left at speed $v_{R,I}$; have the **red cart move faster** than the blue cart. The blue cart and red cart should stick together and move together after the collision at some speed v_f. **In your before and after pictures, label the carts and indicate m, 3m, $v_{B,i}$, $v_{R,i}$, and v_f.**

Part 2: Bouncing Collisions Observations.

In this next series, the carts will collide and bounce off each other. This will be achieved by having magnet ends oriented towards each other so that after the collision they don't stick together.

Scenario G: Equal masses, one cart stationary, bouncing collision. Place the red cart (mass m) so that is stationary on the track. Gently push and release the blue cart (mass m) so that it moves to the right at speed v_i and collides with the stationary red cart (mass m). The blue cart and red cart should bounce and move separately after the collision, with the blue cart moving at $v_{B,f}$ (though you might note something interesting about $v_{B,f}$) and the red cart moving at $v_{R,f}$. **In your before and after pictures, label the carts and indicate m, v_i, $v_{B,f}$, and $v_{R,f}$.**

Scenario H: Unequal masses, more massive cart stationary, bouncing collision. Add mass to the red cart so that its mass is 3m. Place the red cart with extra mass so that is stationary on the track. Gently push and release the blue cart (mass m) so that it moves to the right at speed v_i and collides with the stationary red cart (mass 3m). The blue cart and red cart should bounce and move separately after the collision, with the blue cart moving at $v_{B,f}$ (though you might note something interesting about $v_{B,f}$) and the red cart moving at $v_{R,f}$. **In your before and after pictures, label the carts and indicate m, 3m, v_i, $v_{B,f}$, and $v_{R,f}$.**

Scenario I: Unequal masses, more massive cart moving, bouncing collision. Add mass to the blue cart so that its mass is 3m. Place the red cart (mass m) so that is stationary on the track. Gently push and release the blue cart (mass 3m) so that it moves to the right at speed v_i and collides with the stationary red cart (mass m). The blue cart and red cart should bounce and move separately after the collision, with the blue cart moving at $v_{B,f}$ and the red cart moving at $v_{R,f}$. **In your before and after pictures, label the carts and indicate m, 3m, v_i, $v_{B,f}$, and $v_{R,f}$.**

Scenario J: Equal masses, both carts moving at about same speed, bouncing collision. Gently push and release the blue cart (mass m) so that it moves to the right at speed v_i and collides with the red cart (mass m) moving to the left at **about the same speed** v_i. The blue cart and red cart should bounce and move separately after the collision, with the blue cart moving at $v_{B,f}$ and the red cart moving at $v_{R,f}$. **In your before and after pictures, label the carts and indicate m, v_i, $v_{B,f}$, and $v_{R,f}$.**

Scenario K: Unequal masses, both carts moving at about same speed, bouncing collision. Add mass to the red cart so that its mass is 3m. Gently push and release the blue cart (mass m) so that it moves to the right at speed v_i and collides with the red cart (mass 3m) moving to the left at **about the same speed** v_i. The blue cart and red cart should bounce and move separately after the collision, with the blue cart moving at $v_{B,f}$ and the red cart moving at $v_{R,f}$ (though you might note something interesting about $v_{R,f}$). **In your before and after pictures, label the carts and indicate m, v_i, $v_{B,f}$, and $v_{R,f}$.**

Part 3: Mystery Scenarios.

Mystery Scenario I: Consider a collision between a light cart and a massive cart that are both moving (relative to the track). Can you have a collision such that the massive cart comes to rest after the collision? Why or why not?

Mystery Scenario II: Consider a collision between two carts of similar mass that are moving towards each other at about the same speed. Can you have a collision such that the carts move away from each other faster than they were moving towards each other? Why or why not?

After discussing the Mystery Scenarios in your group, discuss with an instructor.

Part 4: 2 Dimensional Collisions.

Next, you will watch a video showing a series of collisions between 2 pucks moving on a low friction surface (here, an air table like in air hockey). The view is a bird's eye (top-down) view. Each collision is shown twice: the first time is just a standard video, while the second time shows some digital effects enhanced version of the same collision. Open the video in LoggerPro using Insert: Movie; you won't be doing video analysis yet, but under Movie Options (right-click on the movie window), you can reduce the playback Speed (for example 0.25 x Original or slower if you prefer). The movie Pucks Collide is available in Handouts: Physics Labs: Physics Lab 5. Watch the collisions several times and take notes on interesting features of the collisions.

Analysis 1: Analysis of 1D Collisions.

a) Consider Scenario A. Explain why you can treat the momentum of the carts as conserved. Use your before and after diagrams and conservation of momentum to show that $v_f = \frac{1}{2} v_i$.
b) Consider Scenario B. Use your before and after diagrams and conservation of momentum to show that $v_f = \frac{1}{4} v_i$.
c) Consider Scenario C. Use your before and after diagrams and conservation of momentum to show that $v_f = \frac{3}{4} v_i$.
d) Consider Scenario D. Use your before and after diagrams and conservation of momentum to show that $v_f = \frac{1}{2} v_i$.
e) Consider Scenario E. Use your before and after diagrams and conservation of momentum to explain why the stuck-together carts move to the right after the collision.
f) Consider Scenario F. Use your before and after diagrams and conservation of momentum to explain why the stuck-together carts move to the left after the collision.
g) Consider Scenarios G – K. Why is a momentum analysis more complicated in these scenarios (compared to the sticking collisions?) Are you able to determine the final velocities of each cart in terms of the initial velocities (and cart mass) like you could in Scenarios A – D? Why or why not?
h) **Discuss your analysis with me.**

Analysis 2: Further Analysis of 1D Collisions.

In Handouts: Physics Labs: Physics Lab 5: Scenarios A – K data, you will find a series of LoggerPro files that correspond to the Scenarios you observed. Copy the files to a usefully named folder in Workspace: Physics: Physics Lab 5. The data was collected using two motion detectors, one aimed at the red cart (Position 1 data, in red) and one aimed at the blue cart (Position 2 data, in blue). Each file shows the position vs. time graph for the motion of the carts before, during, and after the collision described in the corresponding scenario. Note that the graphs are left as connected points for clarity in viewing, but for the analysis below, you should adjust the graphs to show individual points.

1) Review: How do you determine velocity from a position vs. time graph in LoggerPro?
2) Choose a Sticking Collision scenario you found interesting or surprising or that would give you the best practice with momentum conservation problem solving. Examine the graph, and identify regions just before the collision, the collision event, and just after the collision. **Adjust the graph to show individual points**. Highlight 3 or 4 points just before the collision, and determine the velocity of each cart (keep track of signs). Highlight 3 or 4 points just after the collision and determine the velocity of the (combined) carts. Make sure not to include the actual collision time.
3) Determine the momentum of each individual cart before and the combined cart after the collision. Note that $m_{plastic}$ = 250 g (approximately) and m_{metal} = 500 g (approximately). Keep track of the sign of each momentum.
4) Compare the total momentum before the collision to the total momentum after the collision. Note that the low friction carts are not ideally friction-less. Given that, are your results still broadly consistent with the predictions from conservation of momentum?
5) Choose a Bouncing Collision Scenario you found interesting or surprising, and repeat the above analysis. Is your analysis broadly consistent with conservation of momentum?

Analysis 3: Analysis of 2D Collisions (if time)

In the Handouts folder for today's lab, you will find individual moviess for each of the 2D collisions you watched. There are 9 different sequences. Using LoggerPro, perform video analysis on one or two of the sequences you found most interesting. Since momentum is a vector quantity, it is conserved separately in the x-direction and the y-direction. Use the results of your video analysis to investigate momentum conservation in 2 dimensions.