PHYS 2LA: Lab 7
Collisions
(Includes Pre-Lab Assignment)

Objectives

These lab activities will focus on the concepts associated with inelastic and elastic collisions. You will simulate different forms of linear collisions in one dimension using “frictionless” carts that glide on a track. By measuring the mass and pre- and post-collision speeds, you will calculate the changes in momentum and kinetic energy that occur in each collision. These measurements will be used to test the laws of Conservation of Momentum and Conservation of energy.

For the following activities, you will use a physics simulation program. Visit: https://uglabs.physics.ucr.edu/ for lab downloads and links.
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Introduction

Collisions occur when two or more bodies possessing some finite amount of energy and momentum impact each other. All collisions can be described as “perfectly elastic”, “perfectly inelastic”, or as a mixture of the two. With the appropriate model, we can predict the result of these collisions according to the physical conditions before and after the event. This model relies on the physical laws that say when the quantities energy and momentum must be conserved in a system.

Things get more challenging to predict when the colliding objects are really small (like atoms) or when they are REALLY BIG (like galaxies), and they also get more complicated in systems with many colliding bodies traveling in three dimensions. In this lab, we will simplify reality and study collisions between two bodies in one dimension in what we can approximate to be a closed system (meaning no energy is added or removed from the system during the collision, i.e. no work is done on the system and the system does no work on its surroundings).

Elastic Collisions:

Both momentum and energy are conserved in an elastic collision. We will be performing measurements on a “frictionless” horizontal track, so the only form of energy we need to consider is kinetic energy.

You will make collisions in which only one glider is moving before the collision, and collisions in which both gliders are moving. The general case of both moving is presented here. Note – be careful to indicate the sign of the velocity of the gliders on your measurements! Use the convention that a glider moving to the right has positive $v$, and a glider moving to the left has negative $v$.

Each measurement begins with both gliders moving, one with mass $m_1$ moves with velocity $v_{1i}$, and the other has mass $m_2$ and velocity $v_{2i}$. 
After the collision, the first glider (mass $m_1$) has velocity $v_{1f}$ and the other glider has velocity $v_{2f}$. Conservation of momentum gives $P_i = P_f$, or:

$$m_1 v_{1i} + m_2 v_{2i} = m_1 v_{1f} + m_2 v_{2f}$$

For an elastic collision, the change in momentum in the collision should be zero:

$$\Delta P = P_f - P_i = (m_1 v_{1f} + m_2 v_{2f}) - (m_1 v_{1i} + m_2 v_{2i}) = 0$$

Conservation of (Kinetic) Energy gives $K_i = K_f$, or:

$$\frac{1}{2} m_1 v_{1i}^2 + \frac{1}{2} m_2 v_{2i}^2 = \frac{1}{2} m_1 v_{1f}^2 + \frac{1}{2} m_2 v_{2f}^2$$

For an elastic collision, the change in total kinetic energy in the collision should also be zero:

$$\Delta K = K_f - K_i = \left(\frac{1}{2} m_1 v_{1f}^2 + \frac{1}{2} m_2 v_{2f}^2\right) - \left(\frac{1}{2} m_1 v_{1i}^2 + \frac{1}{2} m_2 v_{2i}^2\right) = 0$$

**Perfectly Inelastic Collisions:**

In contrast with elastic collisions, only momentum is conserved in an inelastic collision. A perfectly inelastic collision is a particular event in which the two colliding bodies stick together and move as a single mass.

You will make collisions where only one glider is moving before the collision and collisions where both gliders are moving. The general case of both moving is presented here. Again, we define a glider moving to the right as having positive $v$, and one moving to the left as having negative $v$.

We begin with both gliders moving, one with mass $m_1$ moves with velocity $v_{1i}$, and the other has mass $m_2$ and velocity $v_{2i}$. 

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Colliding gliders before (above), and after (below).

After the collision, the gliders (mass = $m_1 + m_2$) have velocity $v_f$. Conservation of Momentum gives $P_i = P_f$, or:

$$m_1 v_{1i} + m_2 v_{2i} = (m_1 + m_2) v_f$$

For an inelastic collision, the change in momentum in the collision should be zero:

$$\Delta P = P_f - P_i = (m_1 + m_2) v_f - (m_1 v_{1i} + m_2 v_{2i}) = 0$$

Note that, for any real inelastic collision, the change in total kinetic energy cannot be positive or zero (there is no way for the energy to increase unless additional energy is added to the system, which is not the case in this model), so we can say:

$$\Delta K = K_f - K_i = \frac{1}{2} (m_1 + m_2) v_f^2 - \left( \frac{1}{2} m_1 v_{1i}^2 + \frac{1}{2} m_2 v_{2i}^2 \right) \leq 0$$
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1. Experiment Setup

In this section, we will learn how to utilize the simulation and practice setting up two collisions before collecting actual data.

1.1: First, let’s begin by learning how to adjust the mass of the carts:

- To add mass onto a cart, click and drag a weight from the bottom-left and place it on top of the cart.
- The total mass of the cart will be updated in the display above the cart.
- To remove a mass, double-click the cart or click the “remove masses” button.

1.2: Now, we are going to try our first collision.

- Begin by adjusting the knob of the right launcher. Click and drag it all the way to the right. Repeat with the left launcher.
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- Drag the blue glider to the right launcher and the red glider to the left launcher.
- Click “release both” to release the gliders.
- To stop the motion of the carts, press “stop carts.”

1.3: Now let’s try to generate data from a collision with both gliders.

- Pull the launchers back as far as they will go then place both gliders (both without added mass) against their respective launchers.
- Click the sensor at the far left of the track to collect data.
- Then click the “release both” button to simultaneously release the gliders.
- After the gliders have made contact, click the sensor to stop recording data.
- The time and position of the red and blue carts will be recorded as shown below:
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- In section 2, you will be asked to calculate pre- and post-collision glider velocities using the data in your table.

- To clear the data, click the sensor and begin a new trial.

- Remember to record the total mass of the red and blue gliders, respectively, each time you begin a new trial.

1.4: Prepare your notebook. Start by writing down definitions of energy and momentum. Draw pictures of your apparatus and describe how the apparatus will be used to create both elastic and inelastic collisions. Next, explain why you can approximate the collision events as occurring within a closed system, and explain as well what factors may be injecting or extracting work from the carts (which will affect the uncertainty in your measurements). Write down the equations that you will use to calculate $\Delta P$ and $\Delta K$ for elastic and for inelastic collisions with two bodies.
2. Elastic Collisions

2.1: Open the Excel template corresponding with this week’s lab. In Excel, you have a table where you can input values for mass and velocity that will be used to calculate changes in momentum and energy during elastic collision events – copy the table into your notebook. When you perform a collision, record the mass of each glider, and the measured velocities pre- and post-collision event in the table. For each case, calculate the initial and final velocities of both carts using $\frac{\Delta x}{\Delta t}$. A sample of a position vs. time plot of a collision is shown below. To calculate $v_{1i}$ and $v_{2i}$, obtain $\Delta x$ and $\Delta t$ values from region A and to calculate $v_{1f}$ and $v_{2f}$, obtain $\Delta x$ and $\Delta t$ values from region B.

**NOTE:** Avoid using the first and last few points in any given region, as they may throw off your data.

*Remember to record velocities, not speeds.* Once you calculate $v_{1i}$, $v_{1f}$, $v_{2i}$, and $v_{2f}$, Excel will calculate $\Delta P$ and $\Delta K$ for you, but be sure to copy all of the data into your notebook.
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2.2: For all elastic collisions make sure “Spring Plunger” is selected as your cart accessory setting.

Perform one collision for each of the cases below:

Case 1: One glider initially at rest, the other glider moving; neither glider has added mass.

Case 2: One glider moving with 100 grams added mass, the other glider initially at rest with no added mass.

Case 3: Both gliders in motion, neither with added mass.

Before moving on, test your model’s predictive power. Use conservation of energy to calculate $v_{1f}$ in terms of $v_{2f}$ for Case 4. Use the values from Case 2 for $v_{1i}$ and from Case 3 for $v_{2i}$. After you perform the collision, compare your measured values to your predicted values and discuss the comparison.

Case 4: Both gliders in motion, one with 100 grams added mass, the other with no added mass.

2.3: Questions:

- Are momentum and kinetic energy conserved in each collision? How do you know? How precisely can you verify this with your measurements?

- If energy is not perfectly conserved, where does the imbalance go (or come from)? Think about what you wrote down earlier for sources that may be injecting or extracting work from the collision system, do you still think what you wrote is valid? (Discuss.)
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3. Perfectly Inelastic Collisions

3.1: Switch to the second tab in *Excel*. Copy the table into your notebook. Change the cart accessory to Velcro®.

3.2: Perform one collision for each case below:

Case 1: One glider initially at rest, the other glider moving; neither glider has added mass.

Case 2: Both gliders in motion, neither with added mass. (Think about what you should expect to observe with this one!)

Case 3: One glider moving with 100 grams added mass, the other glider initially at rest with no added mass.

Use conservation of momentum to calculate what $v_f$ should be for Case 4. Use the values from Case 3 for $v_{1i}$ and Case 2 for $v_{2i}$. After you perform the collision, compare your measured values to your predicted values and discuss the comparison.

Case 4: Both gliders in motion, one with 100 grams added mass, the other with no added mass.

3.3: Questions:

- Is momentum conserved in each collision? How do you know? How precisely can you verify this with your measurements?

- How much kinetic energy is lost in the inelastic collisions? Where does it go? Is it still in the “closed system” or has it been lost to surroundings?

4. Free-fall Analysis

Think back to the labs in which you measured the acceleration due to gravity acting on objects in free-fall. You released objects from rest at a certain height
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and measured the time it took to fall to the ground. Use what you now know about energy and momentum to analyze the same system using a different model.

4.1: What energy is internal to the system (the ball in free-fall)? Is any work injected or removed from the system during free-fall? What happens to the ball in free-fall after it collides with the floor? Describe the ball’s motion after the collision. Where does the energy go during this collision?

4.2: How much total energy and momentum are in the system prior to the collision with the ground? (There are a couple of ways to figure these out).

4.3: Now let’s consider the system after the collision with the ground. How much total energy and momentum is in the system after the collision with the ground? (Again, there are a couple of ways to figure these out).

• Was this an inelastic or elastic collision? Why?
• How much energy and momentum was lost in the collision? Where did it go? Discuss this in terms of the free-fall system doing work on the surrounding environment.

5. Summary and Conclusions

• Suppose you catch and hold a baseball, and then someone invites you to catch and hold a bowling ball with either the same momentum or the same kinetic energy as the baseball. Which would you choose? Why?
• When rain falls from the sky, what happens to its momentum as it hits the ground? What about its energy? Where does the energy go?
• Can any real collision ever be truly perfectly elastic? Why or why not? (You should think about this in two ways: first consider what effects of the environment surrounding the collision might have on energy and momentum conservation; second, consider the objects themselves – how must an object react to a collision in order to be considered “perfect”?).
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Pre-Lab Assignment (1 point)

1. A 0.5kg ball is thrown horizontally towards a wall with a speed of 10 m/s. The initial velocity is chosen to be the positive x-direction for this question. The ball horizontally rebounds back from the wall with a speed of 10 m/s in the negative x-direction. Give both magnitude and direction for answers a through c.
   a. What is momentum of the ball before it hits the wall, $p_i$?
   b. What is momentum of the ball after it hits the wall, $p_f$?
   c. What is the change in momentum of the ball, $\Delta p$?
   d. Is momentum conserved for the ball?
   e. Is total momentum conserved for this situation?