1-D Collisions and Conservation of Momentum

Goals and Introduction

When Isaac Newton first formulated his second law of motion, it was not stated in terms of mass and acceleration, but in terms of change in a quantity called "momentum" over time. The *momentum* ($\vec{p}$) of an object is a vector quantity that depends on the object's mass (*m*) and velocity ($\vec{v}$), as seen in Eq. 1.

$$\vec{p} = m\vec{v} \qquad \text{(Eq. 1)}$$

According to the modern version of Newton's third law, when two objects collide they exert equal and opposite forces on one another. An interesting aspect of momentum is that when two objects collide, if we are able to ignore the influence of any forces other than the ones described by Newton's third law, then the sum of the momentum of the objects both before and after the collision will be equal. This is often referred to as the *conservation of momentum*. In this lab, you will quantify aspects of several collisions to investigate whether momentum is indeed conserved.

The concept of the conservation of momentum can be summarized by the equation

$$\vec{p}_{\text{total}_i} = \vec{p}_{\text{total}_f} \qquad \text{(Eq. 2)}$$

or that the total momentum of the objects before the collision is equal to the total momentum of the objects after the collision. For a collision between two objects, Eq. 2 could be written as

$$m_1\vec{v}_{1i} + m_2\vec{v}_{2i} = m_1\vec{v}_{1f} + m_2\vec{v}_{2f} \qquad \text{(Eq. 3)}$$

where for the case of a one-dimensional collision, we often drop the vector symbols on the velocities and designate one direction as positive and the other as negative. It is very important to keep track of the direction an object is moving, and thus, the sign of its velocity.

In a certain subset of collisions, the sum of the kinetic energies of the objects before the collision will equal the sum of the kinetic energies of the objects after the collision. This type of collision is called an *elastic collision.* For the case of two objects colliding in an elastic collision, the conservation of energy condition would be expressed as shown in Eq. 4, where $KE = (1/2)mv^2$.

$$KE_{1i} + KE_{2i} = KE_{1f} + KE_{2f} \qquad \text{(Eq. 4)}$$

Today, you will perform time measurements in order to calculate the initial and final velocities of two gliders undergoing several collisions. You will then be able to evaluate the principle of conservation of momentum in each scenario, and verify which scenarios represent elastic collisions.

Goals: (1) Develop a better understanding of conservation of momentum and various types of collisions.

(2) Observe and verify the qualities of elastic collisions.

Procedure

Equipment – linear air track, two photogates, computer with DataLogger interface and LoggerPro software, two gliders, a set of removable masses, bumpers for the gliders, needle-cork system for the gliders

1) Level the air track using a provided shim and/or the adjustable feet at the end of the track where the hose is attached. The track is level when, with the air turned on, the glider can be placed at any point along the track and it is able to remain nearly motionless.

2) Plug the photogates into the DataLogger interface – one in DIG/SONIC 1 and the other in DIG/SONIC 2.

3) Open LoggerPro by clicking on the link on the lab website.

4) You have two gliders at your lab table. Attach a bumper to the bottom hole on the right side of each glider. One glider will be “glider A” and the other will be “glider B”. Also, attach a bumper to the left side of the air track.

5) **Measure and record** the length of the top of each glider. Do not include the bumper. Label your results as L_A and L_B. We will later record transit times for the gliders through the photogates. The times measure how long it takes for the length of the glider to pass through the gate, so we will be able to use these lengths and the times to find velocities in Data Analysis.

6) Place glider A on the left side of the track and glider B on the right side of the track. Place the photogate plugged into DIG/SONIC 1 on the left side of the air track, 70 cm from the end. Place the photogate plugged into DIG/SONIC 2 on the right side of the air track, 70 cm from the end.

7) Adjust the vertical positions of the photogates to make sure the gliders activate the photogates when passing through and that the gliders can pass through without bumping into the photogates.

Check to be sure that only the top part of the glider activates the gate (the red light on top of the gate will be on when the gate is triggered).

8) Turn on the air, click the *green* button at the top of the screen to begin to collect data, and practice timing measurements by pushing glider A through the left photogate and catching it in the middle of the air track. Move it off to the side. Push glider B through the right photogate and catch it in the middle of the air track. Then, turn the air off. Verify that a time is recorded for each photogate on the screen and that you know which time is for which gate.

We will now go through several scenarios investigating different collisions. You should take care to organize your data for each scenario so that you know to which scenario your data belongs. Be sure to turn the air on before each trial and off afterwards. Also, be sure that your hand is not in contact with the gliders as they pass through the photogates. You don't want to be in the process of pushing the gliders while the time measurements are being made. Finally, make sure that all collisions occur between the photogates so that a glider is not undergoing an acceleration while it is in a photogate.

Scenario Alpha

9) **Measure and record** the mass of each glider with their attached bumpers. Label your results as m_A and m_B.

10) Place glider B midway between the two photogates and glider A on the far left of the air track.

11) With the air on, click the *green* button to begin to collect data and push glider A towards glider B so that they collide. Be sure you are not pushing the glider while it is in the photogate. Also, be sure that glider B is not moving significantly before the collision. In this scenario, glider A should more or less stop after colliding with glider B and glider B will move through the other photogate. **Record** the transit time for each glider and label them as t_{Ai1} and t_{Bf1}.

12) Repeat steps 10 and 11 two more times and when labeling your times, change the subscript "1" to a "2" and then a "3" to distinguish the trials.

Scenario Beta

13) Place the two masses on glider B by hanging one on each side of the glider. **Measure and record** the mass of each glider with their attached bumpers and any added mass. Label your results as m_A and m_B.

14) Place glider B midway between the two photogates and glider A on the far left of the air track.

15) With the air on, click the *green* button to begin to collect data and push glider A towards glider B so that they collide. Be sure you are not pushing the glider while it is in the photogate. Also, be sure that glider B is not moving significantly before the collision. In this scenario, glider A will rebound after colliding with glider B and move back through the first photogate, so there will be two times to record for glider A. Glider B will move through the other photogate. **Record** the transit time for each glider and label them as t_{Ai1}, t_{Af1} and t_{Bf1}.

16) Repeat steps 14 and 15 two more times and when labeling your times, change the subscript "1" to a "2" and then a "3" to distinguish the trials.

17) Remove the two masses from glider B.

Scenario Gamma

18) Remove the bumpers from each of the gliders and place the needle on the front end of glider A and the cork on glider B so that it faces the needle. **Measure and record** the mass of each glider with their new attachments. Label your results as m_A and m_B.

19) Place glider B midway between the two photogates and glider A on the far left of the air track. Be sure the cork and needle are in the bottom holes on each glider and that they do not contact the track as they slide.

20) With the air on, click the *green* button to begin to collect data and push glider A towards glider B so that they collide. Be sure you are not pushing the glider while it is in the photogate. Also, be sure that glider B is not moving significantly before the collision. In this scenario, glider A will link with glider B and move through the second photogate. Redo the trial if the gliders to not link and move in tandem through the second photogate. You will see that two times are recorded at the second photogate because of a small gap between the linked gliders. Record the first of those times at the second photogate as the final time. **Record** the transit time for the gliders and label them as t_{Ai1} and t_{f1}.

21) Repeat steps 19 and 20 two more times and when labeling your times, change the subscript "1" to a "2" and then a "3" to distinguish the trials.

Scenario Delta

22) Place the two masses on glider A by hanging one on each side of the glider. **Measure and record** the mass of each glider with their attachments and any added mass. Label your results as m_A and m_B.

23) Place glider B midway between the two photogates and glider A on the far left of the air track.

24) With the air on, click the *green* button to begin to collect data and push glider A towards glider B so that they collide. Be sure you are not pushing the glider while it is in the photogate. Also, be sure that glider B is not moving significantly before the collision. In this scenario, glider A will link with glider B and move through the second photogate. You will see that two times are recorded at the second photogate because of a small gap between the linked gliders. Record the first of those times at the second photogate as the final time. **Record** the transit time for the gliders and label them as t_{Ai1} and t_{f1}.

25) Repeat steps 23 and 24 two more times and when labeling your times, change the subscript “1” to a “2” and then a “3” to distinguish the trials.

As always, be sure to organize your data records for presentation in your lab report, using tables and labels where appropriate.

Question 1: What was the initial velocity of glider B in each scenario? Explain.

Data Analysis

First, we need to calculate the velocities of the gliders in each of the trials of each scenario. Label these results as you see fit, but remember to group your calculations and results by scenario. Also, for the purposes of this lab, a velocity should be positive (+) if the glider is moving to the right and negative (-) if the glider is moving to the left. Be sure to think about the necessary sign of the velocity you calculate based on what was happening in any scenario.

The velocity of a glider can be found by using the length of the gliders and the transit times through either gate. Be sure to use the correct glider length with any referenced time. Fundamentally, assuming there is no acceleration after the initial push, the velocity will be equal to the distance over time, $v = L/t$.

Use the length of the gliders, the transit times, and the details of the procedure for each scenario to find the initial and final velocity for each glider in each trial. Note that in scenarios gamma and delta, your final time that was recorded was for glider B, so you should use the length of glider B in calculating velocity. Also, the final velocity of gliders A and B will be the same in scenarios gamma and delta, because they are connected.

Now that you have the initial and final velocities for each of the gliders, calculate the initial and final momentum for each glider in each trial. Remember that your velocities could have been positive or negative and that sign should be retained in this step.

Evaluate whether or not momentum was conserved in each trial of each scenario. To do this, find the total initial momentum for the gliders (the left side of Eq. 3) and the total final momentum for the gliders (the right side of Eq. 3) in each trial of each scenario. We will later evaluate the percent difference between the initial and final momentum of the system.

Question 2: Was momentum conserved in each scenario? Explain and support your answer.

Question 3: In scenario alpha, we did not measure the final transit time of glider A because it was more or less motionless after the collision. How might this lack of a measurement affect the results for scenario alpha?

The kinetic energy of an object is given by $KE = (1/2)mv^2$. Calculate the initial and final kinetic energy of each glider in each trial of each scenario.

Evaluate whether or not kinetic energy was conserved in each trial of each scenario. To do this, find the total initial kinetic energy of the gliders (the left side of Eq. 4) and the total final kinetic energy of the gliders (the right side of Eq. 4) in each trial of each scenario. We will later evaluate the percent difference between the initial and final kinetic energy of the system.

Question 4: Was kinetic energy conserved in each scenario? Explain and support your answer.

Error Analysis

The percent difference between two quantities, *X* and *Y*, would be given by the equation shown below.

$$\%diff = \left| \frac{X - Y}{(X + Y)/2} \right| \times 100\%$$

For each trial in each scenario, find the percent difference between the total initial momentum and the total final momentum.

For each trial in each scenario, find the percent difference between the total initial kinetic energy and the total final kinetic energy.

Question 5: Do your results here for the percent differences in each scenario support your assertions in Questions 2 and 3? Explain how your percent differences either support or contradict your answers.

Questions and Conclusions

Be sure to address Questions 1-5 and describe what has been verified and tested by this experiment. What are the likely sources of error? Where might the physics principles investigated in this lab manifest in everyday life, or in a job setting?

Pre-Lab Questions

Please read through all the instructions for this experiment to acquaint yourself with the experimental setup and procedures, and develop any questions you may want to discuss with your lab partner or TA before you begin. Then answer the following questions and type your answers into the Canvas quiz tool for "1-D Collisions and Conservation of Momentum," and submit it before the start of your lab section on the day this experiment is to be run.

Valerie and Jake are performing the 1-D Collisions experiment. They measure the mass of glider A to be 255 g and its length to be 17.3 cm. The same properties of glider B are 252 g and 17.2 cm.

PL-1) Val pushes glider A through photogate #1, and Jake reads the transit time from the computer display as 0.49 seconds. What is the speed of glider A, in m/s, as it passed through the photogate?

PL-2) Jake pushes glider B through photogate #2 and calculates its speed to be 0.45 m/s. What is the momentum of glider B in kg˙m/s?

PL-3) Val and Jake run one of the four scenarios described in the Procedure section. They add an additional 50.0 g of mass to glider B and start the experiment with glider B initially at rest. They measure the time for glider A to pass through photogate #1 to be 0.258 s. The collision occurs and glider A rebounds, going backwards through photogate #1 with a transit time of 2.883 s, while glider B passes forward through photogate #2 with a transit time of 0.282 s. Calculate the total momentum of gliders A and B *after* the collision in kg˙m/s.

PL-4) In the trial run in PL-3, what is the total kinetic energy, in Joules, of gliders A and B *before* the collision?

PL-5) Which of the four scenarios described in the Procedure section did Val and Jake perform in question PL-3?

[Data from above: glider B started at rest carrying an additional 50.0 g of mass. The time for glider A to pass through photogate #1 was 0.258 s. After the collision, glider A rebounded, going backwards through photogate #1 with a transit time of 2.883 s, while glider B passed forward through photogate #2 with a transit time of 0.282 s].

- (A) Scenario Alpha,
- (B) Scenario Beta,
- (C) Scenario Gamma,
- (D) Scenario Delta,
- (E) Scenario Omega.