Conservation of Linear Momentum
Fall 2023

Purpose

You will create a collision between two carts on an air track to study both elastic and inelastic collisions and observe whether linear momentum ($p = mv$) and kinetic energy ($K = \frac{1}{2}\,mv^2$) are conserved in each case.

Introduction

If two objects collide with each other, the total momentum of the system (the two objects) is conserved if there are no outside forces – even though there are huge forces between them. We will study the (scalar) x component of the momentum, which can be positive or negative.

There are two types of momentum-conserving collisions: If the two objects stick together after collision, we refer to the collision as *inelastic*; if they move apart after the collision, we call the collision *elastic*.

> IMPORTANT NOTE: YOUR TRACK WILL USE EITHER BLACK OR GOLD CARTS. BE SURE TO FOLLOW THE APPROPRIATE INSTRUCTIONS FOR THE CARTS THAT YOU ARE USING.

A general sketch of the apparatus on the lab bench appears below. You will use an air track to provide a *low-friction* environment, some air carts with flags and masses, and two photogate timers:
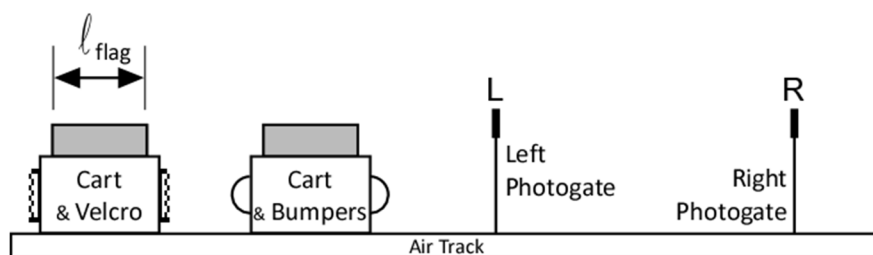
Equipment Check and Photogate Setting

1. Your instructor has already checked that the air track is ready for your use, but you briefly double-check the set up, so that your results may be interpreted correctly (*actual phenomenon, or equipment problem?*).

   a. **Level track**: With the air supply turned on, place a cart in the middle of the track. It should remain relatively motionless. You instructor can assist you if the cart moves appreciably.

   b. **Cart test**: Push each cart that will be used during the experiment, one at a time, on the track, letting it bounce back and forth. Note if any cart slows down significantly. If so, have your instructor inspect the cart.

2. **Photogate setting**: Set the photogates to the *gate* mode and set the silver memory switch to "ON" (a red light comes on). Gate mode will measure the amount of time it takes the length of the flag on the cart to pass through the timer. Record the photogate settings in your journal (you can add them to your sketch of the apparatus). *Note that the memory function **will remain on** during the entire experiment!*

Perfectly Inelastic Collisions

Theory

Colliding carts stick together and move off as though there were one larger cart in an inelastic collision. The usual bounce, prevented by the Velcro, results in a large loss of kinetic energy, but the momentum should be conserved (*if there are no outside forces*). *Note that it is* **essential** *that these collisions occur* **between the two photogates** *to obtain reasonable results!*

Procedure

1. The inelastic collision will be performed as shown in the sketches below. The arrow represents the direction of the carts motion, and the relative magnitude of the velocity:

Before Collision   During Collision   After Collision
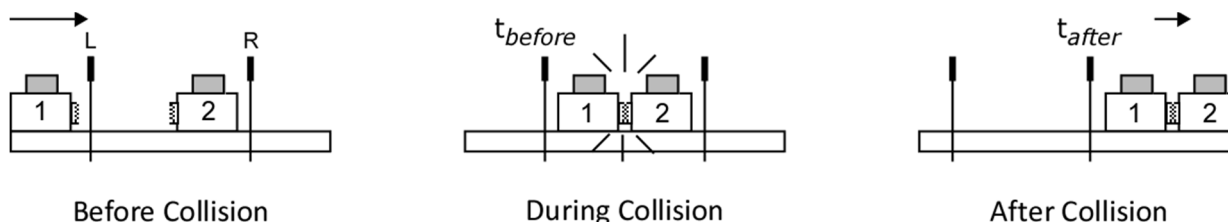
2. Begin an initial data table like the one shown below (*please include the track letter: A, B, C, etc.*) Sketch the *before*, *during* and *after* positions of the carts and timers in your journal to *define the direction of each velocity* and to know which timer is recording which cart. <u>Leave room for 10 collisions</u>.

<div align="center">

Data Table: Inelastic Collision   **Track _____**

	Left Photogate (L)	Right Photogate (R)
Trial	t_{before} (s)	t_{after} (s)
1	—	—
⋮	—	—

</div>

3. Follow the appropriate directions for the carts you are using:

   Black Carts: Use two carts *without* bumpers and <u>place a single 50 g mass on top of each cart</u> (this will make the carts more stable during collision). Put the carts on the track with the Velcro strips facing each other so that the carts will stick together after collision.

   Gold Carts: Arrange the carts so the Velcro sides face each other. These carts are larger than the black carts, so you do not need to add any additional mass

   With one cart motionless between the photogates, launch the other cart into it (be sure to perform the collision from *left* to *right*, as shown in the figure above). The left photogate (L) will measure the time the flag interrupts the beam for the single cart moving in (t_{before}); the right photogate (R) measures the time for the **pair** to move out (t_{after}). Perform *ten* inelastic collisions, recording times for each collision in your initial data table. Try collisions at different speeds; later you'll use a spreadsheet to analyze all your data, and it will be interesting to note any dependence upon speed.

> **Note:** The spreadsheet you will use later to analyze your data assumes that the cart motion moves from *left* to *right*. Be sure to perform your collisions in this manner!

4. Measure the mass (cart + flag + extra mass) of each cart and use a ruler to measure each flag length. Convert the units to *kg* and *m* and enter those values into a calculation table (*below*).

5. Draw the calculation table (*below, ignoring the red hints*) **sideways on a new page** in your journal so that you have room for corrections. Choose a trial near the middle of your data table and transfer the times into your table. Record the trial number and calculate the total momentum before and after the collision. Finally, compare the total momentum before and after collision by calculating their *% difference*.

   Note: *The % difference calculation allows you to quickly compare the agreement between two values. (See the Introduction to Laboratory Practices, "Calculation", section B "Percent Difference")*

<div align="center">

Calculation Table   ***Trial #_____***

</div>

|	m (kg)	ℓ_{flag} (m)	t_{before} (s)	t_{after} (s)	v_{before} (m/s)	v_{after} (m/s)	p_{before} (kg•m/s)	p_{after} (kg•m/s)
Cart 1							p_{before} for Cart 1	p_{after} for Cart 1
Cart 2							p_{before} for Cart 2	p_{after} for Cart 2
						Total ⇒	Total p_{before}	Total p_{after}
						%Diff⇒	%Diff between p_{before} and p_{after}	

Perfectly Elastic Collisions

Theory

   Colliding carts bounce off each other, and then continue in the same direction during an elastic collision. Both kinetic energy and momentum should be conserved (*if there are no outside forces*). *Note that it is* **essential** *that these collisions occur* **between the two photogates** *to obtain reasonable results!*

Procedure

6. Again, follow the appropriate directions for the carts you are using:

   Black Carts: Use the carts *with* two attached bumpers. Place a single 50 *g* mass on top of one cart (m_3), but <u>no additional mass </u>on the other (m_4) and place them on the track as shown below ($m_3 > m_4$ in the sketches below).

   Gold Carts: Arrange the carts so the bumpers *without Velcro* face each other. Place <u>two</u> 50 *g* masses, one on the screw on each side of one cart (m_3), but *no additional mass* on the other (m_4) and place them on the track as shown below ($m_3 > m_4$ in the sketches below).

Before Collision   During Collision   After Collision
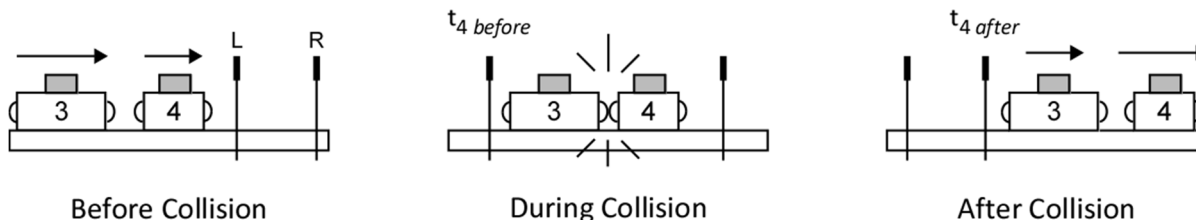
7. Sketch the cart positions above and create a data table (*shown on next page*) to keep track of the times. During this collision, each photogate will have two carts pass through; therefore, each timer will record two time intervals. After collision, the time displayed on the *left* photogate (L) will be for cart 4 *before* collision ($t_{4\ before}$). Pull the **Memory** switch on the timer to "read" and release to display the *sum* of the times for carts 4 and 3 ($t_{L\ total}$). The same reasoning holds for the right photogate (R), revealing the time for each cart *after* collision.

Data Table: Elastic Collision   Track _____

	Left Photogate (L)		Right Photogate (R)	
Trial	$t_{4\ before}$ (s)	$t_{L\ total}$ (s)	$t_{4\ after}$ (s)	$t_{R\ total}$ (s)
1	—	—	—	—
⋮	—	—	—	—

8. Both carts will be traveling in the same direction (left to right). Launch cart 4 first, then launch cart 3 so that the collision takes place between the photogates. *Do not allow the carts to pass through the photogates a third time!* Perform this collision 10 times, recording your measurements in the data table (again, try collisions at different speeds).

9. You now need to calculate the time that it took for cart 3 to pass through each photogate. *Choose a trial near the middle of your data table*, and subtract the left and right photogate times as follows:

Left photogate: $t_{3\ before} = t_{L\ total} - t_{4\ before}$ *Right photogate*: $t_{3\ after} = t_{R\ total} - t_{4\ after}$

10. Measure the cart masses again. Construct *another* calculation table, transfer the four times from the trial you chose in the previous step, and calculate the total momentum before and after collision.

Further Analysis

11. You will now use a Microsoft Excel spreadsheet to quickly calculate momentum and kinetic energy for *all* your collisions. Start Excel and then click on the **File** tab and choose **Open Other Workbooks**. Click **Browse**, navigate to the *Teaching Drive (T:)*, open the "PHYS151" folder, and then select *Conservation of Momentum*. You must use one of our lab computers to successfully run this spreadsheet! Some tips:

    * *Click **Enable Content** if the security warning appears,* and then *carefully read* the Instructions and Notes on the first page. Click the big button and enter the following:

        o Your name, and your lab partner's names
        o *All* the flag lengths
        o *All* the cart masses

    * Click the **Inelastic** button, and then enter your measured times for the inelastic collisions *from your data table* (not the calculation table!) Enter the times for the first trial, click the **Calculate** button, and then enter the times for each subsequent trial, in the order they were collected.

    * *Be sure to double-check the results of the collision that you calculated by hand; if there is a discrepancy, you should find the cause!*

    * Repeat with the measured times for your elastic collisions.

12. All the results calculated in Excel will appear on a sheet that you can print and include with your journal. You will need to print the elastic and inelastic results separately as follows:

    * Click the **View/Print Results** button on the *Elastic* or *Inelastic* collisions sheet (note that you'll have to perform these steps for *each* set of collisions); a preview of the output appears.

    * If the page looks ok, click the **Print** button, and print a copy for each member of the group.

    * *Indicate the trial that you used for hand calculations of your collision results on the printout!*

Discussion

- As always, begin by restating your numerical results. For today, just calculate the average percentage of momentum loss for each set of 10 collisions (don't average in results from a bad collision). Also calculate the average percentage of kinetic energy loss results for each type of collision. Be sure to state the results you were expecting here.

- Look at the % difference results (momentum and kinetic energy) for each type of collision you performed and discuss their consistency for each type of collision.

- Conservation of momentum should not depend on the type of collision but only on whether there are outside forces acting on the system. Apply this principle to a discussion of your results for the two types of collisions you studied in this lab. You can be sure that if momentum was not conserved in either collision, there must have been an external force.

    - It is important to note that since an external friction force is always opposite to the velocity, friction can only *reduce* the magnitude of the momentum after collision.

- Be sure to briefly discuss any outliers in your results (excessive momentum loss, apparent gain in momentum, etc.).