

Introduction

You have a summer job at Amtrak with a group examining the crash between two trains. Your supervisor wants you to calculate the results of two different cases. The first is a perfectly inelastic collision where the two trains stick to each other. The other case is an elastic collision where the two trains bounce off each other with no loss of kinetic energy. Since the trains may be carrying different cargo, their masses may be different. Your supervisor wants you to calculate the final velocity of the trains as a function of the masses and initial velocities of the trains. You decide to calculate the resulting velocities for the system and then build a laboratory model using gliders to check your calculation.

Your Objective: To experimentally determine the final velocities of two objects after collision.

Pre-lab questions:

Read sections 6.1, 6.2, 6.3 in Serway & Faughn

Answer each of the following questions in a few sentences of your own words:

1. A 0.50 kg ball is thrown horizontally towards a wall with a speed of 12 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 12 m/s in the negative x-direction. What is momentum of the ball before it hits the wall, p_i ? What is momentum of the ball after it hits the wall, p_f ? What is the change in momentum of the ball, Δp ? (Give both magnitude and direction for each of the previous answers.) Is momentum conserved for the ball?
2. **Perfectly Inelastic Collision.** Draw diagrams showing a situation where a bigger, moving train, v_i , collides with a smaller train that is not moving. Assume that after the collision the trains stick together. Show separate diagrams for the situation just before the collision and just after the collision. Assume the trains have different masses (m_{big} and m_{small}). Make sure you identify your isolated system. Write down the momentum conservation equation for the scenario in question. Solve for the final velocity of the two trains, v_f , in terms of v_i , m_{big} , and m_{small} .
3. **Elastic Collision.** Draw two diagrams for the situation where a moving train (with initial speed v_o) collides elastically with a target train that is not initially moving, and the trains use their springy bumpers to bounce off each other without damage. One diagram should show the instant just before the collision and the other the instant just after the collision. Assume the trains have different masses (m_{moving} and m_{target}) Make sure you identify your *isolated system*. Show that the final velocity of each train will be:

$$v_{target} = \frac{2v_o}{\left(1 + \frac{m_{target}}{m_{moving}}\right)} \quad v_{moving} = \frac{(m_{moving} - m_{target})}{(m_{moving} + m_{target})} v_o$$

Hint: use conservation of momentum and the relation between the relative velocities before and after collision that arises due to conservation of energy.

4. Make all the data tables you'll need for experiments B & C ahead of time in your lab notebook. B7 has an example of how your columns should look for experiment B. C9 tells you how many columns you should have for experiment C. Don't turn the carbon copies of these tables in with your pre-lab – your TA will check to make sure you have the tables at the beginning of lab.

LAB WORK**A. Becoming Familiar with the Photogates****How the photogates work:**

The photogates measure the amount of time an object remains inside the gate. In the case of this experiment, the photogates measure the amount of time it takes for the flag attached to the glider to pass through the gate (in seconds).

- A1.** Can you calculate the velocity of the glider with the photogates? If so, how? If not, what other information do you need?
- A2.** Open the file *Lab7.xml* using Logger Pro.
- A3.** Start collecting data and try pushing a glider with a flag through one gate. Note that Logger Pro gives the total time it takes for the flag to pass through the gate. Only record data accurate to 10ms (i.e. 0.01 sec). Note that a red LED will light on top of the gate when something is in the middle.
- A4.** Try pushing the glider so that it passes through both gates. What is the velocity of the glider as it passes through each of the gates? Record your raw data and your calculations in your notebook. Make sure the units of the velocity are m/s.
- A5.** Think about how you can tell if your track is level, and if the track is frictionless? If the track is not level, trim its angle by adjusting the legs of the track.

B. Perfectly Inelastic Collisions

In this experiment, a moving glider will collide and stick to a stationary glider. The velocity of the moving glider and the two gliders stuck together after collision will be measured.

Prediction:

- B1.** Consider the following scenario: a moving glider collides with a glider at rest, and after the collision, the gliders stick together.

Make a diagram of this scenario, showing the system before the collision and after the collision. Show and label velocity vectors for every object in your drawing (be conscientious about the relative lengths of these vectors; use the same values for the masses of the gliders that you have been given for the actual experiment in Step B1).
- B2.** Which conservation principle(s) should you use to predict the final velocity of the stuck-together gliders? Why?
- B3.** Look at your answers for the pre-lab questions 2 and 3. Identify all the terms in the equation. Write down which physical quantities all the variables correspond to in your notebook. Are there any of these terms that cannot be measured with the equipment at hand?

Prediction: Solve the appropriate equations to find the final velocity of the gliders in terms of the measurable variables.

Experimental Practice:

- B4.** Install the pin on one glider and the wax cup on the other. Give the gliders different mass by adding weights. Keep the weights balanced on the glider (left vs. right).
- B5.** Practice colliding the gliders without taking data. Make sure the gliders move freely along the track. You will only get good results if the gliders don't collide too harshly – the pin should not 'bottom out' in the cup. Observe qualitatively what happens. How does the final velocity of the stuck-together glider compare to the initial velocity of the moving glider? Think about both magnitude and direction. Does this make sense?
- B6.** Place the glider on the side of the track where the initially moving glider will start. Give the glider a push toward to stationary glider. When performing this experiment, use a range of initial velocities.

Experiment & Analysis:

- B7.** Make a table for your results. Your table should include all raw data and all calculations. Please include both time measurements from the photogates, both calculated velocities, and any other information that you feel is relevant. All columns should be labeled and should include units. If a calculation is made, the column containing the result should include the equation used to make the calculation. An example for a measurement of a speed is shown but your table will have more columns than this.

Time [s]	Distance [m]	Speed[m/s]
		Distance/Time
0.23	0.15	0.65

- B8.** Make a run. Think about any peculiarities that you notice during the trial that might suggest that the data are unreliable.
- B9.** Determine the initial and final velocities of the gliders from your experimental data.
- B10.** Determine the predicted final velocity of the glider using the initial velocity from the data and your Prediction equation.
- B11.** Repeat steps B8-B10 two times with a range of initial velocities. Include each of your three data points in your table. Be sure to keep in mind the error associated with the photogates when recording your results in your table.
- B12.** Make a plot of the final velocity of your glider from your experimental data verses the initial velocity of glider one. Please plot three data points on this graph. Remember, when making a plot, the independent variable goes on the x-axis and the dependent variable goes on the y-axis. In this situation, which variable is which? On this graph, please include error bars and a straight line that represents the best fit to the data. Note that the "best fit line" will not in general pass through any of your data points. Ask your TA for assistance if error bars and/or best-fit lines are unfamiliar to you.

- B13.** Find the slope of the best fit line for your plot. Compare this slope to the predicted slope from your Prediction equations. Are they consistent? Is momentum conserved?

C. Elastic Collisions

In this experiment, a moving glider will collide with a stationary glider and bounce off without sticking. The velocities of the moving glider before collision and the velocities of the two gliders after collision will be measured. Three velocities in all will be measured.

- C1.** In part B, you used the photogates to measure two different velocities in one trial run. In this part you will have to measure *three* different velocities in one trial run. How can you accomplish this? (*Hint: you may want more than one person to look at the timer control during the trial run. The timer may be reset after a velocity measurement.*)
- C2.** Elastic collision.
- Place a glider at one end of the track and a rubber band bumper at the other end, with the two photogates along the track.
 - Push the glider so that it passes through both gates, bounces off the bumper at the other end, and passes through one of the gates again. Be sure to catch the glider while it is between the two gates.
 - Calculate the velocity of the glider when it passes through each of the gates. Record your results in your notebook.
- C3.** Does your method introduce any new experimental uncertainty into your measurement of the velocity? If so, how much? (Be quantitative)
- C4.** What are the experimental uncertainties of your measurements?
- C5.** Now think about how will you simulate this collision, and how you will measure the velocities of the gliders after the collision.

Prediction:

- C6.** Look at your answers for the pre-lab question 3. Identify all the terms in the equation. Write down which physical quantities all the variables correspond to in your notebook. Are there any of these terms that cannot be measured with the equipment at hand?

Experimental Practice:

- C7.** You will do three experiments with three different mass ratios.
- 1) The initial glider has more mass than the incident glider,
 - 2) Both gliders have equal mass,
 - 3) The initial glider has less mass than the incident glider.

With each mass ratio, do 3 to 4 trials. Make sure the mass is as evenly distributed on the left/right sides of the glider as possible for each case. Use a range of initial velocities during each experiment. Do not launch the glider so fast that the rubber bumper 'bottoms' out during the glider-glider collision.

- C8.** Practice colliding the gliders without taking data. Make sure the gliders move freely along the track. Observe qualitatively what happens. Think about how the final

velocities of the gliders compare to the initial velocity of the moving glider and to each other. Think about both magnitude and direction. Does this make sense?

Experiment & Analysis:

- C9. Make a table for your results. Remember, your table should include all raw data and all calculations. All columns should be labeled and should include units. If a calculation is made, the column containing the result should include the equation used to make the calculation. There should be 9 total columns. Time/Distance/Speed for initially moving cart, incident cart, and reflected cart.
- C10. Make a run. Are there any peculiarities that you notice during the trial that might suggest that the data are unreliable?
- C11. Determine the initial and final velocities of the gliders from your experimental data.
- C12. Determine the predicted final velocity of each glider using the initial velocity from the data and your Prediction equation.
- C13. Repeat steps C10-C12 with different initial velocities to obtain 3 to 4 trials. Now repeat steps C10-C12 for your other two mass cases. Make separate tables for each mass ratio.
- C14. Make a plot of the final velocity of the initially moving glider vs. the final velocity of the other glider for your third mass case. Remember, plots should include both error bars and a best-fit line.
- C15. Find the slope of the best-fit line for this plot. How can we tell if momentum is conserved from this slope? Is momentum conserved?
- C16. How does your data match the theory for your final mass case? Explain.

Post-lab questions:

1. Train A (mass = 4500 kg) successfully couples with a Train B (mass = 7500 kg). Train A is moving at 6.0 m/s before the collision, and Train B is initially at rest. What is the final velocity of the coupled trains? What is the initial kinetic energy of the system? What is the final kinetic energy of the system? How much kinetic energy is lost? What fraction of the initial KE is lost? (Hint: refer to part B of this lab)
2. A 75.0 kg archer, standing on frictionless ice, shoots a 100 g arrow at a speed of 150 m/s. What is the recoil speed of the archer?
3. Two objects have the same kinetic energy. Object 1 has twice the mass as object 2. Which object (if any) has the larger magnitude of momentum? Explain.