Mechanics Laboratory 1105, Spring 2025

Prof. Dr. T. Neumann, Prof. R. Guarino

https://www.physics.smu.edu/tneumann/110X_Spring2025/

Lab 8 — Elastic and inelastic collisions with smart carts Max. points: 64

Your preparation: Work through before coming to the lab

- Prepare for the lab by thoroughly reading and understanding the measurement and analysis procedures on this worksheet. Photos of the equipment and further introductory material will be made available on https://www.physics.smu.edu/tneumann/110X_Spring2025/schedule-mechanics/.
- Collect all your questions and ask your instructor at the beginning of the lab.
- Work through the chapter on "Linear Momentum and Collisions" [1]. Focus especially on these topics:
  - Understand the concept of linear momentum and its conservation. Be able to define momentum for a single particle and a system of particles.
  - Understand the difference between elastic, inelastic, and perfectly inelastic collisions. Know what quantities are conserved in each type of collision.
  - Review the concept of impulse and its relationship to the change in momentum.
  - Understand how to calculate the center of mass for a system of particles. Consider how the velocity of the center of mass behaves in different collision scenarios.
  - Specifically for this lab: Review how to calculate kinetic energy for a moving object. You will need this to analyze energy conservation (or lack thereof) in your collisions.

Pre-lab: Upload to Canvas before coming to the lab

A reminder: Upload your answers as a text document (exported as PDF) to Canvas before the lab begins (Canvas uploads are no longer possible 30 minutes before the lab starts!).

Pre-lab 1 — 8 points

1. (1 point) Define impulse in the context of a collision. In the Measurement section, you will be analyzing Force vs. Time graphs. How is the impulse related to the Force vs. Time graph?
2. (1 point) You will be performing collisions with two different bumper types (rubber and magnet) and then with Velcro tabs. Rank these three interaction types (rubber, magnet, Velcro) in order from most elastic to most inelastic. Briefly explain your reasoning.

3. (2 points) In the inelastic collision part of the experiment, you will collide two carts of masses m_1 and m_2, with initial velocities v_{1i} and v_{2i}, respectively. After the collision, they stick together and move with a final velocity v_f. Derive the formula for v_f in terms of m_1, m_2, v_{1i}, and v_{2i}, starting from the principle of conservation of momentum. Show all steps of your derivation.

4. (1 point) You will be using PASCO Smart Carts that measure velocity. Suppose a cart's velocity changes from +0.5 m/s to -0.3 m/s during a collision. What is the change in velocity, Δv, for this cart? Be careful with signs! Explain what the sign of Δv indicates.

5. (1 point) In the Analysis section, you will calculate the percentage difference between initial and final momentum, and the percentage loss of kinetic energy in the inelastic collisions. Explain why we calculate the percentage difference for momentum but the percentage loss for kinetic energy. What is fundamentally different about these two quantities in the context of collisions?

6. (2 points) Consider potential sources of error. You will be leveling the track at the beginning of the experiment. Explain why it is important to have a level track for this experiment. Specifically, how would a non-level track affect your measurements of momentum and/or kinetic energy, and why?

Lab measurements and report: submission by end of class

A reminder: All measurements must be fully documented . The final report must be uploaded to Canvas *by the end of the class* exported as PDF with plots and tables from Excel embedded as images. Canvas will stop accepting uploads 10 minutes after the class ends. If you have not fully completed your report, you must upload the documents as far as you have completed them for grading.

Measurement 1 *Elastic Collisions with Rubber Bumpers* 15 points

Equipment: Two PASCO Smart Carts (Red and Blue), Track, Level, Rubber Bumpers, Magnet Bumpers, Velcro Tabs, Computer with Capstone Software, Weighing Scale.

1. (2 points) **Setup and Leveling:**
   (a) Place the track on the lab table.
   (b) Use the level to ensure the track is level in both the longitudinal (along the track) and transverse (across the track) directions. Adjust the feet of the track as needed. Record in your report how you ensured the track was level.
   (c) Weigh each cart (without attachments) using the weighing scale and record their masses (m_1 for the red cart, m_2 for the blue cart) in your Excel spreadsheet.

2. (2 points) **Cart and Software Setup:**
   (a) Attach the rubber bumpers to the force sensors on both carts.
   (b) Place the carts on the track, ensuring the rubber bumpers are facing each other.

(c) Turn on both Smart Carts.

(d) Connect both carts to the Capstone software via Bluetooth.

(e) In Capstone, enable the following sensors for *both* carts:

- Position
- Velocity
- Acceleration
- Force (from the force sensor)

(f) Before starting any collisions, zero the force sensors in Capstone while the carts are on the track and not touching.

(g) Adjust the sampling rate: Set the force sensor sampling rate as high as possible while ensuring that the other sensors (position, velocity, acceleration) have a sampling rate of at least 20 Hz. Record the sampling rates you are using in your report.

3. (4 points) **Elastic Collision - Cart 1 Moving, Cart 2 Stationary:**

(a) Place the blue cart (cart 2) at rest near the center of the track.

(b) Position the red cart (cart 1) at one end of the track.

(c) Start data recording in Capstone.

(d) Give the red cart a gentle push towards the blue cart, causing a collision. Ensure the push is firm enough to cause a clear change in velocity, but not so strong that the carts jump the track.

(e) Stop data recording after the collision has occurred and the carts have separated. Save your recorded data for later access with a descriptive name.

(f) In Capstone, identify the time interval *immediately before* the collision and the time interval *immediately after* the collision. Use the velocity vs. time graph to do this. Record these time intervals in your report.

(g) Use Capstone's analysis tools to determine the following values and record them in your Excel spreadsheet:

- v_{1i}: Velocity of cart 1 *immediately before* the collision.
- v_{2i}: Velocity of cart 2 *immediately before* the collision (should be close to zero).
- v_{1f}: Velocity of cart 1 *immediately after* the collision.
- v_{2f}: Velocity of cart 2 *immediately after* the collision.

(h) Also, record the maximum force measured by *each* force sensor during the collision.

4. (4 points) **Elastic Collision - Both Carts Moving:**

(a) Position both carts at opposite ends of the track.

(b) Start data recording in Capstone.

(c) Simultaneously push both carts towards each other, causing them to collide near the center of the track. Aim for a collision where both carts have noticeable, but not excessive, speeds.

(d) Stop data recording after the collision.

(e) Repeat steps (e)-(g) from part 3 to determine and record v_{1i}, v_{2i}, v_{1f}, v_{2f}, and the maximum force on each cart.

5. (3 points) **Elastic Collision - Magnet Bumpers:**

   (a) Replace the rubber bumpers on *both* carts with the magnet bumpers.

   (b) Repeat steps 3 and 4 (both collision scenarios) using the magnet bumpers. Record all relevant data in your Excel spreadsheet in a new table, clearly labeled as "Magnet Bumper Data."

Analysis 1 *Analysis of Elastic Collisions* 17 points

1. (6 points) **Momentum Conservation (Rubber and Magnet Bumpers):**

   (a) For *each* collision scenario (rubber bumpers, cart 1 moving; rubber bumpers, both moving; magnet bumpers, cart 1 moving; magnet bumpers, both moving), calculate the following in your Excel spreadsheet:

   - Total initial momentum: $p_i = m_1 v_{1i} + m_2 v_{2i}$
   - Total final momentum: $p_f = m_1 v_{1f} + m_2 v_{2f}$
   - Percentage difference between initial and final momentum: $\%\text{Diff} = \frac{|p_i - p_f|}{(p_i + p_f)/2} \times 100\%$

   (b) Discuss whether momentum was conserved within experimental uncertainties for each scenario. Consider the percentage differences you calculated. *Justify your answer.*

2. (6 points) **Kinetic Energy Conservation (Rubber and Magnet Bumpers):**

   (a) For *each* collision scenario, calculate the following in your Excel spreadsheet:

   - Total initial kinetic energy: $K_i = \frac{1}{2} m_1 v_{1i}^2 + \frac{1}{2} m_2 v_{2i}^2$
   - Total final kinetic energy: $K_f = \frac{1}{2} m_1 v_{1f}^2 + \frac{1}{2} m_2 v_{2f}^2$
   - Percentage difference between initial and final kinetic energy: $\%\text{Diff} = \frac{|K_i - K_f|}{(K_i + K_f)/2} \times 100\%$

   (b) Discuss whether kinetic energy was conserved within experimental uncertainties for each scenario. *Justify your answer.* Compare the results for the rubber bumper collisions to the magnet bumper collisions. Are the magnet bumper collisions *more* or *less* elastic than the rubber bumper collisions?

3. (5 points) **Impulse and Force Analysis:**

(a) For *one* of the rubber-bumper collisions, create a plot of Force vs. Time in Capstone, showing the force measured by *one* of the force sensors during the collision. Include a screenshot of this plot in your report.

(b) The impulse delivered to a cart during the collision is equal to the change in its momentum. Calculate the change in momentum ($\Delta p = m\Delta v$) for the cart you chose in part (a).

(c) The impulse is also equal to the area under the Force vs. Time curve. Estimate the area under your Force vs. Time curve. Describe how you estimated the area (e.g., approximating the curve as a triangle, using a built-in integration tool in Capstone, etc.).

(d) Compare the change in momentum (from part b) to the estimated impulse (from part c). Are they approximately equal? Discuss any discrepancies, considering sources of error.

Measurement 2 *Inelastic Collisions with Velcro Tabs* 9 points

1. (1 point) **Setup for Inelastic Collisions:**

   (a) Remove the bumpers from both carts.

   (b) Rotate both carts by 180 degrees so that the Velcro tabs are facing each other. This will cause the carts to stick together after the collision. Note: You will not be using the force sensors for this part of the experiment.

2. (4 points) **Inelastic Collision - Cart 1 Moving, Cart 2 Stationary:**

   (a) Place the blue cart (cart 2) at rest near the center of the track.

   (b) Position the red cart (cart 1) at one end of the track.

   (c) Start data recording in Capstone.

   (d) Give the red cart a gentle push towards the blue cart, causing them to collide and stick together.

   (e) Stop data recording after the carts have stuck together and are moving as a single unit.

   (f) Determine and record the following values in your Excel spreadsheet:

   - v_{1i}: Velocity of cart 1 *immediately before* the collision.
   - v_{2i}: Velocity of cart 2 *immediately before* the collision (should be close to zero).
   - v_f: *Common* final velocity of the combined carts *after* the collision.

3. (4 points) **Inelastic Collision - Both Carts Moving:**

   (a) Position both carts at opposite ends of the track.

   (b) Start data recording in Capstone.

   (c) Simultaneously push both carts towards each other. *Aim for a collision where the carts stick together and move as a single unit after the collision.*

(d) Stop data recording after the collision.

(e) Determine and record v_{1i}, v_{2i}, and the common final velocity v_f in your Excel spreadsheet.

Analysis 2 *Analysis of Inelastic Collisions* 15 points

1. (5 points) **Momentum Conservation (Velcro):**

   (a) For *each* inelastic collision scenario (cart 1 moving, both moving), calculate the following in your Excel spreadsheet:

   - Total initial momentum: $p_i = m_1 v_{1i} + m_2 v_{2i}$
   - Total final momentum: $p_f = (m_1 + m_2) v_f$ (Note: the combined mass!)
   - Percentage difference between initial and final momentum.

   (b) Discuss whether momentum was conserved within experimental uncertainties for each scenario.

2. (5 points) **Kinetic Energy Loss (Velcro):**

   (a) For *each* inelastic collision scenario, calculate the following:

   - Total initial kinetic energy: $K_i = \frac{1}{2} m_1 v_{1i}^2 + \frac{1}{2} m_2 v_{2i}^2$
   - Total final kinetic energy: $K_f = \frac{1}{2}(m_1 + m_2) v_f^2$ (Note: the combined mass!)
   - Percentage *loss* in kinetic energy: $\%\text{Loss} = \frac{K_i - K_f}{K_i} \times 100\%$ (Note: This is *loss*, not difference).

   (b) Discuss the percentage loss of kinetic energy in each scenario. Where did the ”lost” kinetic energy go?

3. (5 points) **Comparison of Elastic and Inelastic Collisions**

   a) Compare your results for momentum and energy conservation across all *three* types of collisions (rubber bumper, magnet bumper, Velcro).

   b) Summarize the key differences between elastic and inelastic collisions, based on your experimental findings. Which type of collision conserved kinetic energy? Which type did not? Which type conserved momentum?

   c) Explain any deviations you observed.

Learning Outcomes

- Experimentally verify the principles of conservation of linear momentum in both elastic and inelastic collisions.
- Experimentally investigate the conservation of kinetic energy in elastic collisions and the loss of kinetic energy in inelastic collisions.

- Gain hands-on experience with measuring velocity and force using sensors (Smart Carts and force sensors) in a dynamic system.
- Learn to use software (Capstone and Excel) for data acquisition, plotting, and quantitative analysis of collisions.
- Calculate and compare impulse and change in momentum in a collision.
- Analyze experimental data to distinguish between elastic and inelastic collisions based on energy conservation.
- Evaluate potential sources of error and their impact on the measurement of momentum and kinetic energy in collision experiments.

References

[1] D. Halliday, R. Resnick, and J. Walker. *Fundamentals of Physics*. Fundamentals of Physics. John Wiley & Sons.