LAB 8: MOMENTUM AND COLLISIONS(TPL1)

Goals:
- Compare the forces on each of two objects in a collision
- Demonstrate conservation of momentum for inelastic and elastic collisions by measuring velocities before and after the collisions (with equal and unequal masses)

Introduction Using the very low friction carts and the tracks, we can demonstrate the principle of conservation of momentum. Inelastic and elastic collisions will be studied with the carts and gate-timers. The ULI program will be used to compare the forces (simultaneously) on each cart in a variety of collisions.

Part 1 Forces in collisions (table with dual Force Probes)

When one mass collides with another mass, there are forces exerted on each mass by the other (Newton's third law). Mass A exerts a force on mass B during the collision. This force could be a spring force, a contact force, or even a magnetic repulsion force. This force will affect the motion of mass B. Simultaneously, mass B exerts a force on mass A during the same collision. This force affects the motion of A. In this section, we will investigate the relationship between these forces in different collision situations.

1. Prepare equipment. Connect two force probes to the USBLinks, and then to your laptop. Start the DataStudio software.

2. DataStudio Experiment file. Download the experiment file Lab08_CollisionsForce.ds from the lab schedule webpage, and load it in DataStudio. The force graph in the file has one force "inverted" from the other force so that you can see them both without overlapping each other. This is consistent with picking one direction in the lab to be the positive direction, thus, you should see the forces acting opposite each other. (Technically, the forces, as measured, are 'relative to the probe'.)

3. Spring cushions. To ensure that there is a clean, effective collision between the two probes (thus recording the "cart collision"), there are springs that fit the force probes. When colliding, the springs will allow the force probe to have time to accurately measure the collision. Set the carts on the horizontal track as shown in the diagram below:

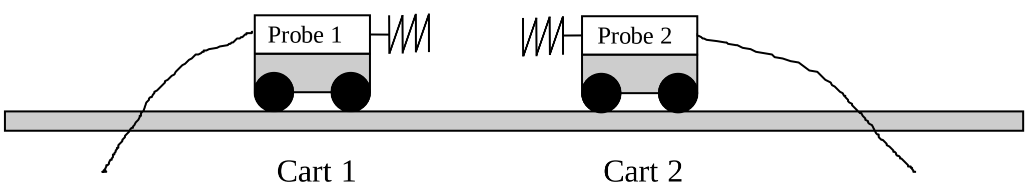


Figure 1 – Force probes on carts with spring cushions.

4. Prepare the force probe. Press the ZERO button on the side of the probe (this is a "mechanical" tare for the probe). You can't "zero" the probe in DataStudio, so occasionally you might need to keep track of a zero "offset" and account for it.

5. Data rate and display. The data is being taken at 1000 points per second (to give us a smooth picture of the collision) for 2 seconds, while the collision lasts a fraction of a second. If DataStudio display

all data points in the 2 seconds, you will probably see a sharp spike of force; use the selective zoom button to see the details of how the collision forces change with time.

6. Collision - one mass at rest. Give one cart a push, click START in DataStudio, so that the moving cart hits the one at rest within the 2 second mark.

Question Answer on the Data/Question sheet.
How do the two force curves compare with each other (shape, peak magnitude, and direction)?

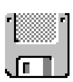
7. Analyze the force curve - area. Zoom the graph to expand one of the "bumps" of the collision (one probe graphing positive, one negative, but they should be symmetrical). Show only the data run you want to analyze. Use your mouse to drag a rectangle around the particular curve (upper or lower) for that run. Only **include the bump – not the horizontal sections on either side (refer to the online help page)**. Under the summation button Σ, make sure the AREA option is checked. This will calculate the area (integral) under the force vs. time curve (the impulse) and display it on the graph in the graph legend. Select the other data run, and repeat the same procedures to get the area for the other force probe.

Question Answer on the Data/Question sheet.
a) How do the two integral values compare to each other? Is this expected from the shape of the curves?
b) How does the relationship between the two integrals explain the connection between the force cart A exerts on cart B and the force cart B exerts on cart A?

8. Store data for comparison. Rename this run "Equal, Mass2 at rest", and hide the run.

9. Both carts moving. Repeat the collision for the situation where both carts are moving toward each other when they collide. Highlight the collision event and compare the integrals for the two force graphs of this collision. Rename this run as "Equal, both moving" and hide it.

Questions Answer on the Data/Question sheet.
a) Does the comparison of these integrals with each other follow the comparison of the previous collision?
b) How does the magnitude of these new integrals compare to the magnitudes of the previous integrals? What factors determine the magnitude of the integral?



Save the data from this section.

Prediction Suppose a heavy car collides with a lighter car, and you could measure the forces in the collision (similar to the above procedures). What would be the relationship between the force of the heavy car on the light car and the force of the light car on the heavy car? Explain your reasoning on the Data/Question sheet.

10. Heavy cart vs. light cart. Put the two bar weights in **one** of the carts and collide them together. This would simulate a heavy vehicle hitting a lighter vehicle. Analyze the force curves, and find the integrals of the area under the curve. Try collisions with the carts at rest or moving initially.

Question a) Does the comparison of these integrals with each other follow the comparison of the previous collision?

b) How does the magnitude of these new integrals compare to the magnitudes of the previous integrals? What factors determine the magnitude of the integral?

10. Print one of the Collision Graphs. Pick the better of the two graphs and print it for the report.

Part 2 - Inelastic Collisions

Introduction The linear momentum of an object is a vector defined as the product of the mass and the velocity:

$$\vec{p} = m\vec{v}$$

where m is the mass of the object (kg), and $\vec{v}$ is the velocity (m/sec) and $\vec{p}$ is the momentum ($\text{kg} \cdot \text{m/sec}$). The principle of Conservation of Momentum states that if two bodies with masses m_1 and m_2 moving with initial velocities of $\vec{v}_{1i}$ and $\vec{v}_{2i}$ respectively, collide with each other, they will move with final velocities of $\vec{v}_{1f}$ and $\vec{v}_{2f}$ such that:

$$m_1\vec{v}_{1i} + m_2\vec{v}_{2i} = m_1\vec{v}_{1f} + m_2\vec{v}_{2f}$$

The above relationship covers both elastic and inelastic collisions – we will study these relationships in these next two sections.

1. Replace sensors. Remove the force probes from the carts and return them to your instructor. Ask your instructors for 2 motion sensors; refer to the online help page to mount the sensors on the track. Connect the 2 sensors to your laptop through USBLinks.

2. Another experiment file. Download the experiment file Lab08_CollisionsMotion.ds from the lab schedule webpage, and load in DataStudio.
   Please note that for a motion sensor, motion away from it is positive, toward it is negative. For the 2 sensors facing each other, a motion positive to one sensor is negative to another. Please keep this in mind when you interpret the data graphs.

3. Inelastic collisions. The term inelastic is applied to a collision if the mechanical energy is not conserved in the collision. This represents the majority of collisions we are familiar with in everyday life. For our inelastic collisions, this means that the kinetic energy before the collision will be greater than the kinetic energy after the collision – some of the energy will be lost in the collision, sticking the masses together. Since the masses stick together after the collision and one of the masses is initially at rest, the above momentum equation gets modified as follows:

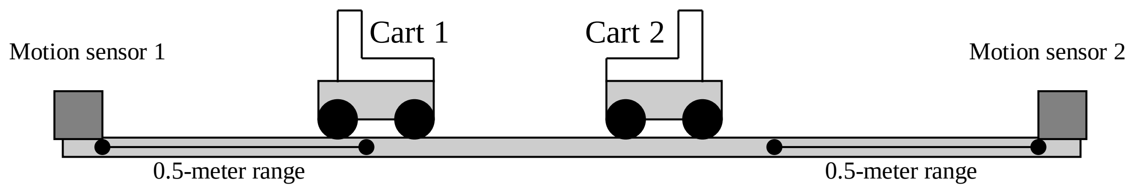
   $$m_1\vec{v}_{1i} = (m_1 + m_2)\vec{v}_f \quad \text{so} \quad \vec{v}_f = \frac{m_1\vec{v}_{1i}}{m_1 + m_2} \qquad \text{Equation (1)}$$

   You will use this relationship to test the inelastic collisions you measure.

4. Preparing the equipment. You will be using two carts that can collide in different ways on the horizontal track. The carts should be oriented so that the Velcro sides are facing each other (“hooks” on one cart and “felt” on the other). There should be additional masses that can be put into the carts to make one cart heavier than the other. Weigh the two carts (keep track of which cart is which) with the Plexiglas L-bracket and weigh the additional masses. Record the values on the Data/Question sheet.

5. Setting up motion detectors. The two motion sensors are set up on opposite ends of the track (as shown below). This leaves only a small “window” in the middle where the collision can occur (so that both carts are more than 0.5 meters from each detector) – this collision zone is approximately between the 50 and 130 cm on the track scale. We will have one cart hit and stick to another cart.

Each motion detector will measure whatever cart is closest to it. [If they stick together, both probes will measure that same velocity, but if they separate, as in future sections, we can still keep track of the before/after velocities of each cart.]



Motion detectors and carts with L-brackets.

6. Collision techniques. Start with the second cart at rest inside the collision zone, but a little closer to motion sensor 2. Start with the first cart closer to the first motion detector range limit (could actually be inside, since you will start the cart before you start collecting data). Slide the first cart so that it will hit the second cart, and right away click START (this gives a nice smooth motion to the cart as DataStudio starts recording. To ensure a good reading, make sure of the following:

    - Let go of the first cart before the motion sensor "clicking" noise begins. (so DataStudio doesn't record your hand)
    - Make sure the carts stick together, but don't "scrape" on the track during the collision.
    - Make sure the combined cart is moving smoothly and completely after the collision.

Prediction Suppose two equal-mass carts collide (one at rest, the other in motion). What would you expect the final velocity of the combined mass to be relative to the initial velocity of the first mass? Explain your reasoning on the Data/Question sheet.

7. Equal masses. Using the carts without the bar weights, perform an inelastic collision. Measure the velocity (the "mean" value) of the moving Cart 1 (Velocity 1) just before the collision, and then the velocity of the combined cart (Velocity 2) just after the collision. It would probably be better to find the "mean" velocity for a "constant" data region before and after the collision. Notice that the velocity starts decreasing over time after the collision – that is the effect of air resistance (and/or friction with the cart axles). Try to take the velocity measurements as close to the time of collision as possible (refer to the online help page for more instruction). Record the values on the Data/Question sheet.

8. Check the collision equation. Calculate the expected final velocity based on the masses and the initial velocity of the first cart. Then calculate the % difference between your calculated and the measured value above. Record on Data/Question sheet.

Prediction Suppose a heavy cart collides with a stationary lighter cart. What would you expect the final velocity of the combined mass to be relative to the initial velocity of the first mass? Explain your reasoning on the Data/Question sheet.

9. Heavy cart hits light cart. Put the bar masses in the first cart and set up the collision as you did previously. Collide the heavier cart into the lighter cart and record the velocities on Data/Question sheet.

10. Check the collision equation. Calculate the expected final velocity based on the masses and the initial velocity of the first cart. Then calculate the % difference between your calculated and the measured value above. (Remember to account for the masses in the first cart.) Record the information on the Data/Question sheet.

Prediction Suppose a light cart collides with a stationary heavy cart. What would you expect the final velocity of the combined mass to be relative to the initial velocity of the first mass? Explain your reasoning on the Data/Question sheet.

11. Light cart hits heavy cart. Put the bar masses in the second cart and set up the collision as you did previously. Collide the lighter cart into the heavier cart and record the velocities on the Data/Question sheet.

12. Check the collision equation. Calculate the expected final velocity based on the masses and the initial velocity of the first cart. Then calculate the % difference between your calculated and the measured value above. (Remember to account for the masses in the second cart.) Record on Data/Question sheet.

13. Print the Graph. Print one of the collision graphs (one for which your data calculations worked out very well).

DATA/QUESTION SHEET - LAB 8: MOMENTUM AND COLLISIONS

Part 1 Forces in collisions

6. Collision - one mass at rest.

Question How do the two force vs. time curves compare with each other (shape, peak magnitude, and direction)?

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7. Analyze the force –vs. time area.

Questions a) How do the two integral values compare to each other? Is this expected from the shape of the curves?

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b) How does the relationship between the two integrals explain the connection between the force cart A exerts on cart B and the force cart B exerts on cart A?

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9. Both carts moving.

Questions a) Does the comparison of these integrals with each other follow the comparison of the previous collision?

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b) How does the magnitude of these new integrals compare to the magnitudes of the previous integrals? What factors determine the magnitude of the integral?

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Prediction Suppose a heavy car collides with a lighter car, and you could measure the forces in the collision (similar to the above procedures). What would be the relationship between the force of the heavy car on the light car and the force of the light car on the heavy car? Explain your reasoning.

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10. Heavy cart vs. light cart.

Question a) Does the comparison of these integrals with each other follow the comparison of the previous collision?

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b) How does the magnitude of these new integrals compare to the magnitudes of the previous integrals? What factors determine the magnitude of the integral?

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Part 2 - Inelastic Collisions

4. Preparing the equipment. Masses of the carts:

Mass of Cart 1 = ________ kg

Mass of Cart 2 = ________ kg

Mass of both bars together = ________ kg

6. Collision techniques.

Prediction Suppose two equal-mass carts collide (one at rest, the other in motion). What would you expect the final velocity of the combined mass to be relative to the initial velocity of the first mass? Explain your reasoning.

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7. Equal masses.

Mean velocity for Cart 1 (before) = V_{1i} = _________ m/sec

Mean velocity for combined carts (after) = V_f = _________ m/sec

$$\vec{v}_f = \frac{m_1\vec{v}_{1i}}{m_1 + m_2}$$

8. Check the collision equation. Use Equation (1) shown earlier.

$V_{f\_calculated}$ = _________ m/sec

% diff = __________

$$\%\ diff = 100x\frac{|A-B|}{\left(\frac{(A+B)}{2}\right)}$$

Prediction Suppose a heavy cart collides with a stationary lighter cart. What would you expect the final velocity of the combined mass to be relative to the initial velocity of the first mass? Explain your reasoning on the Data/Question sheet.

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9. Heavy cart hits light cart.

Mean velocity for Cart 1 (before) = V_{1i} = __________ m/sec
Mean velocity for combined carts (after) = V_f = __________ m/sec

10. Check the collision equation. Use Equation (1) shown earlier.

$V_{f\_calculated}$ = __________ m/sec % diff = ___________

Prediction Suppose a light cart collides with a stationary heavy cart. What would you expect the final velocity of the combined mass to be relative to the initial velocity of the first mass? Explain your reasoning.

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11. Light cart hits heavy cart.

Mean velocity for Cart 1 (before) = V_{1i} = __________ m/sec
Mean velocity for combined carts (after) = V_f = __________ m/sec

12. Check the collision equation. Use Equation (1) shown earlier.

$V_{f\_calculated}$ = __________ m/sec % diff = ___________

Questions/Suggestions → James Nolta - Nolta@LTU.EDU