Impulse and Momentum

The impulse-momentum theorem relates impulse, the average force applied to an object times the length of time the force is applied, and the change in momentum of the object:

\[ \overline{F}\Delta t = mv_f - mv_i \]

Recall that the impulse is equivalent to the integral of the force vs. time graph:

\[ \overline{F}\Delta t = \int_{t_{\text{initial}}}^{t_{\text{final}}} F(t)dt \]

For this experiment, a dynamics cart will roll along a level track. Its momentum will change as it reaches the end of an initially slack elastic tether cord, much like a horizontal bungee jump. The tether will stretch and apply an increasing force until the cart stops. The cart then changes direction and the tether will soon go slack. The force applied by the cord is measured by a Force Sensor. The cart velocity throughout the motion is measured with a Motion Detector. Using Logger Pro you can test the impulse-momentum theorem.

OBJECTIVES

- Measure a cart’s momentum change using the mass and the initial and final velocities.
- Compare to the impulse it receives by using the software to integrate the force over the chosen time interval.

MATERIALS

- Power Macintosh or Windows PC
- LabPro or Universal Lab Interface
- Logger Pro
- Vernier Motion Detector
- Vernier Force Sensor
- dynamics cart and track
- clamp
- elastic cord
- string
- 500-g mass

PROCEDURE

1. Measure the mass of your dynamics cart and record the value in the data table.
2. Connect the Motion Detector to DIG/SONIC 2 of the LabPro. Connect the Force Sensor to Channel 1 of the interface. Set the range switch to 50 N.
3. Open the Experiment 19 folder from Physics with Vernier. Then open the experiment file that matches the force sensor you are using. Logger Pro will plot the cart’s position and velocity vs. time, as well as the force applied by the Force Sensor vs. time. Data are collected for 5 s, at a rate of 50 Hz.

4. Calibrate the Force sensor as you have done in previous experiments.

5. Place the track on a level surface.

6. Attach the elastic cord to the cart and then the cord to the string. Tie the string to the Force Sensor a short distance away. Choose a string length so that the cart can roll freely with the cord slack for most of the track length, but be stopped by the cord before it reaches the end of the track. Clamp the Force Sensor so that the string and cord, when taut, are horizontal and in line with the cart’s motion.

7. Place the Motion Detector beyond the other end of the track so that the detector has a clear view of the cart’s motion along the entire track length. When the cord is stretched to maximum extension the cart should not be closer than 0.2 m to the detector.

8. Click , then , to zero the Force Sensor.

9. Practice releasing the cart so it rolls toward the Motion Detector, bounces gently, and returns to your hand. The Force Sensor must not shift and the cart must stay on the track. Arrange the cord and string so that when they are slack they do not interfere with the cart motion.

10. Click to take data; roll the cart and confirm that the Motion Detector detects the cart throughout its travel. Inspect the force data.

   Note: If the peak is flattened, then the applied force is too large. Roll the cart with a lower initial speed. If the velocity graph has a flat area when it crosses the x-axis, the Motion Detector was too close and the run should be repeated.

11. Once you have made a run with good distance, velocity, and force graphs, save it and include a printout with your report.

12. Identify the region of the graph where the cart is bouncing. Identify the points immediately before and after the bounce. These are your points before and after impact.

13. To verify the impulse-momentum theorem, figure out which quantities you need to record.

   Hint: Look at the equations on page 1 of this outline. Which parameters will let you evaluate the change in the momentum?

14. Record them in your Data Table. Remember to include uncertainties for each measurement.

**ANALYSIS**

15. Make your own Analysis Table. Calculate the change in the momentum of the cart before and after impact.

16. Hopefully by now you are in the habit of recording uncertainties. In this class you will learn how to propagate uncertainties.

17. Error propagation: if a quantity is given by

   \[ x = \frac{ab}{c} \]

   where a, b and c are measured, and each of the measured quantities have an uncertainty given by:
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\( \delta a, \delta b \) and \( \delta c \),

You can then calculate the resultant uncertainty as:

\[
\frac{\delta x}{x} = \sqrt{\left( \frac{\delta a}{a} \right)^2 + \left( \frac{\delta b}{b} \right)^2 + \left( \frac{\delta c}{c} \right)^2}
\]

Note: You can generalize this for any given formula by finding the \( \delta x \) for each measurement, then find the ratio \( \delta x/x \). Next, square each of these ratios, adding up all the terms and then taking the square root of the sum.

18. Record the resultant uncertainty in your change in momentum.

19. Now record impulse. First calculate Impulse as the average force multiplied by the time interval and add that to your table (with the propagated errors). Then, recall that the impulse is equivalent to the integral of the force vs. time graph, or

\[
F \Delta t = \int_{t_{initial}}^{t_{final}} F(t) dt
\]

On the force vs. time graph, select the region between your initial and final points. Find the area under the force vs. time graph by clicking the integral button, \( \int \). Remember to include the uncertainty in this measurement. This is given by the software.

20. Perform two more trials by repeating Steps 10 – 14; record the information.

21. Print out a screen shot of any one of the trials and include it in your report.

22. You have calculated the change in the momentum using the mass, initial and final velocities. Then you have calculated the impulse by using the average force and the time interval (and also the integral as a way to check the accuracy of your result). Recall from previous labs how to compare two different values (percentage difference). Present it in the Analysis table.

Food for thought: What would happen if you tried this with a stiffer elastic band? What if you used a looser one?

CONCLUSION

Present your result in this section. Remember to include possible sources of error as part of your conclusion. Also, answer the following:

1. Does the impulse match the change in momentum within your uncertainty?

2. If you used stiffer or tighter elastic material, what effect will it have on the duration of the impulse? What affect will it have on the maximum size of the force? Can you develop a general rule from these observations? Explain.

3. You want to close an open door by throwing either a 400-g lump of clay or a 400-g rubber ball toward it. You can throw either object with the same speed, but they are different in that the rubber ball bounces off the door while the clay just sticks to the door. Which projectile will apply the larger impulse to the door and be more likely to close it? Prove it mathematically.