LAKE FOREST COLLEGE
Department of Physics

Physics 114 Experiment 9: Impulse and Momentum v2 Fall 2024

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Date: 10/31/2024
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Preliminary Instructions
Create a folder for you and your lab partner. Save a copy of these instructions for each student to that folder. Include your name in the filename. Save one copy of the Excel template with both your and your partner's name included in the filename.

Experimental purpose of today's experiment
Test the relationship between impulse and momentum.

Pedagogical purpose of today's experiment
Study how an applied force is related to an impulse and how this results in a change in the momentum of an object.

Background
The *impulse-momentum theorem* relates the impulse applied to an object and the resulting change in the momentum of the object. Here we will only consider *x* components of forces and velocities.

$$I_x = \Delta p_x$$
$$(\text{area under } F_x \text{ vs. } t \text{ curve}) = mv_{x\,\mathrm{f}} - mv_{x\,\mathrm{i}}$$
$$F_{x\,\mathrm{avg}}\Delta t = m\left(v_{x\,\mathrm{f}} - v_{x\,\mathrm{i}}\right)$$

If the force is variable, the impulse will be the "area" under the force vs. time curve. This is equal to the average force multiplied by the time over which the force is applied.

For this experiment, an air car will move with little friction along a level air 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 car stops and turns around. The tether will soon go slack again as the car moves in the opposite direction. The force applied by the cord is measured by a Force Sensor, and the car's velocity throughout the motion is measured with a Motion Detector. Logger Pro will compute the impulse applied to the car. This will be compared to the change in the car's momentum.

Procedure

1. Setup
    a. Place two cylindrical masses on each side of the car. Place two hooks on each end of the car. Measure the mass of the car with these pieces. The uncertainty in the mass is negligible in this experiment.
    b. Use the car to level the air track at a position around 30 cm from the force sensor.
    c. Make sure that the Dual Range Force Sensor is set to the 10 N range.
    d. Download the "Impulse and Momentum" Logger Pro file from Teams onto the Desktop and then open the file. This file measures the velocity of the car and the force exerted by the force sensor simultaneously.
    e. Calibrate the force sensor using a 200 g mass. You will have to temporarily turn the force sensor to face the pulley mounted to the table. The string from the force sensor to the hanging mass should run horizontally over the pulley.

2. Connect the car to the force sensor with two stretchable bands and a thread. Put the stretchable bands on the sensor and the thread on the cart. Make sure that the force sensor is at the same height as the hook on the car.

3. **Paste a picture of the setup here. Label the important components.**

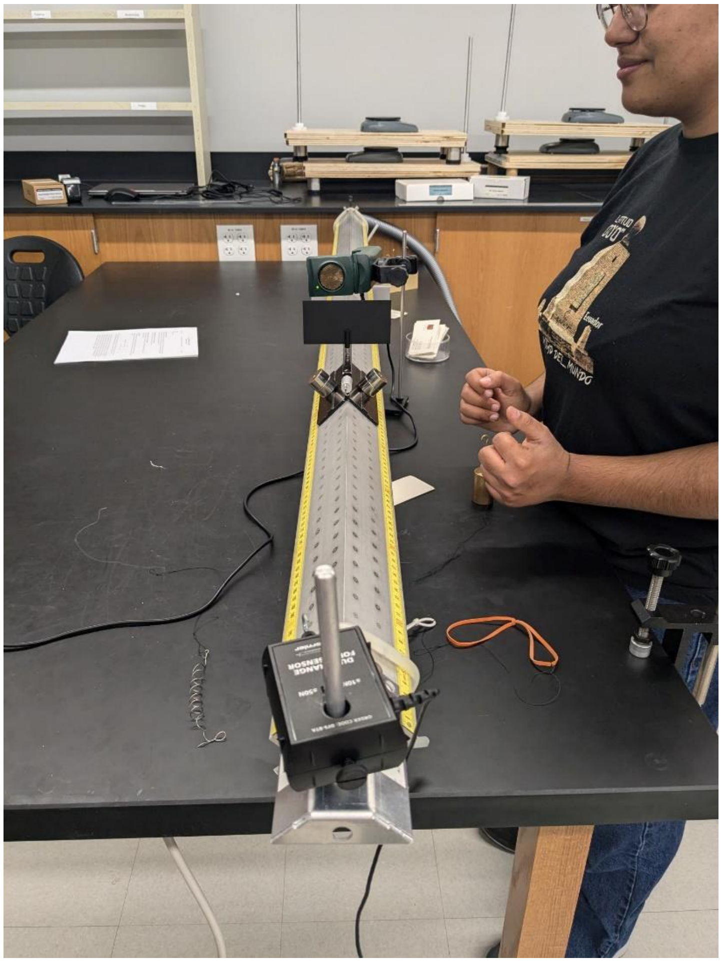

Figure 1. Impulse Apparatus. The cart rests on a vernier air track. The air track is used to simulate zero friction when the air supply pump is active. The green Vernier motion detector 2 detects the velocity of the cart. The black Vernier dual force sensor detects the tension force on the cart. The 3 different tethers are beside the track. The orange band is the stretchy tether, the white band is the elastic tether, and the gray wire is the inelastic tether. The 200g mass was used for calibration of the force sensor.

Vernier Motion Detector 2
Vernier Air Track to simulate zero friction

4. Zero the force sensor when the thread is slack. It is not necessary to zero the motion sensor.

5. Begin collecting data and smoothly push the car away from the force sensor. Make the initial speed between 0.35 m/s and 0.45 m/s. Several tries may be needed to obtain constant velocities before and after the thread and stretchable band reverses the car's velocity.

6. Select regions of the velocity graph before and after the collision where the velocity is constant. Use the "STATS" button to determine the mean and standard deviation of the

velocity before and after the force is applied. The standard deviation is the absolute uncertainty of the velocity. Note that the *x*-component of the initial velocity is negative and the *x*-component of the final velocity is positive. The *x*-component of the force is positive.

7. Select the region of the force versus time graph where the force is significant. Use the "INTEGRAL" button to determine the area under the force curve. Note that the force is positive. Assume the absolute uncertainty of the area is $0.01\ \mathrm{N \cdot s}$.

8. Use the cursor button  to estimate the beginning and ending time of the force. Then calculate the duration the impulse. Use an Excel formula to calculate the magnitude of the average force for each trial ($I = F_{avg}\Delta t$)

9. **Paste your graph here.** Save the LoggerPro file to your folder.

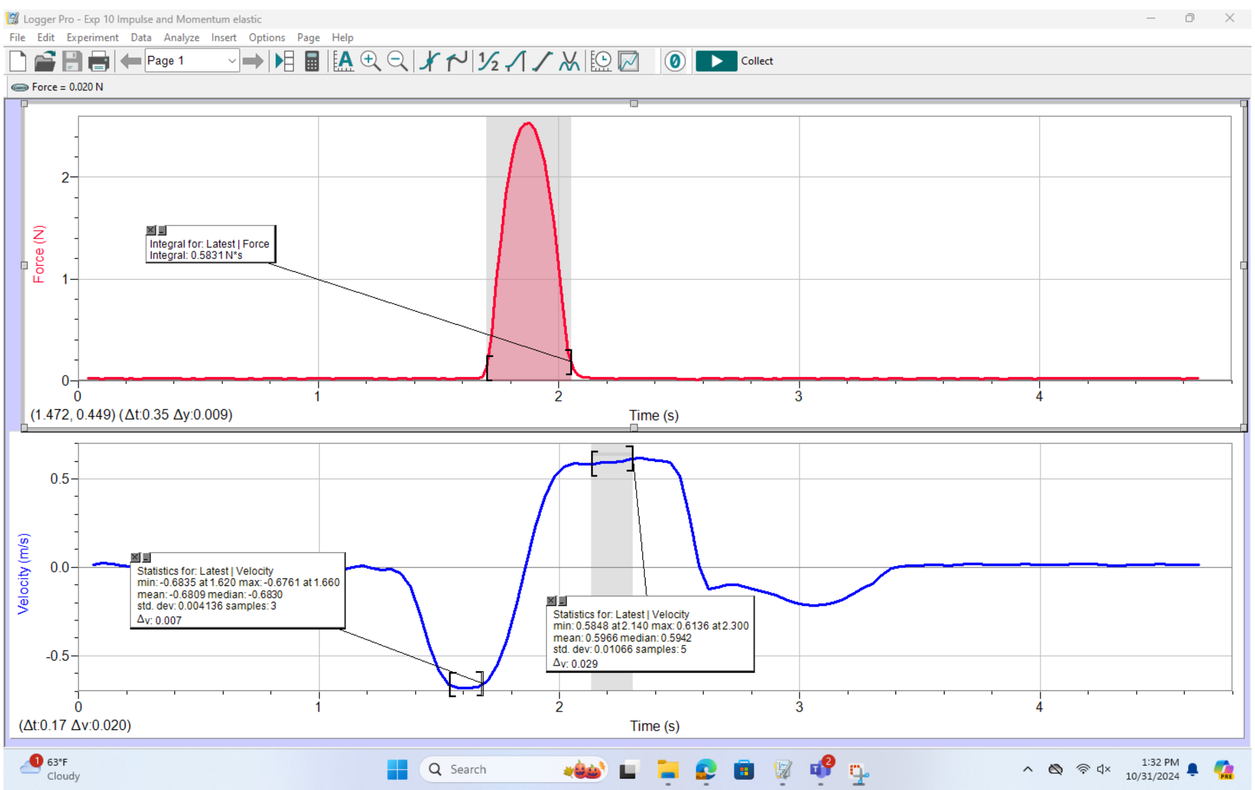

Figure 2. Elastic Band Impulse Graph. The top graph, in red, shows the force on the cart over time, as detected by the Vernier force sensor. The integral of this graph is the impulse. The second graph, in blue, represents the velocity of the cart over time, as detected by the Vernier motion detector. The difference in the average velocity of the plateaus of the graph times the mass of the cart are another way to calculate impulse. The standard deviation of the plateaus is

the absolute uncertainty of the velocity. This graph comes from the trial where the cart was tethered with a stretchy band.

The integral of the spike in the Force over time graph is the first way of calculating impulse. The constant velocity areas of the velocity over time graph times the mass is the second way of calculating impulse.

10. Use Excel formulas to calculate the change in momentum of the car and its uncertainty.

11. Compare the change in momentum of the car to the impulse delivered to the car using the ratio test.

12. Repeat steps 4-11, but with the stretchable bands replaced by the stiffer white elastic cord. Make the initial speed similar to the stretchable-band trial.

13. Repeat steps 4-11, but with the elastic cord replaced by an inelastic "solder spring," which does not return to its original shape after being stretched.

14. **Paste your spreadsheet here.**

Car mass (kg)
0.41087

type of tether	initial velocity (m/s)	abs. unc. in initial velocity (m/s)	final velocity (m/s)	abs. unc. in final velocity (m/s)	change in momentum (kg m/s)	abs. unc. in change in momentum (kg m/s)
stretchy bands	-0.6835	0.004	0.5966	0.010	0.5260	0.014
stiff elastic cord	-0.187	0.003	0.1336	0.003	0.1317	0.006
inelastic coiled solder	-0.2228	0.008	0.07168	0.002	0.1210	0.010

type of tether	impulse (N s)	duration (s)	average force (N)	abs. unc. in impulse (N s)	ratio test comparing impulse and change in momentum
stretchy bands	0.5831	0.35	0.2041	0.01	2.38
stiff elastic cord	0.148	0.24	0.6167	0.01	1.02
inelastic coiled solder	0.1357	0.47	0.063779	0.01	0.735

Table 1. Impulse Excel Spreadsheet. A single trial was run for each condition. The stretchy band was a rubber band attached to a bit of string. The stiff elastic was a small piece of elastic attached to a bit of string. The inelastic coiled solder was a bit of wire that had been coiled around a pencil attacked to a bit of string. For all conditions the tether was attached to the Vernier force sensor and the string was attached to the cart.

15. **Paste a picture of the equations used in the spreadsheet here.**

Impulse (I)

$\vec{I} = \Delta\vec{p} = \vec{p}_f - \vec{p}_i = m\vec{v}_f - m\vec{v}_i$

$I = F\Delta t$ for constant force

$I = \int F \Delta t$

Figure 3. Impulse Equations. The variable I represents the impulse of the cart in kg times m per second. The variable p represents the momentum and the momentum vector of the cart in kg times m per second. Variable m represents the mass of the cart in kg. The variable F represents the force detected by the force sensor in Newtons. The variable t represents time. The subscript f stands for final and the subscript i stands for initial.

16. **Write an analysis here.** What were the qualitative differences between the different tethers? Compare the average force magnitudes for the stretchy band trial and the stiff elastic cord trial. Are the impulses similar? Are the durations and average forces similar?

The results for the stretchy rubber band are inconclusive while the results for the stiff elastic cord and coiled solder agreed with each other. The time intervals were mostly similar, however the stiff elastic had shorter intervals. This may be because it stretched the least or because the cart was started further forward. The stiff elastic cord also exerted the most force on the cart, according to the interval impulse measurement. The elastic band exerted the most for according to the velocity impulse calculation.

17. **Write a brief conclusion here.** Did the impulse agree with the change in momentum in each trial?

There may be errors from the motion sensors. There was a delay between the force sensor detecting the peak and the motion sensor detecting the change in velocity. We had a lot of trouble getting the motion sensor to consistently detect the motion of the cart. It took us almost about an hour and a half to start collecting data. The results for the stretchy rubber band are inconclusive while the results for the stiff elastic cord and coiled solder agreed with each other.

18. Adjust the formatting (pagination, margins, size of figures, etc.) of this report to make it easy to read. Save this report as a PDF document. Upload it to the course Moodle page.

19. Clean up your lab station. Put the equipment back where you found it. Remove any temporary files from the computer desktop. Make sure that you logout of Moodle and your email, then shut down the computers. Ensure that the laptop is plugged in.

20. Check with the lab instructor to make sure that they received your submission before you leave.