Experiment 4:
Momentum and Impulse

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Lab performed on: May 8, 2018
Lab section: Lab 6- Tuesday 11am
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Discussion:

Mass of the glider (with flag and bumper): m = 202.4 $\pm$ 0.5 g
Width of the photogate flag: w = 3.80 $\pm$ 0.05 cm

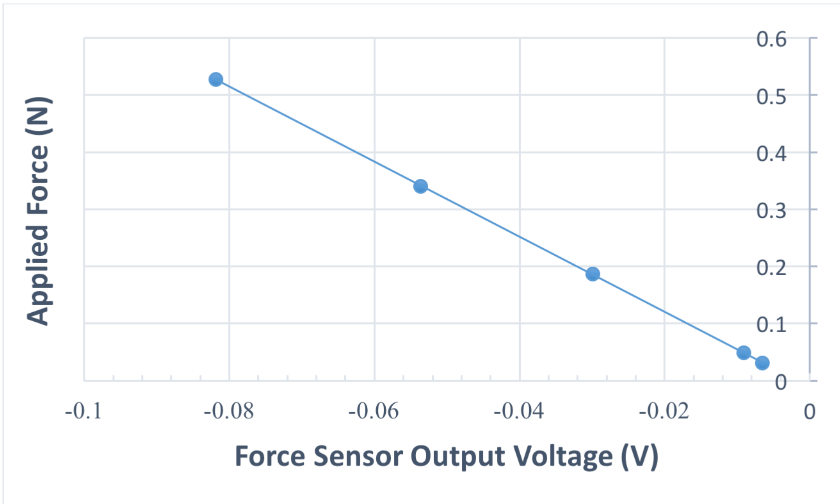

Figure 1— Calibration of the Force Sensor. The voltages of five different masses that were hung from the sensor hook was recorded. This plot shows the applied tension (weight of the masses) against the output voltage. The value of the calibration constant, k, is obtained from the the value of the slope of the fit line, which is -6.57$\pm$0.02 N/V. By using this value, it is possible to calculated the impulse of the glider on the sensor hook during collision. The equation of the fit line is y = (-6.57$\pm$0.02)x – (0.011$\pm$0.001).

Momentum $P = mv$, where m is the mass and v is the velocity and impulse $\Delta P = P_f - P_i = m(v_f - v_i)$. I was able to calculate the impulse from the first set of data run ΔP_1 = 0.162$\pm$0.005 Ns and the second set of data run ΔP_2 = 0.143$\pm$ 0.005 Ns.

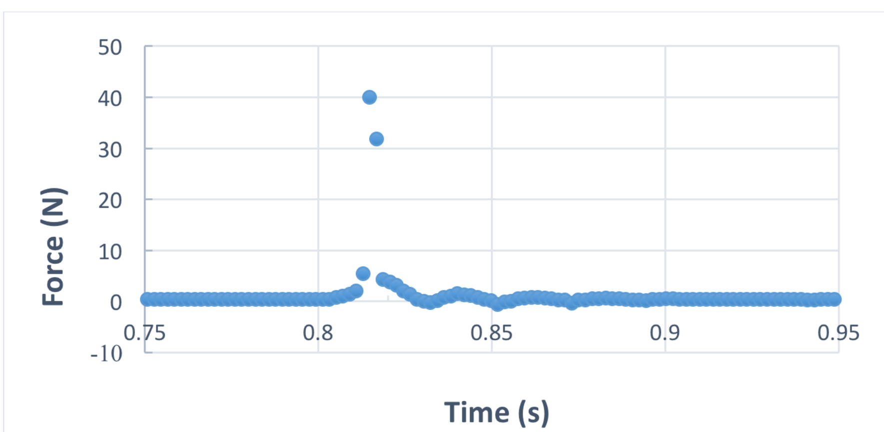

Figure 2 — First Run: Force Sensor Data Before, During, and After Collision. The background was subtracted from the force sensor data values to provide an initial reading of 0 N. The area under the curve is the impulse between the glider and sensor hook.

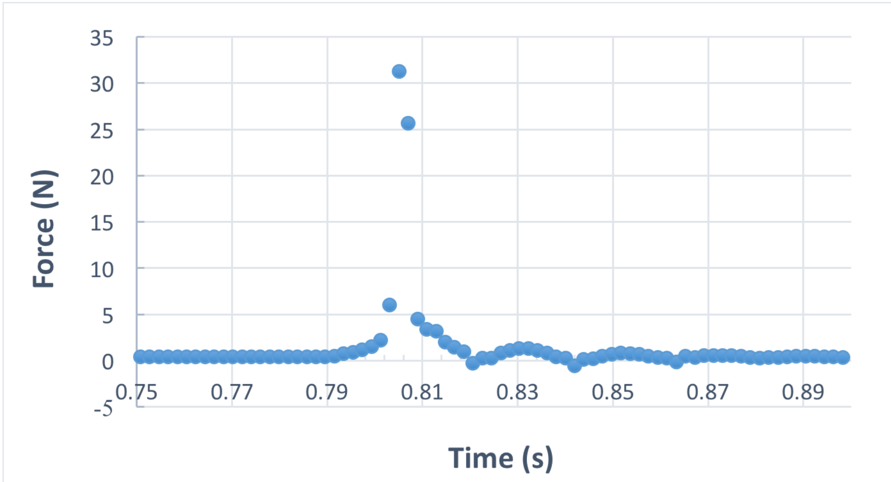

Figure 3 — Second Run: Force Sensor Data Before, During, and After Collision. The background was subtracted from the force sensor data values to provide an initial reading of 0 N. The area under the curve is the impulse between the glider and sensor hook.

From Equation 4.3 in the Lab Manual[1]:

$$\Delta P = \int_{t_1}^{t_n} dt\, F(t) \approx \Delta t \sum_{i=1}^{n} F(t_i)$$

I converted the output voltage values recorded from the DAQ to the force values by multiplying the voltages by the calibration constant, k, obtained from Figure 1. Then, I calculated the value for time difference, Δt, from the equation stated above by subtracting a time data point from the following one, which resulted in 0.019 s. Afterwards, I calculated the total sum of all the force values, $\sum F$, for each run (with background values subtracted from the force values). Then I multiplied the total sum of the force values, $\sum F$, by the time difference, $\Delta t = t_{i+1} - t_i$, to get the value of the impulse, ΔP for each data run. By numerical integration, I obtained the values of the impulse of the first data run $\Delta P_1 = 0.172 \pm 0.006$ Ns and the second data run $\Delta P_2 = 0.140 \pm 0.005$ Ns.

Method	Impulse for the First Data Run, ΔP_1 (Ns)	Impulse for the Second Data Run, ΔP_2 (Ns)
Based on Photogate Speed Measurements	0.162 ± 0.005 Ns	0.143 ± 0.004 Ns
Based on Numerical Integration	0.172 ± 0.006 Ns	0.140 ± 0.005 Ns

Table 1— Impulse Values. This table shows the calculated values of impulse with the two different methods for both runs. The impulses calculated between the two methods are not exactly equal because of the low sampling rate with the force sensor.

Extra Credit

Velocity (m/s)	Initial Glider 1	Final Glider 1	Initial Glider 2	Final Glider 2
Sponge Trial	0.837120$\pm$0.000005 m/s	0.074210$\pm$0.000005 m/s	0.692210$\pm$0.000005 m/s	0.188840$\pm$0.000005 m/s
Rubber Trial	0.643440$\pm$0.000005 m/s	0.368170$\pm$0.000005 m/s	0.698730$\pm$0.000005 m/s	0.336330$\pm$0.000005 m/s

Table 2— Initial and Final Velocity of Two Gliders. The table above shows the initial and final velocities recorded while colliding two gliders using two photogates.

The velocities in Table 2 and the mass of the first glider (202.4 g) and the mass of the second glider (190.0 g) allows us to calculate the coefficient of restitution, kinetic energy, and the momentums. The coefficient of restitution of the sponge and sponge and rubber and rubber were:

$$C_{R_s} = \frac{v_b - v_a}{u_a - u_b} = 0.79104 \pm 0.00008$$

$$C_{R_r} = \frac{v_b - v_a}{u_a - u_b} = 0.5759 \pm 0.0003$$

These calculations show that the sponge is more elastic than the rubber. The calculated percent kinetic energy and momentum conserved were:
K conserved for sponge = 3.39%
K conserved for rubber = 27.71%
P conserved for sponge = 16.91%
P conserved for rubber = 52.63%
These calculations show that the collision using rubber was more efficient at kinetic energy conservation.

Presentation Mini-Report

Introduction

Conversation of momentum is a fundamental principle in physics. Newton's re-expressed second law states that the net force is the time rate of change of mass times velocity, which is used so physicists could solve problems that couldn't be solved directly using the second law.[2] Moreover, impulse is a vector quantity that quantifies how a force acts on an object and the motion of the object. The objective of this experiment was to verify that calculating impulse by the change in linear momentum and calculating impulse by numerical integration of the data produced by the force sensor would produce the same results. The first method, calculating the impulse by change in linear momentum, relied on the initial speed (before collision) and final speed (after collision) of the glider, which were recorded by the photogate. The speeds were then used to calculate impulse using the equation to show the change of momentum between the initial and final values. The second method was calculating impulse by numerical integration. Before, during, and after the collision, the force sensor was recording the output voltage. The output voltage was then converted into force data using the calibration constant, and the force was integrated to define impulse for the second method during the collision. As a result, both methods produced identical impulse values for both methods.
(220 words)

Methods

My lab partners an I calibrated the force sensor by recording output voltages for five different masses using the Capstone and the 850 Universal Interface. The five masses were hung vertically on the force sensor hook and produced the weight recorded. Using the User Defined Sensor in Capstone, we recorded the output voltage. By graphing the data in a scatter plot (force measured in N vs. voltage measured in V) with a fit line, I was able to to obtain the calibration constant, k, which was the slope of the fit line.

The glider's mass (with flag and bumper) was measured using the balance scale and the length of the flag was measured using the ruler.

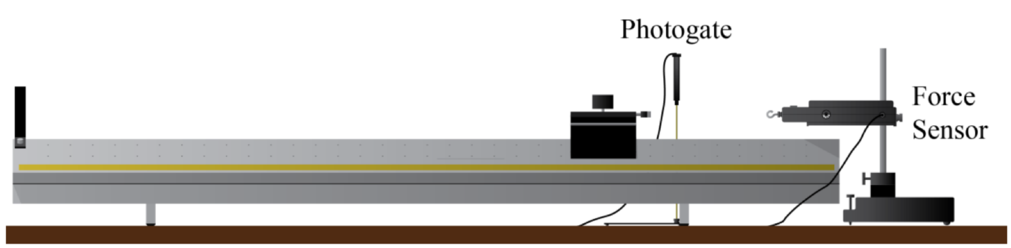

Figure 4 — Apparatus Setup Used for Momentum and Impulse. This figure depicts the experimental set up for the momentum and impulse. The photogate records the speed of the glider before and after the collisions, while the force sensor records the force before, during, and after the collisions of the glider and the sensor hook. This figure is taken from the Lab Manual[1].

To calculate the impulse, the experiment set up is shown in Figure 4, with the force sensor, photogate, glider with flag and bumper, and the frictionless air track. The glider was placed on the air ramp, and the level of air was adjusted until the glider remained in place on the surface to decrease the effects of friction and reduce to systematic error. Afterwards, we set up the force sensor so that the force sensor hook was horizontally leveled with the bumpers on the glider. This way, the force sensor hook does not oscillate following the collision with the glider and cause statistical uncertainty in the force data recorded. The photogate was placed near the force sensor in that while the glider's flag passed, it would temporarily block the light of the photogate. The glider did not collide with the force sensor hook while the photogate was recording the speed of the glider. This prevented systematic errors in measured speeds, which made the impulse value obtained more accurate.

My lab partners and I created the Pre-Configured Timer for a photogate in Capstone and set up the software to record in Continuous mode to obtain sufficient data to plot the force against time graph and calculate the numerical integration. To record the data, we moved the glider towards the photogate and began to record right before it reached the photogate. As the glider started moving the opposite direction and passed through the photogate after the collision occurred, we stopped recording. My lab partners and I performed these collisions six times in order to obtain two data sets for each of us.
(448 words)

References

1. Campbell. W. C. et al. Physics 4AL: Mechanics Lab Manual (ver. August 31, 2017). (Univ. California Los Angeles, Los Angeles, California).
2. Young, H. D., Freedman, R. A. and Ford, A. L. *Sears and Zemansky's University Physics with Modern Physics.* 238 (Pearson, 2015).