EXPERIMENT 4: MOMENTUM AND IMPULSE

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LAB PERFORMED ON 5/9/2018

LAB SECTION: WEDNESDAY 2PM

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WORKSHEET

2 DISCUSSION

Mass of glider, Photogate flag, and Bumper: $M = 0.19920 \pm 0.00005$ kg
Length of Photogate Flag: $l = 0.0379 \pm 0.0005$ m

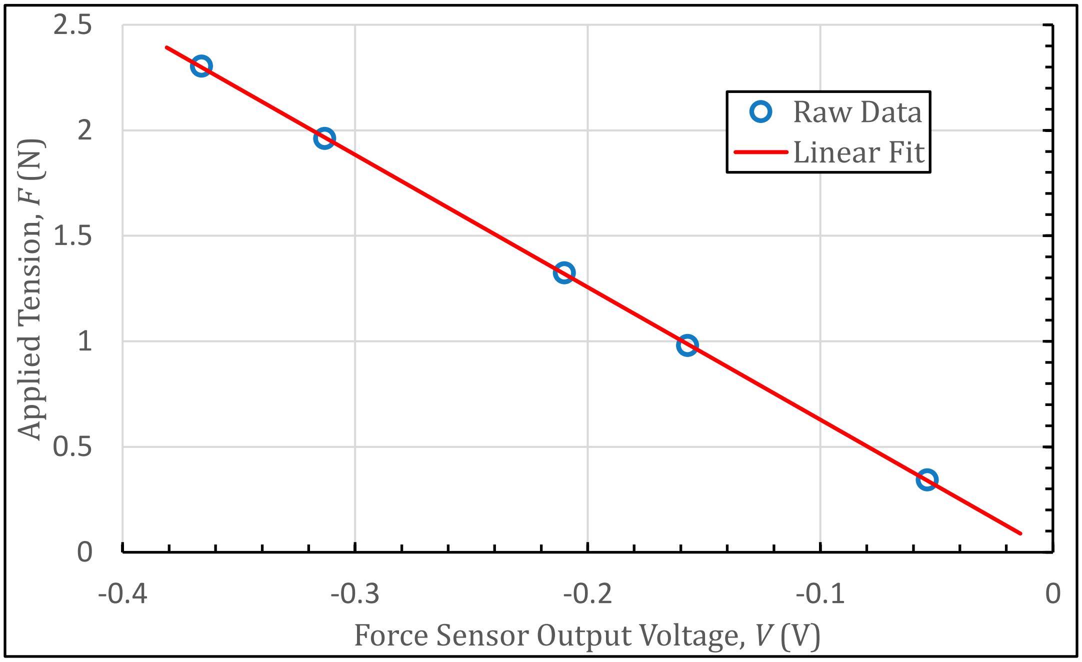

Figure 1: Calibration of Force Sensor. The force sensor was calibrated by hanging several different masses from the hook and recording the sensor's output voltage, V. The Applied Tension to the sensor, F, was calculated by multiplying the hanging mass by g. The blue points are the raw data, and the red line is a linear fit to the data with the equation $F = aV + b$, where $a = (-6.28 \pm 0.03)$ N/V and $b = (0.001 \pm 0.006)$ N. The slope a is the value for the sensor calibration coefficient needed to convert output voltage V into a Force quantity. Uncertainties determined from linear regression.

Impulse values calculated from photogate speed measurements and Equation 4.1:[1]

$$\Delta P = P_f - P_i = Mv_f - Mv_i = M(v_f - v_i) = M\Delta v$$

Trial #	Initial Velocity (m/s)	Final Velocity (m/s)
Trial 1	-0.206 ± 0.003	0.128 ± 0.002
Trial 2	-0.224 ± 0.003	0.139 ± 0.002

Table 1: Velocity Measurements made by the photogate head before and after collision. Note that uncertainties are derived from the fact that the fractional uncertainties in velocity and photogate length are equivalent.

Trial 1: $\Delta P = (0.0664 \pm 0.0006)\ \mathrm{N \cdot s}$
Trial 2: $\Delta P = (0.0721 \pm 0.0007)\ \mathrm{N \cdot s}$
Uncertainties in ΔP are derived from equations ii.22[1] and ii.23.[1]

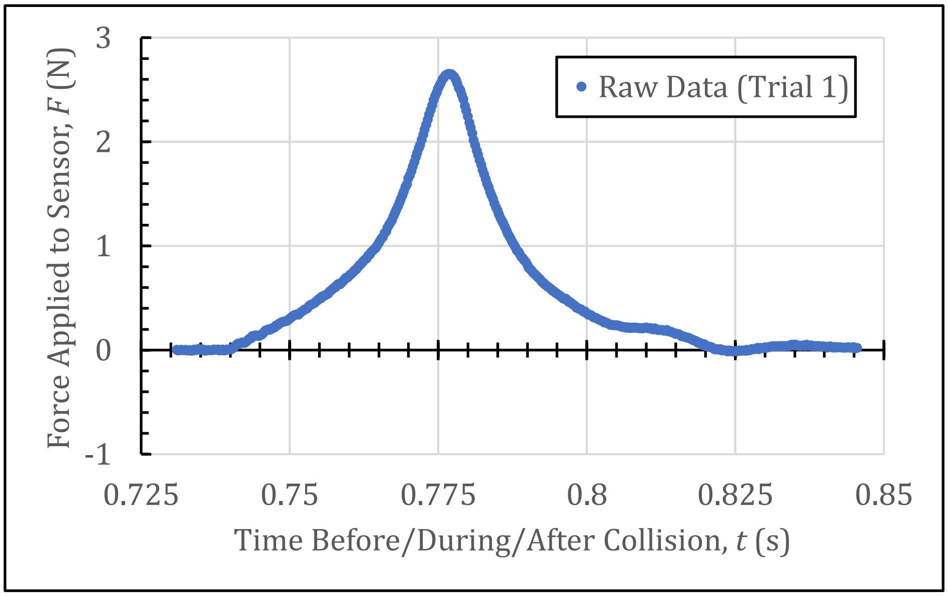

Figure 2: Force Sensor Measurements During Glider Collison, Trial 1. A glider traveling across a track collides and rebounds off a Force Sensor. The blue points are data collected at a rate of 4kHz over the time during the collision by the Force Sensor (in Volts) and then converted to Force values (in Newtons) using the conversion factor $a = (-6.28 \pm 0.03)$ N/V determined from Figure 1. The curve has background subtracted out to zero the Force values before and after impulse. The area under the curve and above the x-axis between the time values t_1 and t_n represents the value for the impulse of this collision, where t_1 is the time when the Force first increases beyond zero and t_n is when the Force reaches zero once again.

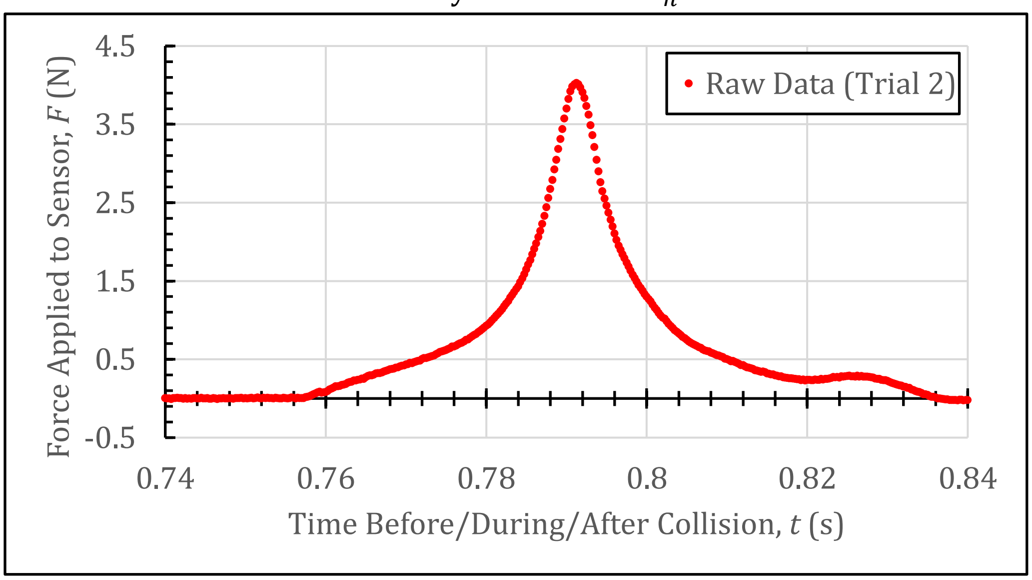

Figure 3: Force Sensor Measurements During Glider Collison, Trial 2. Trial 2 obeys the same conditions as described in the caption for Figure 2, Trial 1, except the glider traveled at a different initial speed before impact. Again, the conversion factor a was used to generate Force values, and background was subtracted out. The red data points are all Force values recorded at different times t during the glider's run. Calculating area under the curve between values t_1 and t_n as described above will give the impulse for Trial 2.

To determine Impulse values for Trials 1 and 2, a Riemann sum was used to estimate the area under each curve in Figures 2 and 3. Riemann sums are calculated using Equation 4.3:[1]

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

Δt is the time between when each Force value was collected. Our sensor collected at a rate of 4 kHz, or every 0.00025 seconds. Using excel, multiplying every Force value by 0.00025 seconds and summing these should give a reasonable estimate for the integral and value for impulse. Using this method to calculate impulse:

Trial 1: $\Delta P = (0.0640 \pm 0.0003)\ \mathrm{N \cdot s}$
Trial 2: $\Delta P = (0.0696 \pm 0.0003)\ \mathrm{N \cdot s}$
Note that uncertainties were derived from the fact that the fractional uncertainty in the integral and fractional uncertainty in the calibration coefficient a are equivalent.

Trial #	ΔP from Photogate Speed Measurements (N·s)	Impulse from Numerical Integration (N·s)
Trial 1	0.0664 ± 0.0006	0.0640 ± 0.0003
Trial 2	0.0721 ± 0.0007	0.0696 ± 0.0003

Table 2: Values for Impulse using the two different methods, two trials each. Although the Impulse values are similar, neither trial shows consistency between impulse calculated from the two different methods; they do not overlap with the given uncertainties.

3 EXTRA CREDIT

	Relative Initial Speed (m/s)	Relative Final Speed (m/s)
With Bumpers	0.293 ± 0.004	0.175 ± 0.002
Without Bumpers	0.522 ± 0.007	0.072 ± 0.001

Table 3: Speed Measurements for the two gliders relative to one another before and after their collision, with and without bumpers attached. Again, uncertainties for relative speeds derived from the fact that the fractional uncertainties in speed and photogate length are equivalent. Note that the change in relative speed without bumpers is significantly greater compared to with bumpers.

To determine the degree to which momentum and energy are conserved, we should calculate the ratios of final momentum/energy to initial momentum/energy. For momentum we can use the Coefficient of Restitution for collision: $C_R = \frac{\text{Relative Final Speed}}{\text{Relative Initial Speed}}$. With Bumpers, $C_R = 0.60 \pm 0.01$. Without Bumpers, $C_R = 0.138 \pm 0.003$. For energy we can use equation 3.2:[1] $K = \frac{1}{2}Mv^2$, where M is the mass of the glider and v is its relative speed, and take the ratio of final to initial K. With Bumpers, the ratio is 0.36±0.02, and without bumpers is 0.027±0.005. For all of these ratios, the closer the value is to 1, the higher degree to which that property is conserved. Therefore, the degree to which momentum is higher than that of energy, an expected phenomenon.

PRESENTATION MINI REPORT

Introduction

The concept of momentum has been studied since early philosophers attempted to describe the movement of particles. It was not until the late 1600s that the conservation of momentum was established by the mathematician John Wallis. Isaac Newton later further studied this phenomenon in detail. The momentum of an object is defined as the object's mass times its velocity. Momentum is related to a quantity known as Impulse, defined as the change in linear momentum after a collision, and the integral of the Force as a function of time over the interval of the collision. The purpose of this experiment is to demonstrate the equality in both definitions for impulse, thus showing the conservation of linear momentum during a collision. To prove that these two definitions for impulse produce the same quantity, we will analyze a glider collision and rebound with a Force Sensor. To calculate the change in momentum of the glider, the mass, initial, and final velocities of the glider are measured. To calculate the integral, the Force Sensor records the value of the Force applied by the glider over time from which the area under the Force versus Time curve is approximated using a Riemann sum. In theory, these two values should be identical.
Word Count: 207

Methods

Plug in a Pasco Scientific Force Sensor to the Pasco 850 Universal Interface (DAQ), choose User Defined Sensor in Volts, and suspend the sensor. Hang five different known masses (measured using Ohaus Dial-O-Gram Balance) from the sensor hook and record the Voltage output for each mass. Create a spreadsheet and create columns of Force (mass times g) and Voltage outputs for each mass and produce a scatterplot of Force vs. Voltage (Force on y-axis, Voltage on x-axis). Fit a line to the plot and determine the slope which will define the calibration constant used to convert Voltage Outputs to Force later in the experiment.
Weigh the glider with bumper and photogate flag using the Ohaus Dial-O-Gram Balance and measure the length of the photogate flag using the Starrett Meter Stick. Arrange the Force Sensor at the edge of the Pasco Scientific Air Track so the glider will collide with the hook and bounce off. Plug in a Pasco Scientific Photogate head to the DAQ, choose Pre-Configured Timer for one photogate with a single flag, select speed as the measure variable, enter the photogate flag length, and place it near the edge of the Air track with the force sensor. Choose continuous mode with a frequency of 4kHz to record data. With the bumper and photogate flag properly attached to the glider, the photogate and Force sensor properly set up, and the Air Track turned on and leveled, send the glider towards the Force Sensor and through the photogate, and start recording time, Voltage Output, and Speed just before the glider reaches the photogate. Once the glider bounces back through the photogate, stop recording. Scroll through the data and ensure there are two velocities recorded before completing another trial. Transfer all data to a spreadsheet to be analyzed.

Various methods to eliminate systematic uncertainty include: ensuring the Air Track is completely level and subtracting background from Force versus Time plots.

To calculate the change in momentum, simply subtract the initial velocity from the final velocity (ensuring correct signs) and multiply by the mass of the glider. To calculate the integral described in the introduction, create a plot of Force (Voltage output times calibration constant) versus time, subtract off any background, and use equation 4.3[1] to determine the impulse. Compare these values to analyze the effectiveness of the experiment.

References

[1] Campbell, W.C. *et al*. Physics 4AL: Mechanics Lab Manual (ver. April 3, 2017). (University of California Los Angeles, Los Angeles, California).