PHYSICS 4AL

EXPERIMENT 4: MOMENTUM AND IMPULSE

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Contents

Discussion

Measured Values

The mass of the glider used in the experiment was 203 ± 0.5 g. The length of the flag 38 ± 0.5 mm.

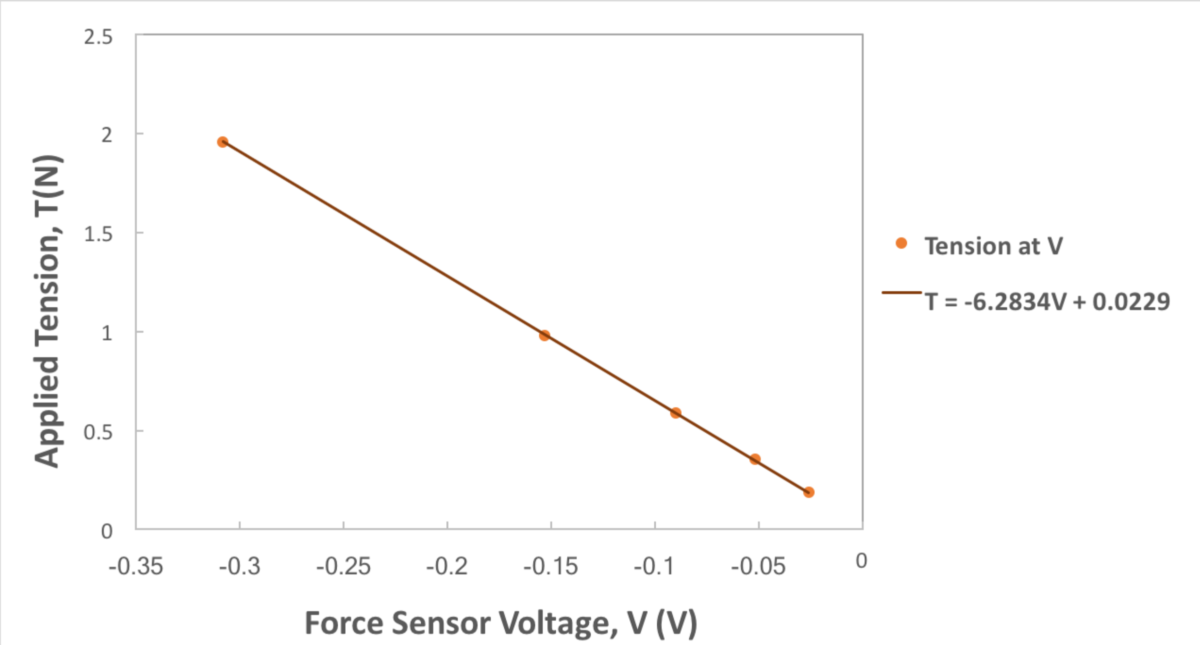

Figure 4.1 Voltage due to applied Tension. The best fit line has the equation $T = (-6.283 \pm 0.004)V + (0.023 \pm 0.002)$. The slope of the best fit line is the calibration constant: -6.283 ± 0.004 N/V.

Trial	Initial Velocity (m/s)	Final Velocity (m/s)
1	-0.1779 ± 0.0005	0.0821 ± 0.0005
2	-0.1415 ± 0.0005	0.0774 ± 0.0005

Table 4.1 Initial and final velocities recorded by the photogate for two trials. Velocity heading towards the force sensor was considered negative, and velocity directed away was positive.

Impulse Calculation - Method 1

Momentum, given by P, is the product of mass m and velocity v, or $P = mv$. The change in momentum is known as impulse, or $\Delta P = P_f - P_i = m(v_f - v_i)$. Using this formula, the velocities given in **Table 4.1**, and the mass of the glider, for Trial one, the impulse $\Delta P_1 = 0.0528 \pm 0.0005$ kg·m/s. For Trial two, the impulse $\Delta P_2 = 0.0408 \pm 0.0005$ kg·m/s.

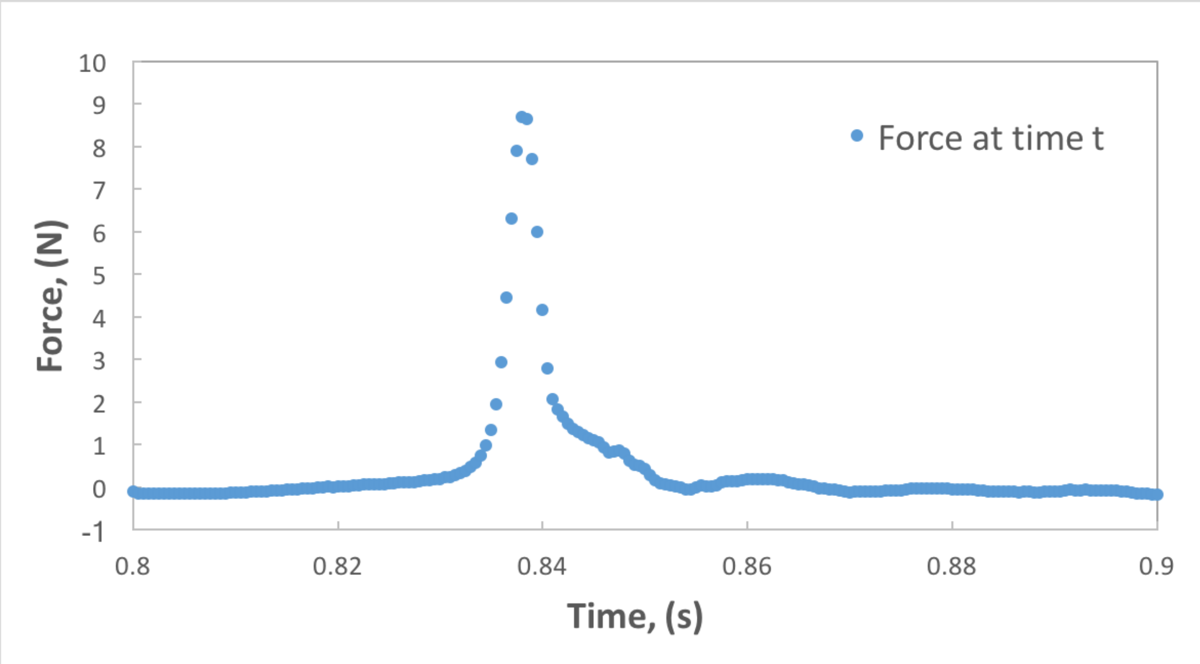

Figure 4.2, Trial 1 of force of a moving glider against time. This glider moved at a faster velocity than Trial 2. The data points represent the force sensor readings in Newtons at a specific time interval before and after the collision. The area under the curve of the peak represents the impulse of the collision.

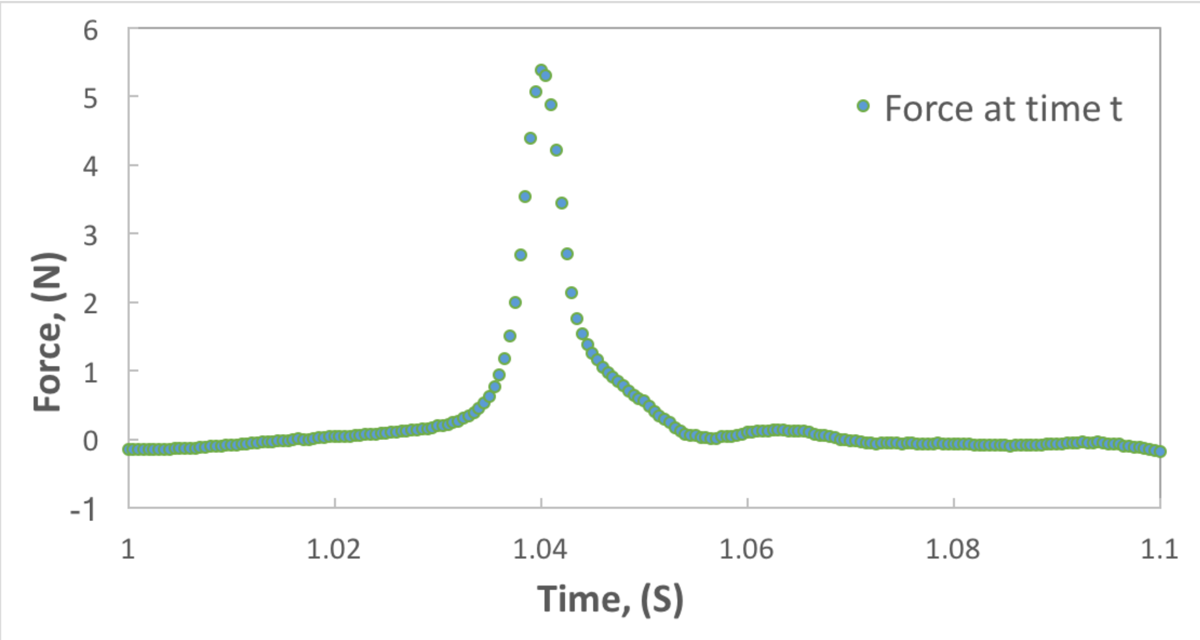

Figure 4.3, Trial 2 of force of a moving glider against time. This glider moved at a slower velocity compared to Trial 1. The data points represent the force sensor readings in Newtons at a specific time interval before and after the collision. The area under the curve of the peak represeents the impulse of the collision.

Impulse Calculation - Method 2

Impulse can also be known as the force F over time interval t. This can be put into the form $\Delta P = \int_{t_i}^{t_f} F(t)dt$. We can approximate this impulse using Riemann sums, or $\Delta P \approx \Delta t \sum_{i=1}^{n} \bar{F}(t_i)$, where Δt is the time interval between each data point, and $\bar{F}(t_i)$ is the average force between t_i and t_{i+1}. For our numerical integration Δt was 0.0005 s, and $\bar{F}(t_i) = \frac{F(t_i)+F(t_{i+1})}{2}$.

To obtain our impulse calculations, we multipled the voltage read by the force sensor by our calibration coefficient found previously in **Figure 4.1**, then subtracted the average background noise of the force sensor. To calculate our numerical integration, we needed to find the range where the force detected went above zero on both **Figures 4.2** and **4.3** (to signify the cart hitting the force sensor). We the calculated the area under the curve with the formula involving Riemann sums derived previously. For Trial 1, $\Delta P_1 = 0.04509 \pm 0.00003$ kg·m/s, and for Trial 2, $\Delta P_2 = 0.03701 \pm 0.00002$ kg·m/s. The fractional uncertainty for the impulse is the same as the fractional uncertainty of the coefficient calibration.

Trial	Impulse by Change in Momentum (kg·m/s)	Impulse by Riemann Sums (kg·m/s)
1	0.0528 ± 0.0005	0.04509 ± 0.00003
2	0.0408 ± 0.0005	0.03701 ± 0.00002

Table 4.2 Results for both trials and methods of impulse calculation.

We can see that calculating the impulse by Riemann Sums results in a lower calculated impulse. We can attribute this error to the "ringing" of the force sensor after it was struck by the cart, which would cause errors in the Reimann sum calculation since impulse is still being exerted after it dipped back down to zero in **Figures 4.2** and **4.3**.

EXTRA CREDIT

We tested two glider-to-glider collisions, one involving two bumpers and one without bumpers at all. For the bumper collision, the coefficient of restitution was 0.3659, the initial energy was 0.0341 J, and the final energy was 0.0046 J. For the no-bumper collision, the COR was 0.5794, the initial energy was 0.0584 J, and the final energy was 0.0198 J. For the bumper collision, the coefficient of restitution was lower, and the energy loss was high, because only around 13% of the energy remained after the collision. Compared to the no bumper collision, which had 34% of the initial energy, the energy loss was greater for the bumper collision. Thus we can conclude with a higher coefficient of restitution that the energy loss is less, because the collision is closer to being an elastic collision.

Presentation

Introduction

Our experiment sought to prove that while energy is lost in inelastic collisions due to friction, change in momentum, or impulse, is constant. Impulse can be defined in two different ways, by the amount of force acting over a certain time period, or the change in momentum. If both these ways of calculating impulse were equal, then we would have proved that impulse is constant during a collision. A glider with a flag on top was set up on an air track with a force sensor at the end of a track and a photogate to track the flag's movement. The collision with the force sensor was monitored with the photogate, and the velocities obtained by the photogate allowed us to calculate impulse by change in momentum. Force over time was measured with the force sensor, and impulse was calculated by summing the force in the time interval of the collision. The two values obtained were compared to verify that the results were close but outside the margin of error.

Methods

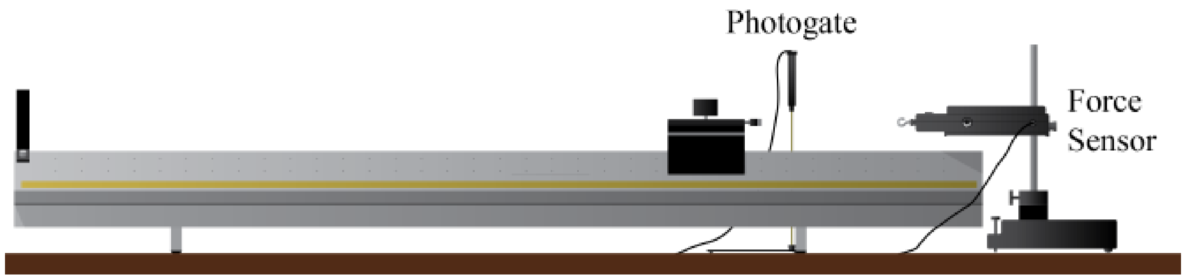

Figure 4.4 Equipment for measuring the impulse of a glider colliding with force sensor. The force sensor measures $F(t)$ in volts, which allows you to gain an independent measure of impulse by numerical integration. The flag passes through the photogate before and after the collision, which allows a different way to measure initial and final momentum. Figure reproduced (with permission) from Fig. 4.1 by Campbell, W. C. et al.[1]

The first step of our experiment was to calibrate the force sensor. We connected it to the PASCO machine and shifted the force sensor so that the hook faced downwards, and hung masses of various weights onto the hook to measure the voltage readings. The masses we used were 0.2 kg, 0.1 kg, 0.06 kg, 0.036 kg, and 0.019 kg. We graphed the voltages measured and compared it to the force exerted by gravity on the masses, to obtain the force sensor's calibration coefficient, which will be used to convert the voltages measured later to volts.

The mass of the glider with the flag was measured with a scale, and the length of the flag was measured with a ruler. The mass measurement will later be used to calculate momentum of the glider. Our equipment was set up in the same fashion as **Figure 4.4**. We connected the photogate and force sensor to the PASCO, so the computer could record the velocity, time, and voltage of the force sensor. A preconfigured timer was chosen for the photogate, where speed was chosen as the variable measured.

The length of the flag was typed in, so the photogate knew how long the flag was and when to measure speed. We kept the same calibrations as before for the force sensor, but set the sample rate to 2kHz. The measurements were measured in Continuous Mode on the PASCO machine.

We turned on the airtrack and slid the glider on the track twice towards the force sensor. When the glider passed through the photogate, the photogate should record the speed of the glider twice, once before and after the glider hits the force sensor. The force sensor should be measuring voltage the whole time during the trial, but should only see a spike in voltage when the glider connects with the force sensor. In the end, you should end up with three columns of data, one for time, speed, and voltage.

We gave the glider less speed for the second trial compared to the first trial. Time of the trial, speed of the glider, and the voltage were measured for each trial, and copied over to an Excel spreadsheet for analysis.

For uncertainty values of the experiment, we used $\pm$ 0.5 mm for the flag length and $\pm$ 0.5 g for the mass of the glider, which are half the smallest precision of the measurement devices. We set the PASCO to measure voltage of the force sensor within one digit of uncertainty (i.e. only the least significant digit measured was flickering on the display). The velocities measured had the same fractional uncertainty as the calibration coefficient of the force sensor, which we can find with regressional analysis on Excel.

To improve the accuracy of our experiment, we employed a few methods to eliminate systematic errors. The glider was put on an air track to reduce the energy lost to friction. The air track was set to be completely level, so that the glider did not experience any acceleration due to gravity. The average background force detected by the force sensor was calculated and removed from our final analysis, to avoid any systematic error by the force sensor. We also made sure to tare our force sensor before each trial, to ensure the background force remains as low as possible.

References

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