Experiment 4: Momentum and Impulse

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(2) Discussion

Our glider has a mass of (201.9 ± 0.28) g with two bumpers and a photogate flag attached to it. Because the scales that we used to measure the glider's mass can only go up to 110 g, we used a (100.0 ± 0.2) g mass as a counterbalance. The photogate flag has a width of (0.375 ± 0.005) m.
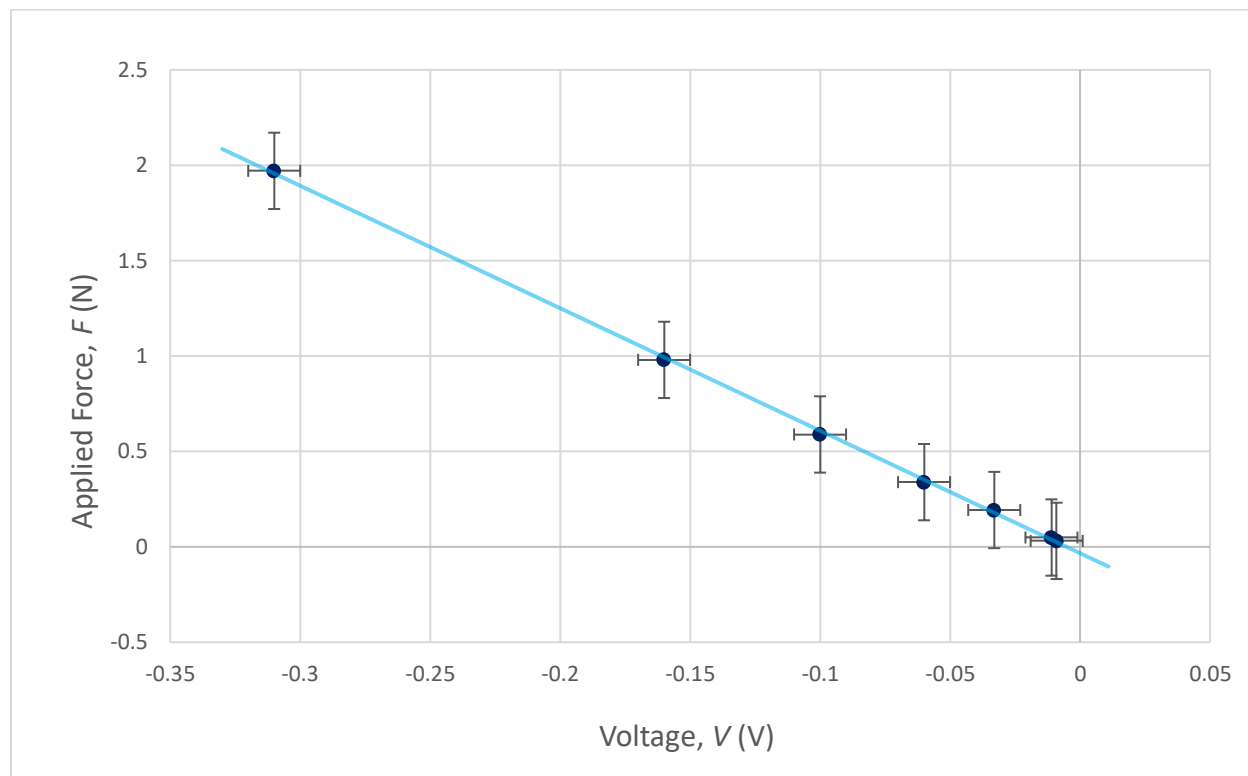

Figure 1: This plot shows the force sensor's voltage reading for different masses that were hung from it. The masses were multiplied by the gravitational acceleration constant 9.80 m/s^2 to convert the mass into applied force. The relationship between the applied force and the voltage readings from the data acquisition system is linear. The calibration constant is equivalent to the slope of the line, so it has a value of (-6.42 ± 0.0617) N/V.

Our force sensor was tared when the sensor was pointing downward, and this is when we recorded data points for our calibration. However, when we turned the force sensor onto its side to measure the force applied by the glider in the next part of the experiment, the noise in the sensor was significantly higher. The noise when it was pointed downward was around 0.001 V. When the sensor was horizontal, the noise was about 0.06 V. It is possible that the sensor's end was loose on our device and was measuring the force of gravity acting on the piece hanging off the end of it.

Trial	Initial Velocity (*m/s*)	Final Velocity (*m/s*)
1	-0.108 ± 0.001	0.084 ± 0.001
2	-0.186 ± 0.001	0.142 ± 0.001

Figure 2: This table shows the initial and final velocities of the glider for each trial where it collides with the force sensor at the end of the track. These values were produced by the photogate by tracking the photogate flag and recording the amount of time that it took the flag to completely clear the photogate. The initial velocities are negative because velocity is a vector value, and we assigned the direction it moved in after the collision to be positive.

Trial	Initial Momentum (*kg*m/s*)	Final Momentum (*kg*m/s*)
1	-0.0218 ± 0.009	0.0170 ± 0.005
2	-0.0376 ± 0.012	0.0286 ± 0.007

Figure 3: This table shows the initial and final momentum of the glider in each trial. These values were calculated by multiplying the mass of the glider (after conversion to kilograms) by the initial and final velocities respectively. The magnitude of the final momentum is lower than initial momentum, so the collision was not entirely elastic.

To calculate the impulse experienced by the glider in each trial, we subtract the initial momentum from the final momentum.

Trial	Impulse from Difference in Momentum (*Ns*)
1	0.0389 ± 0.010
2	0.0662 ± 0.013

Figure 4: The table shows the impulse of the glider for each trial. The trial with higher velocities has higher impulse because more momentum was transferred into the opposite direction after the collision.
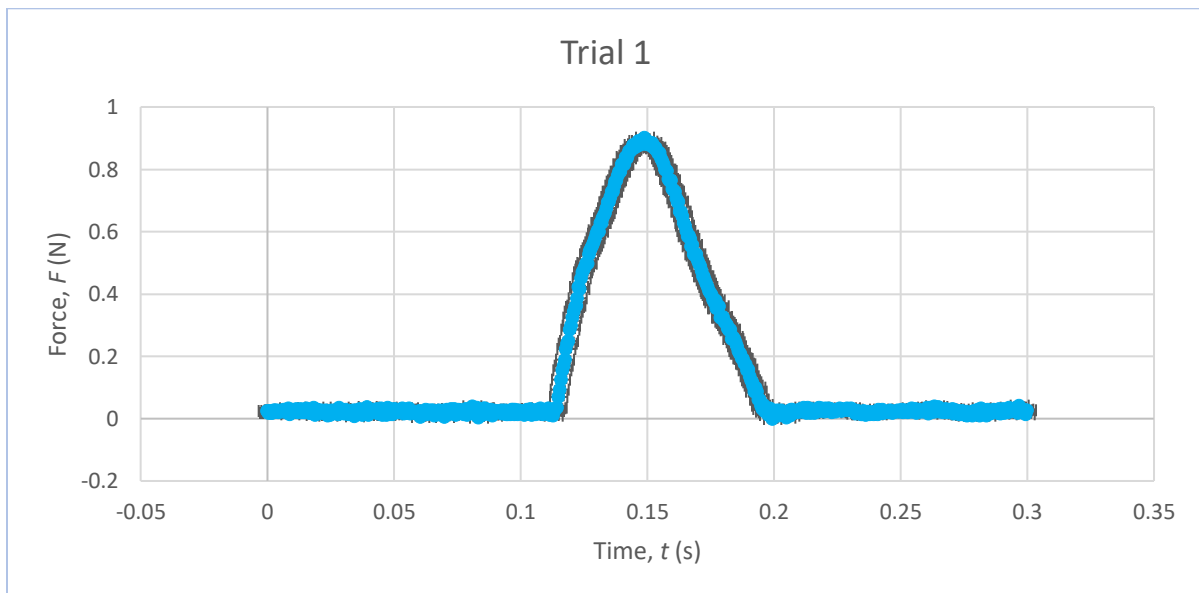

Figure 5: This plot shows the readings of the data acquisition system for the collision between the glider and the force sensor in the first trial. Each data point represents the force acting on the

sensor at each time instance. We converted the readings from voltage into force by multiplying by our calibration constant. Our raw data had a base at around 0.5 N, but we subtracted the background from the readings so that it would be based at zero. The curve in the middle is the force readings of the sensor during the collision with the glider.
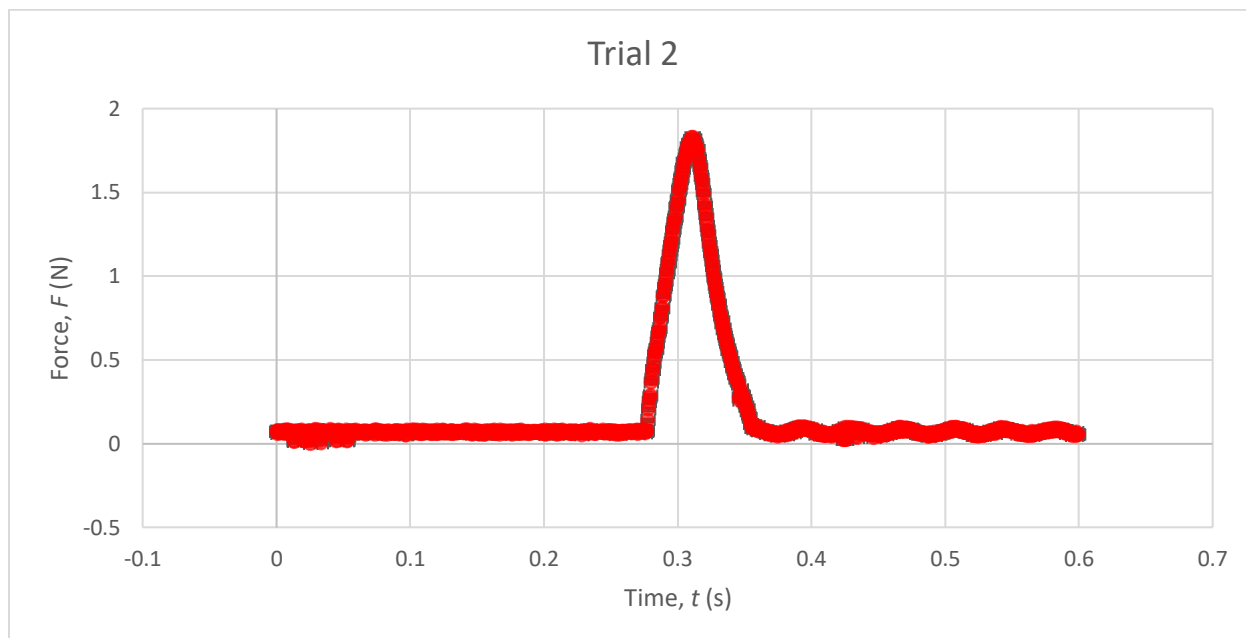

Figure 6: This plot shows the readings from the second collision trial. Each data point represents a reading of voltage by the force sensor at a particular point in time. The curve in the middle of the graph shows the force readings during the glider's collision with the force sensor. Our peak force value was higher in this trial than in the first trial because the glider was pushed faster. The increase force is the reason why the oscillations after the collision are more prominent in this case

We use two different methods to find the impulse experienced by the glider. The first method consists of finding the difference between the final momentum and initial momentum.

$$\Delta P = P_f - P_i$$

The second method is an integration of the force curves in Figure 5 and Figure 6. The integration of the curve is equivalent to adding each value of force for every time instance and multiplying this sum by the time step.

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

Trial	Impulse from Difference in Momentum (*Ns*)	Impulse from Numerical Integration (*Ns*)
1	0.0389 ± 0.010	0.0430 ± 0.00041
2	0.0662 ± 0.013	0.0706 ± 0.00068

Figure 7: This table shows the impulse experienced by the glider in each trial. The values in the middle column were produced by subtracting the initial momentum from the final momentum. The third column was calculated by taking the integral of the force curves shown in Figure 5 and Figure 6 with respect to time.

Though they are not equivalent as we would expect, the results produced by each method are close to each other. Both sets of values are within 0.004 Ns of each other. The differences can be attributed to systematic error from the fluctuations in our equipment's readings. The force sensor records noise, which contributes to the higher valued result from the integration method. We eliminated most of the background by subtracting the minimum recorded value from all of the others, but this did not entirely zero out all noise because the values fluctuate.

(3) Extra Credit

Trial Method	Glider *a* Initial Velocity (*m/s*)	Glider *a* Final Velocity (*m/s*)	Glider *b* Initial Velocity (*m/s*)	Glider *b* Final Velocity (*m/s*)	Coefficient of Restitution
Both bumpers	-0.134	0.0925	0.137	-0.0873	0.662 ± 0.02
No bumpers	-0.347	0.0482	0.340	-0.0365	0.123 ± 0.02

Figure 8: This table contains the vector initial and final velocities of each glider. The ratio between the differences of the gliders' initial and final velocities were used to determine the coefficient of restitution. The value of uncertainty for the velocities is 0.001 m/s.

Glider *a* moved in the negative direction before the collision, and it moved positive direction after the collision. The opposite is true for glider *b*. We must note that our track was not entirely level. The gliders moved in the positive direction would accelerate, and the gliders moving in the negative direction decelerated.

A coefficient of restitution of 1 means that the collision was completely elastic and a value of 0 means the collision was completely inelastic. From our calculated coefficients of restitution, we see that the collision with the two rubber bumpers was more elastic than the collision without bumpers. The rubber material was springy and so each gliders' kinetic energy could be transferred to the other. However, some of the kinetic energy of the gliders was lost as sound waves.

Presentation Mini-Report

Introduction

Along with the law of energy conservation, conservation of momentum is a fundamental principle of physics. Momentum and impulse are crucial areas of focus in safety research. For decades, motor vehicles have seen improvements in their design to handle collisions better and protect their passengers. More recently, the NFL has been scrutinized for the issues they are having with concussions from player-on-player collisions. More resources are being spent on improving helmet design to protect players' heads during impact. All of these fields involve making sure that the surrounding entity minimizes the impulse experienced by the people on the inside. Our experiment uses a glider on an air track that collides with a force sensor to measure the impulse experienced by the glider. We aim to verify that two different methods of calculating impulse produce the same result. One involves measuring the velocity of each glider before and after the collision and calculating the momentum at each instance. From here, the impulse is calculated by taking the difference between the final momentum and the initial momentum. The other method uses integration of the curve in a force versus time graph to find the impulse. In an ideal environment, looking at the start and ending points in a collision to calculate impulse should yield the same result as taking the sum across each individual point in time during the collision. Our results verify that each method produces a value consistent with the other.
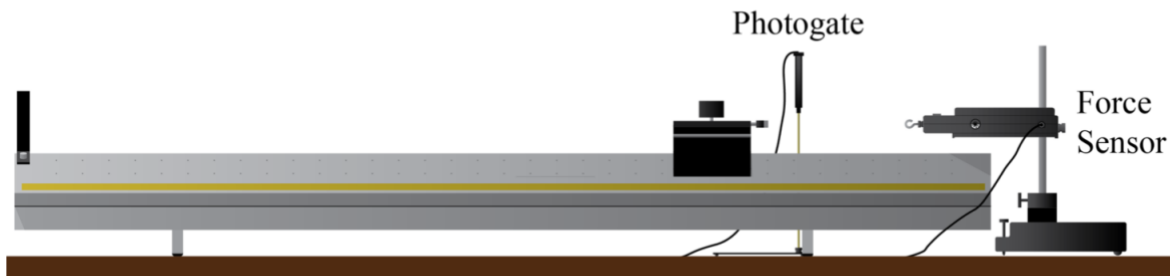
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Methods

Figure 9[1]: This is the set up for the second part of our experiment. They grey horizonal bar is the air track, and the black box that is sitting on it is the glider with a bumper and a photogate flag on top. The photogate hangs over the air track so that the glider can pass through but so that the sensor is blocked by the photogate flag.

The first part of this experiment involves using a force sensor with a Data Acquisition System (DAQ). Before taking measurements to determine the impulse of collisions, we calibrate our force sensor. We do this because we do not trust the internal calibration of the force sensor. We calibrate it ourselves to avoid systematic error. We position the force sensor so that it points downwards and hang various masses onto the end of the it. We set up our DAQ to read a User Defined Sensor with units of Volts. Note that we do not tell the DAQ to read a force sensor. We

record each value of voltage produced by at least 5 different masses up to and including the decimal place at which the value begins to fluctuate.

We want to find a relationship between the Voltage readings that were produced by the DAQ and the force that was applied to the sensor. We first convert the masses' units from grams to kilograms. Then, we multiply each value of mass by the gravitational acceleration constant 9.80 m/s^2 to get the force that each mass applied to the force sensor whilst hanging on the sensor. We plot each value of applied force against the corresponding voltage reading. The relationship between these two is linear. We fit the data with a trendline and use the slope of the line as our calibration coefficient.

The next part of the experiment requires us to set up an air track with our force sensor at the end of it. We also use a glider with a photogate flag and two bumpers on either side, each one made of a different material with different elasticity. Make a note of the mass of the glider with the flag and bumpers attached. In addition, measure the length of the photogate flag. To minimize systematic error, we leveled the track as best as we could. However, the track seemed to be bent in certain areas. One section would be level, but another part would not be. After leveling the track, we placed the force sensor with the sensor lined up with the track. We positioned it so that the glider's bumper would strike the sensor in the center when the glider is pushed toward the sensor. Note that the air should be turned on when lining up the bumper with the sensor because the glider is slightly raised with the air on. The force sensor should be plugged into the DAQ for this part as well. The DAQ should be set up to read a User Defined Sensor as before. Additionally, we set up a photogate in a position over the air track so that the photogate flag on the glider blocks the photogate sensor as the glider passes through it. This is used to measure the velocity of the glider as it moves toward the force sensor before impact as well as its speed moving away from the sensor after the collision. It does not matter how close the photogate is on the track relative to the force sensor because the air track is supposed to provide a frictionless surface for the glider to move on. However, there is some friction on the track, so it is best to keep the photogate close to the force sensor, but far enough away so that the entire photogate flag can pass through the photogate. The DAQ should be measuring the time stamps, velocity of the glider, and voltage produced by the force sensor above 2 kHz. This frequency gives a clear picture of the force being applied to the sensor.

Then, we lightly push the glider toward the force sensor. We start recording values on the DAQ just before the glider passes through the photogate. We need to be careful not to push the glider too hard because it causes oscillations in the data after the glider bounces off. It also might alter the calibration of the sensor and disrupt the positioning if the sensor is struck with too much force. From the DAQ, choose a range of values to keep from a bit before the peak of the voltage readings to a bit after the readings come back down to their resting value. To find the impulse of the glider, we can integrate the force curve and multiply it by time. We can also find the momentum of the glider before and after the collision and find the difference between these two.

For the last (optional) part of this experiment, we need two gliders and two photogates to be set up on a single air track. We place the two photogates far enough apart for the photogate flags to pass through when the two gliders move towards each other.

We push the two gliders towards each other so that they collide between the two photogates. We record the values of the velocity of each glider before the collision and after the collision. We assign a positive and negative direction for movement along the track and apply these directions to the velocities. From these we found the coefficient of restitution by taking the ratio of differences between the final and starting velocities. With the coefficient of restitution we can determine how elastic the collisions were.

Bibliography

1. Campbell, W. C. et al. Physics 4AL: Mechanics Lab Manual (ver. June 27, 2018). (Univ. California Los Angeles, Los Angeles, California).