**“Experiment 4: Momentum and Impulse”**

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**Worksheet:**

**1. Discussion**

The mass of the glider with the photogate flag and bumpers attached was found to be 0.202±.001kg. The length of the photogate flag was found to be 0.039 ± .001m.

Figure 1. Calibration of the Force Sensor. This scatterplot shows the various test forces applied to the force sensor by suspending weights with known masses and the corresponding voltage readings from the sensor. The scatterplot is fitted with a blue-dotted linear fit line of the form y=ax+b where a = -6.299 ± .008 N/V and b = 0.006 ± .002 N. The value for a (6.299 ± .008 N/V) is the calibration constant, and can be used to convert voltage values into force values for the remainder of the experiment.

Impulse, the measurement of the change of momentum of a system, can be calculated using the equation:

Where, in this system, *m* is the mass of the glider in kg with its flag and bumpers attached, is the initial velocity right before the collision with the force sensor in m/s2, and is the final velocity after the collision in m/s2. Using the equation for impulse, and taking the positive x-direction to be to the right, the impulse for Trial 1 was found to be 0.022 ± .002 N\*s, and the impulse for Trial 2 was found to be 0.036 ± .005 N\*s.

Figure 2. Collision of Bumpered Glider with Force Sensor, Trial 1 This scatterplot shows the spike in applied force on the force sensor over the course of the bumpered glider colliding with it. The spike is not straight up and down, instead appearing more to slope up, then spike, then slope fairly quickly down. This is due to the bumper on the glider. As the bumper collided with the force sensor, the bumper compressed, causing this more gradual upward slope as the force causes the velocity to change direction. The impulse, J, of the system can be calculated by finding the integral under the curve, and, here, was found to be 0.022 ± .008 N\*s by taking the Riemann sum.

Figure 3. Collision of Bumpered Glider with Force Sensor, Trial 2 This scatterplot shows the spike in applied force on the force sensor over the course of the bumpered glider colliding with it. The spike is not straight up and down, instead appearing more to slope up, then spike, then slope fairly quickly down. This is due to the bumper on the glider. As the bumper collided with the force sensor, the bumper compressed, causing this more gradual upward slope as the force causes the velocity to change direction. The noise seen in the data before and especially after the collision are due to imperfect equipment, the force sensor was susceptible to vibrations. This is especially evident in this trial. The impulse, J, of the system can be calculated by finding the integral under the curve, and, here, was found to be 0.036 ± .008 N\*s by taking the Riemann sum.

An alternative way of calculating the Impulse, J, is by numerically integrating under the curve produced by plotting the force over time during a collision. Figure 2 and Figure 3 show such curves for Trials 1 and 2. To numerically integrate, a Riemann sum is used. To get a true value of the force, the background variation, which is the average value given by the force sensor before the force is applied, was subtracted from each data point. All the values for force that were a part of the gradual spike that corresponded to the collision were then added as a Riemann sum. The integral being of the form:

Here, we are integrating across the curve of force with respect to time, from some t1 right before impact until tn, right after the glider loses contact with the force sensor. The corresponding Riemann sum using midpoints is of the form:

Where J is , the change in momentum, the value that we are looking to compare with the one found using photogate method. is the step size, which is the time interval between data points, here, 0.0004 s. is the average force for each segment of the sum. Using this method, J for Trial 1 was found to be 0.022 ± .008 N\*s and J for Trial 2 was found to be 0.036 ± .008. The fractional uncertainties of the integrals were assumed to be the same as the fractional uncertainty of the calibration coefficient.

|  |  |  |  |
| --- | --- | --- | --- |
|  | Impulse Using Photogate Method, J1 (N\*s) | Impulse Using Integration Method, J2 (N\*s) | Percent Difference |
| Trial 1 | 0.022 ± .002 | 0.022 ± .008 | 1.2% |
| Trial 2 | 0.036 ± .005 | 0.036 ± .008 | 0.2% |

Table 1. Comparison of the Photogate and Integration Methods The impulses found using the photogate method were calculated using Capstone’s measurements for the final and initial velocity and the equation for impulse. The impulses found using the integration method were calculated by fining the Riemann sum under the curve of the force over time during the collision. The values calculated using each method were very similar within each trial, which indicated the results were precise. The percent differences shown in the final column were calculated using unrounded values. Though the results were very similar, the photogate method was found to be the better method because it had a lesser degree of error.

**2. Extra Credit**

|  |  |  |  |
| --- | --- | --- | --- |
|  | Coefficient of Restitution, CR | Kinetic Energy Ratio,  RKE | Momentum Ratio,  RP |
| Firm Foam Bumpers | 1.00 ± .02 | 1.00 ± .02 | 1.00 ± .02 |
| Soft Foam Bumpers | 0.12 ± .02 | 0.014 ± .02 | 0.12 ± .02 |
| No Bumpers | 0 | 0 | 0 |

Table . Elasticity of Glider Collisions The Coefficient of Restitutions, CR, in the first column show that the firm foam bumpers had a perfectly elastic collision, the collision with nu bumpers had a completely inelastic collision, and the soft foam bumpers produced a collision that was somewhere in between the two, though it leaned more toward inelastic. By the kinetic energy and momentum ratios in the second and third columns, it is shown that both kinetic energy and momentum are conserved for perfectly elastic collisions, and that neither kinetic energy nor momentum are conserved for perfectly inelastic collisions.

**Presentation Mini-Report:**

**Introduction**

Momentum is often described as the measurement of mass in motion. The conservation of momentum is one of the most fundamental kinematics topics, even more so than the conservation of energy.1 This is because, while there is often dissipation of energy in real world scenarios that are hard to keep track of, there is rarely dissipation of momentum. The change in momentum, J, also referred to as impulse, is a useful quantity to consider when considering variable forces. The impulse can be calculated directly by subtracting the initial momentum from the final momentum, or it can be calculated by finding the area under the force-time curve.

In this experiment, both of these methods are attempted in order to compare the results and determine which gives a better result by facilitating a collision between a bumpered glider and a force sensor. A photogate was set up so that the pre-and post- collision velocities could be calculated so that the impulse could be calculated directly. The force sensor readings during the collision gave the data to create a force-time plot, which was used to calculate the impulse through integration.

Word Count: 187

**Methods**

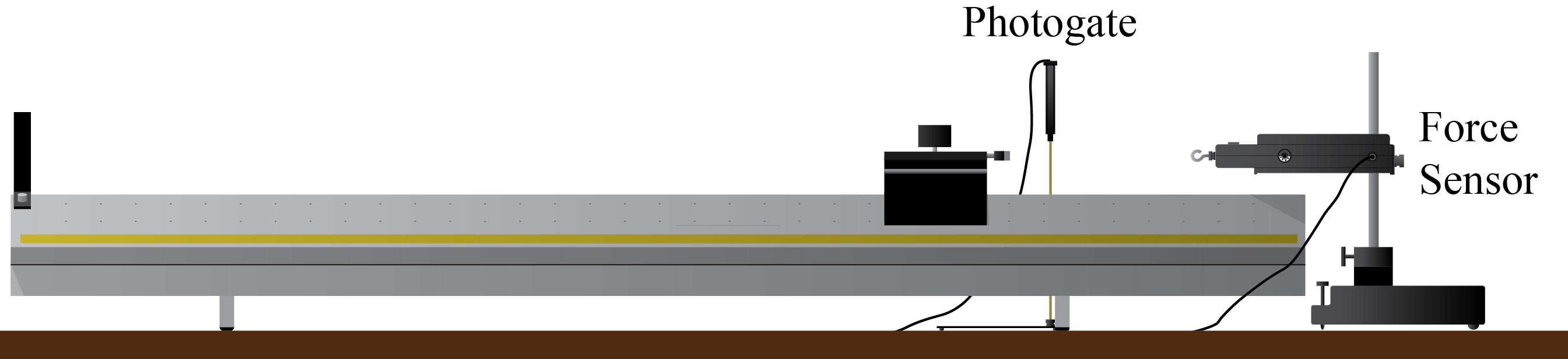


Figure 4. Bumpered Glider and Force Sensor Collision Set-up Figure reproduced (with permission) from Fig 4.1 by Campbell, W. C. et al.1 The force sensor is suspended horizontally facing the glider track as shown. The photogate is then placed a little over a glider’s length away so that the glider is just about to have impact with the force sensor once its flag has fully gone through the photogate.

First the force sensor was suspended vertically and tared using the button on its side. Then, the force sensor calibration was performed by suspending five hooked weights of masses varying from 60g to 300g from the force sensor and recording the measured voltage from the force sensor for each one. Then, the force sensor was moved to a horizontal position facing the end of a glider track as shown in Figure 4. The mass was then recorded for the glider with its foam bumper on one end and a photogate flag attached. The length of the photogate flag was then recorded. The glider with bumper and flag attached was then placed on the glider track, and the glider turned on to level 5. The photogate was then set up so that the bumper was just about to make contact with the force sensor once the flag had passed the gate. This was to ensure that there would not be excess data points that could reduce the clarity of the data. It was ensured that the force sensor was firmly attached and fully level so that these systematic sources of errors could be reduced. The DAQ was then set up to record the time elapsed, the voltage reading of the force sensor, and the velocity of the glider measured by the photogate and flag. For each of the two trials conducted, the glider was gently pushed toward the force sensor, resulting in a collision and the glider returning in the direction it came. The glider was pushed gently so that the post-collision vibrations would be minimized, which reduced the potential for these fluctuations to be a source of error.The DAQ was made to continuously record data from a point right before the photogate was first triggered, until right after the photogate had stopped being triggered when the glider was on its way back post-collision. This resulted in around 5000 timestamps and voltage readings for each trial and two velocity readings for each trial, one final and one initial.

Bibliography:

1. Campbell, W. C. *et al*. Physics 4AL: Mechanics Lab Manual (ver. August 31, 2017). (Univ. California Los Angeles, Los Angeles, California).