

# Momentum and Impulse

## APPARATUS

*Shown in the picture below:*

- Air track
- Glider with bumper and flag
- Photogate
- Force sensor



*Not shown in the picture above:*

- Computer and Pasco interface
- Vernier calipers or meter stick to measure glider flag
- Scale and weight set

## THEORY

Newton's Second Law tells us that the net force acting on an object is equal to the object's mass multiplied by its acceleration:  $\mathbf{F}_{\text{net}} = m\mathbf{a}$ . Using  $\mathbf{a} = d\mathbf{v}/dt$ , where  $\mathbf{v}$  is the object's velocity, we can rewrite this law as

$$\mathbf{F}_{\text{net}} = m d\mathbf{v}/dt. \quad (1)$$

Newton himself believed that this relation should also account for the possibility that the mass is varying:

$$\mathbf{F}_{\text{net}} = d(m\mathbf{v})/dt. \quad (2)$$

Examples of varying masses include rain falling into a rolling open box car and a rocket expelling gases. The above equation can be rewritten as

$$\mathbf{F}_{\text{net}} = d\mathbf{p}/dt, \quad (3)$$

where  $\mathbf{p} = m\mathbf{v}$  is the *momentum* of the object. Eq. 3 is the most general definition of force: the change of momentum with time. If we write it as a differential equation,

$$d\mathbf{p} = \mathbf{F}_{\text{net}} dt, \quad (4)$$

and integrate with respect to time, then Eq. 3 becomes

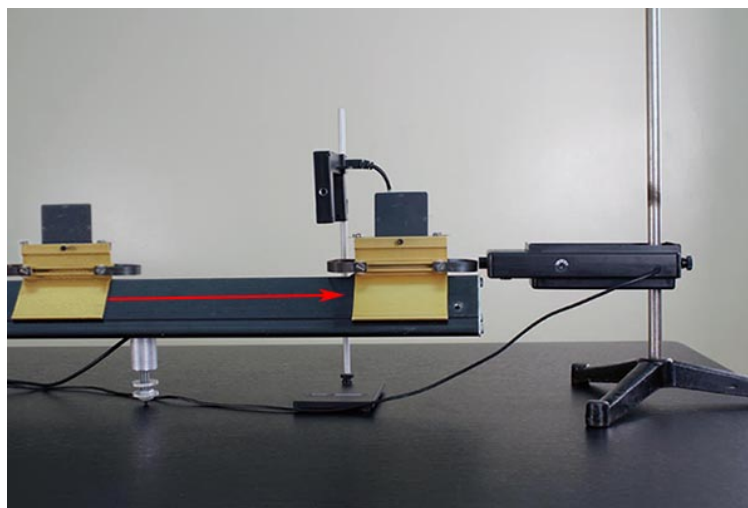
$$\Delta \mathbf{p} = \mathbf{p}_2 - \mathbf{p}_1 = \int \mathbf{F}_{\text{net}} dt. \quad (5)$$

The right side of Eq. 5 is known as the *impulse*, and the left side is the change in momentum. The notion of impulse is often associated with a force that acts for a short period of time. Examples of such forces include a bat hitting a ball and the impact between two objects moving at relatively high speeds.

In this experiment, you will verify Eq. 5 by allowing a glider on an air track to pass through a photogate and strike a force sensor. The sensor allows you to measure the force on the glider as a function of time. This time interval is relatively short, so the impulse approximation is valid. The velocity of the glider is measured when it crosses the photogate, just before and just after the collision. These two velocity measurements, along with knowledge of the glider's mass, allow you to calculate the change in momentum (i.e., the left side of Eq. 5). The sensor generates a force-versus-time curve on the computer, which can be integrated to obtain the impulse (i.e., the right side of Eq. 5). The glider has a foam bumper, so its collision with the force sensor is *inelastic*. In other words, kinetic energy is not conserved during the collision, but the change in momentum is still equal to the impulse.

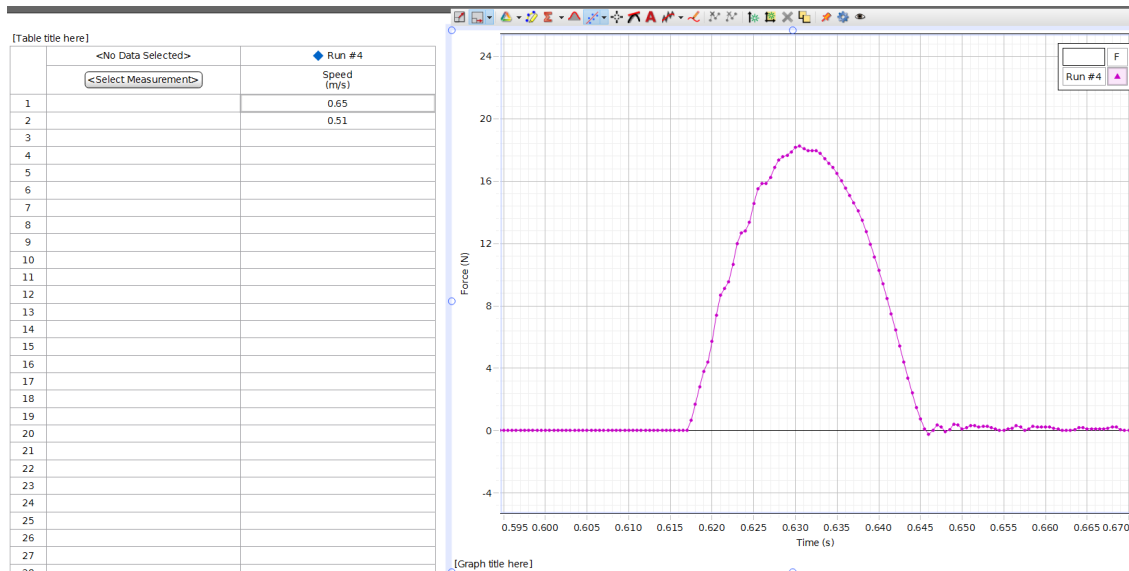
## PROCEDURE

1. Level the air track carefully. Mount the force sensor horizontally on the vertical rod of the ring stand at the end of the track so the glider bumper will strike the sensor as the glider moves down the track. Set up the photogate so the glider flag clears the gate by a few centimeters before the bumper strikes the sensor. Refer to the picture below. Note that while the sensor has two interchangeable end parts (a screw hook for hanging objects from the force sensor, and a rubber bumper for the impulse measurements in the actual experimental runs), we will only be using the rubber bumper in this experiment.



The glider then bounces off the sensor and passes through the photogate again. In an experimental run, you should record the two photogate velocity readings and the force-versus-time curve from the sensor.

2. Weigh the glider, and record its mass (in kilograms) in the “Data” section.
3. Open Capstone and choose “Table & Graph”. Under “Hardware Setup”, click on Channel 1 and choose “Photogate”. Then click on Channel A and choose “Force Sensor”.
4. We want to set up the photogate to measure the velocity of the glider.
  - a. Click on “Timer Setup” and then click “Next” twice.
  - b. Select “One Photogate (Single Flag)”. Make sure “Speed” is selected and click next.
  - c. Make sure the flag width is entered in the white box (0.05 m). Then click “Next” and then “Finish”.
5. Click on “Select Measurement” in one of your table columns and select “Speed (m/s)”. Click on the  $y$ -axis of the graph and choose “Force (N)”.
6. At the bottom of the screen, set the sampling rate to 2000 Hz. Note that the computer will then take a force reading every  $1/2000$ , or 0.0005, second.
7. Turn on the air track, and push the “Tare” button on the side of the force sensor to zero its readings. Click “Record” and send the glider down the track so it passes through the photogate, strikes and bounces off the force sensor, and crosses the gate again. Click “Stop”. Your table should show two velocity readings at the top. The second velocity value is smaller since the collision is inelastic.
8. Zoom in on the part of the graph where the glider hit the force sensor. Your data should look something like that of the image below.



9. Use the “Display area under active data” button to calculate the area under the curve. Use the “Highlight range of points...” button to select only the data of interest.
10. Use the two speed recordings in your table to calculate the change in momentum from this

collision. When you calculate the change in momentum from  $mv_1$  to  $mv_2$ , should you add or subtract these two numbers? Pay attention to the direction the glider is moving and remember that the photogate measures speed, not velocity.

11. Have each lab partner make three measurements with different glider speeds to check the relation  $\Delta \mathbf{p} = \int \mathbf{F}_{\text{net}} dt$ .
12. In the “Data” section, record the three values of change in momentum and impulse, as well as the percentage difference between each set of values.

## DATA

2. Mass of glider (kg) = \_\_\_\_\_

12. In the table below, enter your measured changes in momentum, impulses, and the percentage differences.

	A	B	C
1	Change in P	Impulse	% difference
2			
3			
4			

## ADDITIONAL CREDIT (5 mills)

In this experiment, you need to perform an integral over your force data to calculate the impulse. Capstone performs a summation algorithm to calculate the area under a curve. You can do this same technique using Excel.

The impulse is the area under the force-versus-time curve. Like any integral, it can be approximated using a Riemann sum:

$$\text{Impulse} = \int \mathbf{F}_{\text{net}} dt = \sum \mathbf{F}_i \Delta t_i = \Delta t \sum F_i,$$

where we were able to pull out the  $\Delta t$  in the last step because the time intervals  $\Delta t_i = 0.0005$  second are all equal.

You can obtain the force sum with an Excel function such as “=Sum(b3..b147)”. Perform this calculation on one of your data sets and compare to the results from Capstone. You will need to make a table of force measurements and copy it over to Excel.

Finally, use this force sum to calculate the impulse. As in the main part of the lab, compute this value to the glider's change in momentum and calculate the percent error.