Impulse-Momentum Theorem

Introduction

During a collision, the contact force between the objects participating in the collision is not constant, but varies with time. Thus the accelerations experienced by the objects will also be functions of the time. Since the accelerations are not constant we will not be able to use the kinematics equations of motion to analyze this situation. Instead, we will rely upon the concept of impulse and its relationship to the change in momentum through the Impulse-Momentum Theorem. The purpose of this lab is to determine the validity of the Impulse-Momentum Theorem.

Equipment

Computer with Logger Pro SW	Glider	Ringstands (2)
Vernier Lab Pro Interface	**Wireless Force Sensor**	
Air Track & Air Supply	Motion Detector	
Air Track Accessory Kit (Bumpers)	Scale	

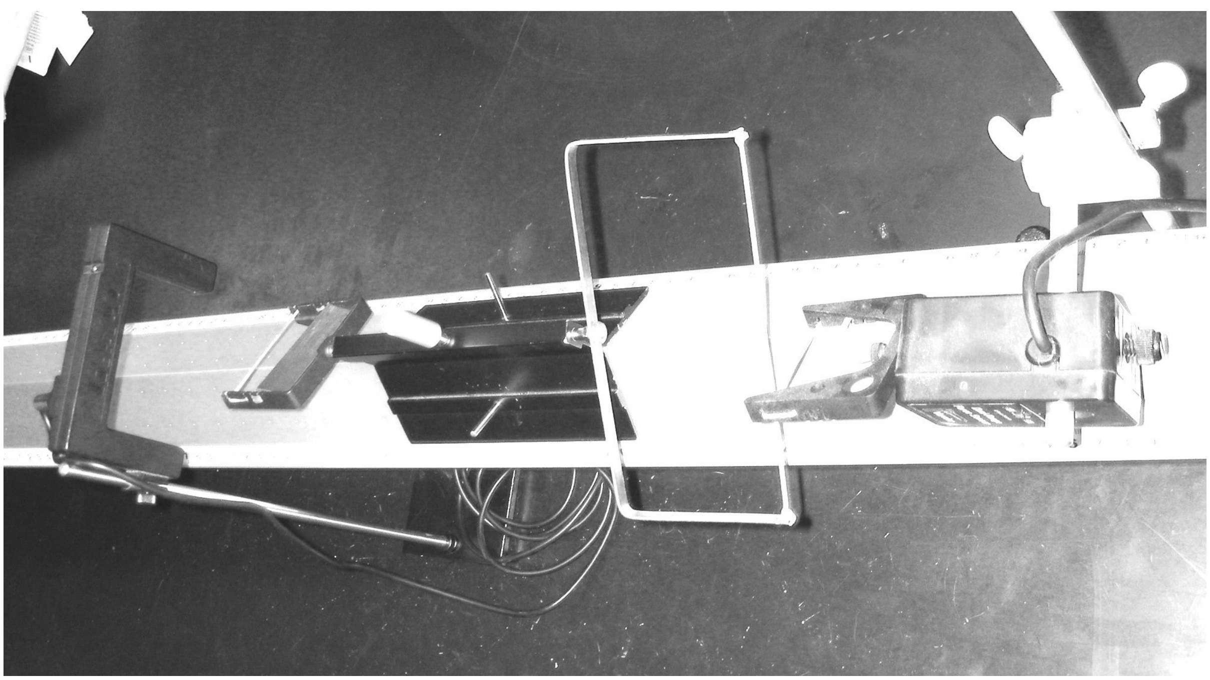


Figure 1. Overhead view of the glider as it is about to impact the bumper attached to the force sensor.

Terminology

Impulse: (*Area under the* ***F****-vs-t graph)* $\vec{J} = \bar{\vec{F}}\Delta t$

Net Impulse: (*Area under the* $\boldsymbol{F}_{net}$*-vs-t graph)* $\vec{J}_{net} = \bar{\vec{F}}_{net}\Delta t$

Momentum: $\vec{p} = m\vec{v}$

Change in Momentum: $\Delta\vec{p} = m\vec{v} - m\vec{v}_0$

Theory

The easiest way to analyze this collision situation is to make a graph of the force versus time. The impulse of this force over a given time interval is the area under the curve over the same time interval. The time interval will usually be the interval during which the force acts. If the force were constant, then the graph of the force versus time would be a horizontal line and the area under the curve would be the value of the constant force multiplied by the time interval. However, since the force varies with time, we need to use the average force, over the time interval.

The net impulse acting on an object is the vector sum of all of the impulses that act on the object, or alternatively it is the area under the curve of the graph of the net force acting on the object versus time. The Impulse-Momentum Theorem states that the net impulse acting on the object is also equal to the change in the momentum of the object.

$$\vec{J}_{net} = \bar{\vec{F}}_{net}\Delta t = \Delta\vec{p}$$

$$\vec{p} = m\vec{v} \quad \& \quad \Delta\vec{p} = m\vec{v} - m\vec{v}_0$$

In this lab we will produce a one-dimensional elastic collision between a glider, riding on an air track, and a stationary force sensor. The motion detector will record the initial and final velocities and the force sensor will record the force as a function of time. We will then use this data to determine the validity of the Impulse-Momentum Theorem.

Equipment Set Up Procedure

Motion Detector – Connect the Lab Pro interface to the computer via the USB port. Connect the motion detector to digital CH1. Turn on the computer and click on the **Logger Pro** icon. The two graphs: position and velocity should show up on the screen.

Wired Force Sensor

For the wired force sensor, connect the force sensor to analog CH1. The Logger Pro software should automatically recognize the force sensor and display a force data table and a force vs time chart.

Setting up your WDSS

1. Turn on the WDSS. Note the name on the label of the device.
2. Make sure Bluetooth is activated on your computer. Some computers have Bluetooth built into them. If that is the case, make sure Bluetooth is turned on.
3. Establish a wireless connection with the WDSS.
   a. Choose **Connect Interface** from the **Experiment** menu. Choose **Wireless** and then **Scan** for Wireless Device.
   b. There will be a short delay while Logger Pro attempts to establish a connection. If the WDSS is not found, try scanning again.
   c. A dialog box will appear showing your WDSS on the list of available devices. Select your WDSS device and then click OK . Once a connection is made, the two LEDs on the WDSS will be lit green.

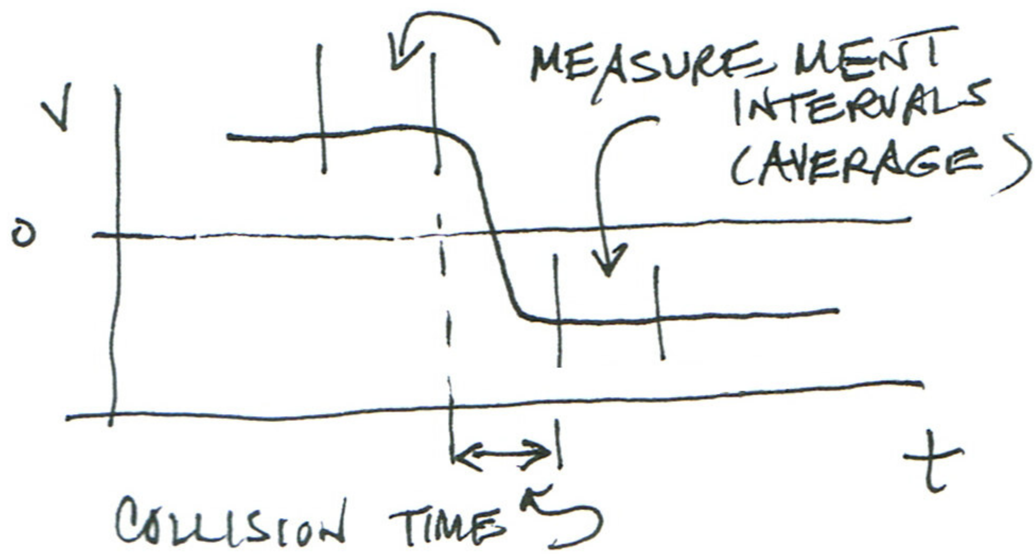
Choose **Data Collection** from the **Experiment menu**. Adjust the data collection experiment length to 10 seconds with a sampling rate of 200 samples/second. Save the set up as **MyImpulse_Temp** on the Desktop. The Data Interval should be 0.005 seconds. You may have to add a chart to display the Force data if one doesn't appear automatically.

Air Track Procedure – Turn on the air track air supply and adjust the volume of the air flow to about 80% of the max value so that the glider rides freely on a cushion of air. To level the air track place the glider at the center of the track and then adjust the feet on the air track until any motion of the glider is minimized.

Glider Procedure –We will be using the smallest rectangular flag as a target for the motion detector.

Bumpers – The bumpers are mounted on each end of the glider (for balance) and on the end of the force sensor. If there are only two (2) bumpers available then another object equal in mass to the bumper needs to be mounted on the other end of the glider.

Motion Detector Placement Procedure - We will use a motion detector to measure the initial velocity of the glider prior to the collision as well as the final velocity of the glider after the collision. Place the motion detector at the opposite end of the air track from the force sensor. Shown below is the trace of the before and after velocities.



Force Sensor Procedure – To ensure the integrity of your data you will need to make sure that the force sensor does not move during the collision. Do not send the glider into the force sensor too hard, if the bumper bracket on the glider and the one on the force sensor touch each other the data will not be accurate and the run will have to be repeated.

Final Alignment Check - You will be using the smallest of the rectangular objects as the flag. Orientation is important. The flag should be oriented perpendicular to the length of the air track. This will provide a target for the motion detector.

Experimental Procedure

Precision - All observations should be recorded to **3 significant figures**. You should carry 3 significant figures in all of your calculations as well.

1. To begin a run first zero the force sensor by clicking the **Zero** button and then click the **Collect** button to start the data collection. Gently push the glider to launch it toward the force sensor. Start close to the motion detector and confine your pushing to within 0.5 m of the motion detector. Keep your hand at or below the level of the track. Let the experiment run all the way out until the end of the collection time and the **Stop** button disappears and the **Collect** button returns.
2. TURN OFF the sensor between runs to conserve battery power.
3. Locate, measure and record the initial and final velocities that occurred before and after the collision. Don't forget to include the directions for these vector quantities.
4. On the Force versus Time graph locate the non-zero region of the graph and highlight it by clicking and dragging the cursor across the region. Click the **Integral** button and record the value of the integral, which is simply the area under the curve, as the Net Impulse in the Data Table. [**Note:** Expand the horizontal axis (time axis) to improve the accuracy of your determination of the time interval.]
5. Record the time interval for the collision as well as the maximum value of the force. Determine these by using the inspection function with the Force versus Time graph.
6. Repeat this process five (5) more times with the first bumper. Print a representative graph for one of these runs. Measure the mass of your glider using the scale.

Data Analysis

- Calculate the following quantities for each run: $\Delta\mathbf{p}$ and compare it through a percent difference with the $\mathbf{J}_{net}$.
- Then calculate the average net force for each run by $\bar{\vec{F}}_{net} = \vec{J}_{net} \div \Delta t$
- Plot a graph (X-Y Scatter) of $\mathbf{J}_{net}$ (y-axis) versus $\Delta\mathbf{p}$ (x-axis). Determine the slope, y-intercept and correlation coefficient of the trendline. Use the LINEST Excel function to determine the uncertainties in these quantities.

Questions

1. In this lab we neglected friction because we have significantly reduced its affect by the use of an air track.
   - If friction were present what would be its affect on the values of the velocities?
   - How would this affect the momentum values?
   - What would this do to the value of the momentum change as it compares to the net impulse?
2. In general, how do the average force and the maximum force for each run compare to one another?
3. Within reasonable limits for experimental uncertainty were you able to verify the Impulse-Momentum Theorem?

Data Tables

Mass of glider = ________________(kg)

Run	**Δt** (s)	$\mathbf{F_{max}}$ (N)	$\mathbf{F}_{avg}$ (N)	$\mathbf{V_0}$ (m/s)	**V** (m/s)
1					
2					
3					
4					
5					
6					

Analysis Table

Run	$\mathbf{p}_0$ (kg*m/s)	**p** (kg*m/s)	**Δp** (kg*m/s)	$\mathbf{J_{net}}$ (Ns)	**% Diff**
1					
2					
3					
4					
5					
6					