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# Collisions – Impulse and Momentum

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## Introduction

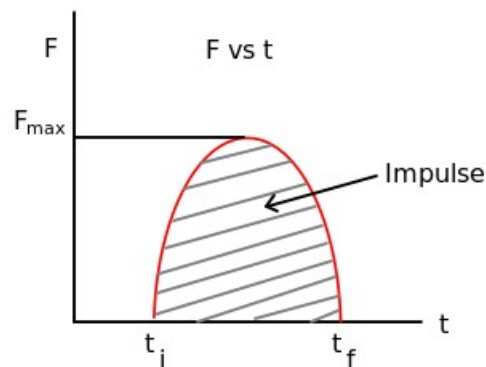
Momentum ( $p$ ) is defined as mass times velocity:  $\vec{p} = m\vec{v}$ , similarly to Newton's 2<sup>nd</sup> Law,  $\vec{F} = m\vec{a}$ . Knowing that  $\vec{a} = \Delta\vec{v}/\Delta t$ , Force can be written as:

$$\vec{F} = m \frac{\Delta\vec{v}}{\Delta t} = m \frac{\vec{v}_f - \vec{v}_i}{t_f - t_i}$$

If both sides of the equation are multiplied by  $\Delta t$ , the definition of Impulse ( $I$ ) is found:

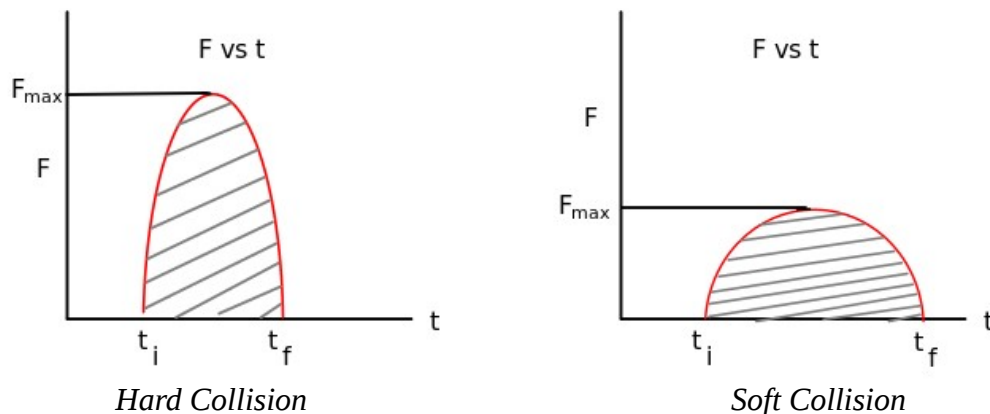
$$\vec{F}\Delta t = m \Delta\vec{v} = m (\vec{v}_f - \vec{v}_i) = \Delta\vec{p} = I$$

Note that Impulse is defined by Force and Time as well as Mass and Velocity, thus Impulse changes the momentum of an object. Impulse is visualized as the area beneath the curve on a Force vs. Time plot:



Collisions can generally be considered either 'soft' or 'hard'. An example of a soft collision would be jumping off a platform onto a trampoline, whereas a hard collision would be jumping off the platform and landing on something else, like concrete. In both cases, your body does not change mass and your initial velocity would be the same as well. Thus, Impulse does not change! What does change is the Force of impact and the time of collision.

Force and collision time are *inversely* related. So the hard collision will have a large force and small collision time as opposed to the soft collision that has (by comparison) a small force and large collision time. This is visualized graphically below:



# Goal

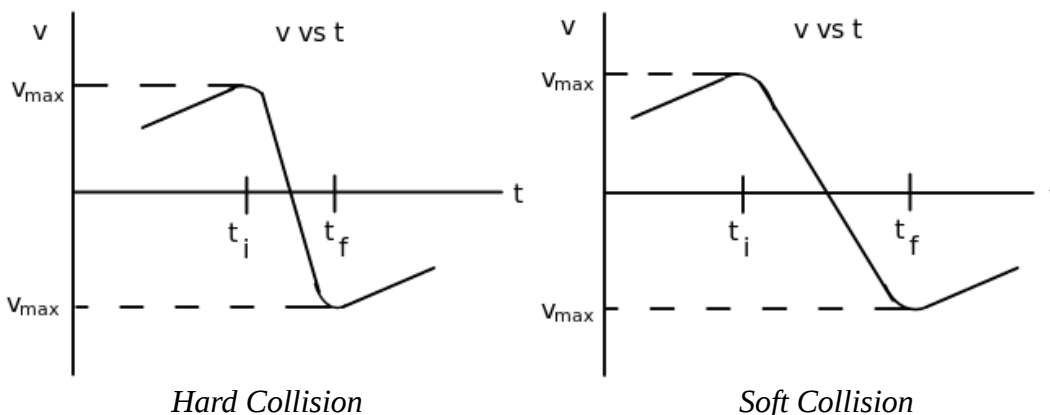
To analyze how different types of collisions affect Force and Duration of a collision, as well as to show that both hard and soft collisions have the same Impulse.

# Equipment

Collision Cart	Force Sensor
Track	Motion Sensor
Balance	Accessory Bracket

# Lab Notes

In this lab, you will allow the collision cart to travel down an inclined track to collide with a spring/bumper attached to a Force sensor. This sensor will record the forces throughout the collision so they can be graphed. They should look like the graphs from the introduction, but may be negative. A motion sensor will record the position of the cart to find its velocity throughout the run, the same way it did during the 'Uniformly Accelerated Motion in 2D' lab already completed. The Velocity vs. Time graphs should look like the following:



Note that the time of collision change is reflected in these graphs as well. Furthermore, there are a few points in the graph to consider:

1. Velocity will initially increase as it moves down the track due to gravitational acceleration.
2. It peaks at  $v_{max}$  at the point of initial contact with the spring/bumper.
3. As the cart compresses the spring/bumper, the cart's velocity is slowed by the restoring force of the spring/bumper.
4. The spring/bumper is fully compressed when  $v = 0$ . It is here that the cart changes direction and thus, there is a sign change.
5. Velocity will increase in the negative direction due to the restoring force of the spring/bumper until  $-v_{max}$ , the point at which the cart leaves contact with the spring/bumper.
6. Then, the velocity will slow due as the cart moves back up the track due to gravitational acceleration.

# Setup

## Collision System

1. The track needs to be set at an incline with the Motion Sensor at the top and force sensor at the bottom. However, it is critical that this incline is *not* very steep. Keep it less than 10cm. This will prevent full compression of the soft spring such that it collides with the force sensor. This will cause a large spike at max force in the force vs. time graph and you will have to redo.
2. You will be causing 3 types of collisions: soft, hard and extra hard, using the thin spring, thick spring and bumper, respectively. These are screwed into the accessory bracket near the force sensor.
3. For each type of collision, unscrew the spring/bumper from the bracket and screw into the front of the force sensor. If there is a spring/bumper already in the force sensor, unscrew it and return to the bracket.

## Computer

1. Log in, open Capstone, then click 'Hardware Setup':



2. Click the Digital Channel 1 button on the interface picture and add 'Motion Sensor'. Set the frequency to 50 hz.
3. Click the Analog Channel A button on the interface picture and add 'Force Sensor'. Set the frequency to 200 hz.

4. Click the 'Data Summary' tab:



1. Click 'Velocity' to highlight, then click the Gear icon to the right of it.
2. Click 'Numerical Format' and change the 'Number of Decimal Places' to 3, then click 'Ok'.
3. Repeat for 'Force'.



5. Click 'Graph' on the right hand pane and drag it into the center of the workspace. Do this again to show 2 graphs, side by side.






6. For one graph, click 'Select Measurement' on the y-axis and choose 'Force'. You should now have a Force vs. Time graph.
7. For the other graph, click 'Select Measurement' on the y-axis and choose 'Velocity'. You should now have a Velocity vs. Time graph.

## Helpful Hints:

1. Ensure track height is less than 10 cm.
  2. Ensure track is clear of debris such as eraser shavings and etc.
  3. Start the cart at least 20 cm away from the Motion Sensor
  4. It is critical that you start the cart at the *same* point for *every* run! You must redo if you don't.
  5. Depending upon the Force sensor's directionality, your force graph may be negative.
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# Procedure

## Objective 1: Soft Collision, Thin Spring

1. Use the balance to find the mass of the collision cart and record its value in the table.
2. Install the thin spring.
3. TARE the Force Sensor.
4. Place the cart at the top of the incline about 20 cm away from the Motion Sensor.
5. **Make a note of where you have the cart, you must start from this position every time!**
6. Start recording
  1. Verify that the Force vs. Time graph is at zero.
  2. If not, stop recording, tare again then start recording. If it will not zero, contact your TA.
7. Release cart. The motion will be displayed on the graphs.
8. Stop recording after the collision.
  1. Both graphs should have smooth progressions. If they don't, check track for debris, check motion sensor eye alignment and redo the run.
  2. \* If the Force vs Time graph has a large spike at the max point, the spring bottomed out on the force sensor. Repeat the run from a position closer to the force sensor (or lower the incline of the track). Then use this position for all remaining runs. \*
9. On the Force vs. Time graph:
  1. Click the area icon  to display the area under the curve. Record this value in the data table.
  2. Click the 'Statistics'  button. Click the drop down arrow next to it and check 'Maximum' to obtain  $F_{\max}$ . Record this value in the data table.
  3. Click the 'Coordinates' button to access the Delta tool. 
    - a) Drag the coordinates box to  $t_i$ , the first point where F deviates from zero.
    - b) Right click inside the coordinates box and click 'Show Delta'; another coordinate will appear. Click inside this 2<sup>nd</sup> box and drag it to  $t_f$ , the last point F deviates from zero.
    - c) Record  $\Delta t$  in the data table.
  4. Calculate Impulse from  $F_{\max}$  and  $\Delta t$ .
10. On the Velocity vs. Time graph:
  1. Click the 'Statistics' button. Click the drop down arrow next to it and check 'Maximum' and 'Minimum' obtain  $V_{\max}$  (before collision) and  $V_{\min}$  (which is  $V_{\max}$ , after collision) Record these values in the data table.
  2. Calculate the momentum before and after collision, as well as  $\Delta p$ .

## Objective 2: Hard Collision, Thick Spring

11. Repeat the procedure as outlined above using the thick spring.

## Objective 3: Harder Collision, Bumper

12. Repeat the procedure as outlined above using the bumper.
  13. For Force and Velocity graphs: combine your 3 runs on the same graph and save a copy (print screen or snippet) to turn in with your lab report.
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## Data

	<b>Soft Collision Thin Spring</b>	<b>Hard Collision Thick Spring</b>	<b>Hard Collision Bumper</b>
<b>Mass of Cart (kg)</b>			
<b>Impulse (Ns) (area under the curve)</b>			
<b>F<sub>max</sub> (N)</b>			
<b>Duration (<math>\Delta t</math>) (s)</b>			
<b>Impulse (calculated) (Ns)</b>			
<b>V<sub>max</sub> (m/s) before Collision</b>			
<b>V<sub>max</sub> (m/s) after Collision</b>			
<b>Momentum (p)(kgm/s) before Collision</b>			
<b>Momentum (p)(kgm/s) after Collision</b>			
<b>Change in Momentum (<math>\Delta p</math>)(kgm/s)</b>			

## Analysis

1. Label each run on your saved Force and Velocity graphs and turn in with your lab report.
2. Explain why you must start the cart from the same position on the track for every run.
  
3. Explain why the cart's acceleration would be the same for each run.

4. How does  $F_{\max}$  and  $\Delta t$  change with each run?

5.

(a) How does impulse ( $\Delta p$ ) change with each run?

(b) Explain possible reasons why they would be different.

6. Why is the Impulse from integration different from the calculated Impulse?

7.

(a) Compare  $\Delta p$  to Impulse (from integration) using percent difference.

(b) Explain possible reasons why they would be different.

8. Use the knowledge you gained from this lab to make a physical argument (ie. explain in terms of Impulse, Force and  $\Delta t$ ) as to why airbags in cars can help to prevent injuries to occupants during a collision.