Teacher's Guide - Activity P11: Collision – Impulse and Momentum (Force Sensor, Motion Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Newton's Laws	P11 Impulse.DS	P14 Collision	P14_COLL.SWS

Equipment Needed	Qty	Equipment Needed	Qty
Economy Force Sensor (CI-6746)	1	Balance (SE-8707)	1
Motion Sensor (CI-6742)	1	Collision Cart (ME-9454)	1
Accessory Bracket (CI-6545)	1	2.2 m Track System (ME-9452)	1

What Do You Think?

How is the force felt during a collision related to the duration of the collision?

Take time to answer the 'What Do You Think?' question(s) in the Lab Report section.
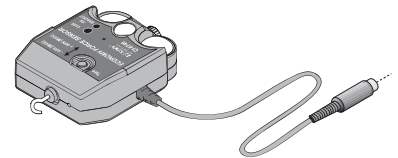
Background

When an object strikes a barrier, the force on the object varies as the collision occurs. Changes in the momentum of the object (the *impulse*) can be calculated in two ways:

•   Using the velocities before (v_i) and after (v_f) the collision:

$$\Delta p = m\,v_f - m\,v_i$$

•   Using the net force and time of impact: $\Delta p = \int F\,dt = F_{net}\,\Delta t$

It is possible for the object to undergo the same change in momentum whether it is involved in an abrupt hard collision or a cushioned collision. We want to determine the difference between how a hard or soft collision affects the force felt by the object.

SAFETY REMINDER

•   Follow the directions for using the equipment.

THINK SAFETY
ACT SAFELY
BE SAFE!

For You To Do

Use the Motion Sensor to measure the motion of a cart as it collides with a bumper. Use a Force Sensor mounted on the track to measure the force of the collision over the same interval of time. Use *DataStudio or ScienceWorkshop* to compare the change in momentum of the cart with the integral of the measured force vs. time graph.

PART I: Computer Setup

1.   Connect the *ScienceWorkshop* interface to the computer, turn on the interface, and turn on the computer.

2.   Connect the Motion Sensor's phone plugs to Digital Channels 1 and 2 on the interface. Plug the yellow-banded (pulse) plug into Digital Channel 1 and the second plug (echo) into Digital Channel 2.

3.   Connect the DIN plug of the Force Sensor to Analog Channel A.

4.   Open the document titled as shown:
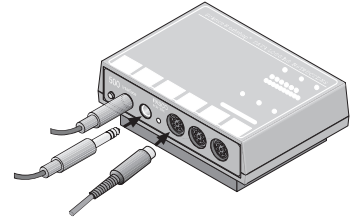
DataStudio	ScienceWorkshop (Mac)	ScienceWorkshop (Win)
P11 Impulse.DS	P14 Collision	P14_COLL.SWS

•   The *DataStudio* document has a Workbook display. Read the instructions in the Workbook.

•   The *ScienceWorkshop* document has a Graph display with Force versus Time and Velocity versus Time.

•   Data recording is set for 500 samples per second (500 Hz) for the Force Sensor.

5.   Set the Trigger Rate for the Motion Sensor to 50 Hz.

•   In *DataStudio*, double-click the Motion Sensor icon in the Experiment Setup window. **Result**: The Sensor Properties window opens. Click the 'Motion Sensor' tab. Select '50' from the Trigger Rate menu. Click 'OK' to return to the Experiment Setup window.
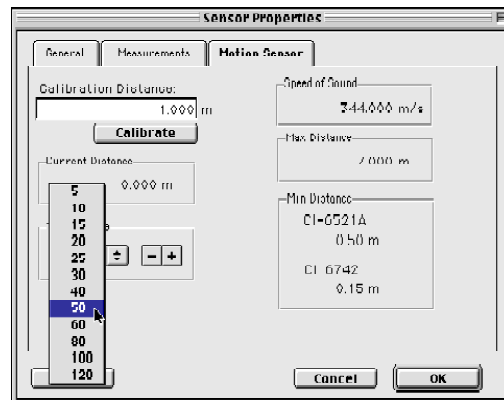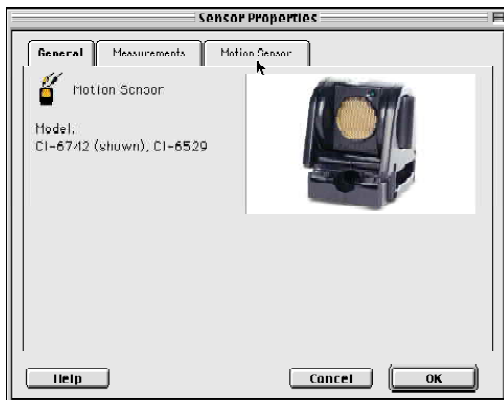
•   In *ScienceWorkshop*, double-click the Motion Sensor icon in the Experiment Setup window. **Result**: The Motion Sensor setup window opens. Select '50' from the Trigger Rate menu. Click 'OK' to return to the Experiment Setup window.
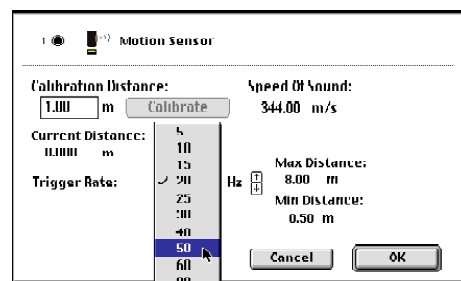
PART II: Sensor Calibration and Equipment Setup

- You do not need to calibrate the Motion Sensor.

- To calibrate the Force Sensor, refer to the tutorial in the introduction of this manual.

1. Place the Dynamics Track on a horizontal surface.

2. Mount the Economy Force Sensor on the Accessory Bracket. Mount the Accessory Bracket in the T-slot on the side of the Dynamics Track.

3. Use a book or other method to raise the end of the Dynamics Track that is opposite to the end with the Force Sensor about 1.5 cm so the cart will have approximately the same speed for each trial.

4. Place the Motion Sensor at the raised end of the Dynamics Track so it can measure the motion of the cart. Put a mark on the Dynamics Track at least the minimum distance away from the Motion Sensor. For all trials start the cart at this place.

5. Brace the Force Sensor end of the Dynamics Track against a heavy mass so the Dynamics Track will not move during the collision.

6. Measure the mass of the cart. Record the mass value in the Data Table in the Lab Report section.

7. Unscrew the hook attachment from the front of the Force Sensor. In its place, put the magnetic bumper from the Accessory Bracket with Bumpers.
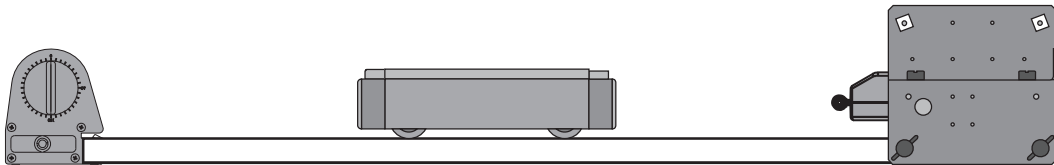
PART III: Data Recording

1. Prior to each data run, press the tare button on the side of the Force Sensor to zero the sensor.

2. Place the cart on the Dynamics Track at the starting mark made during setup.

3. Release the cart so that it rolls toward the Force Sensor. Begin data recording.

4. End data recording after the cart has rebounded from the collision with the Force Sensor's magnetic bumper.
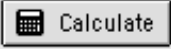
- The data will appear as Run #1.

Analyzing the Data

1. Zoom in about the peak in the force vs. time plot.

•   In the Graph display, click on the zoom button (). While holding down on the mouse button, move the cursor to draw a rectangle around the peak in the force vs. time plot. Make sure that the entire peak is in the rectangle. **Result**: The points will be highlighted. Release the mouse button and the Graph axes will rescale to zoom in about the region.

2. Select the region in the graph window that corresponds to the collision.

•   Hold down on the mouse button and move the cursor to draw a rectangle around the region of the force vs. time plot that shows the collision. Release the mouse button, and the area will be highlighted.

3. Integrate to find the area under the curve.

•   In *DataStudio*, click the 'Statistics' menu button () and select 'Area'.

•   In *ScienceWorkshop*, click the Statistics button () to open the Statistics area on the right side of the graph. In the Statistics area, click the 'Statistics Menu' button () and select 'Integration'.

4. Record the value of the area under the curve in the Data Table in the Lab Report section.

5. Find the velocity just before the collision and the velocity just after the collision from the velocity versus time plot.

•   In *DataStudio*, select the velocity window. Click the 'Smart Tool' button () and move the Smart Tool to the velocity data points. If needed, zoom in about the region during which the collision took place using the zoom tool.

•   In *ScienceWorkshop*, click the 'Smart Cursor' () and move the Smart Cursor to the velocity data points. If needed, zoom in about the region during which the collision took place using the zoom tool.

6. Record the two velocity values in the Data Table in the Lab Report section.

7. Use the mass and velocity values to compute the momenta before and after the collision.
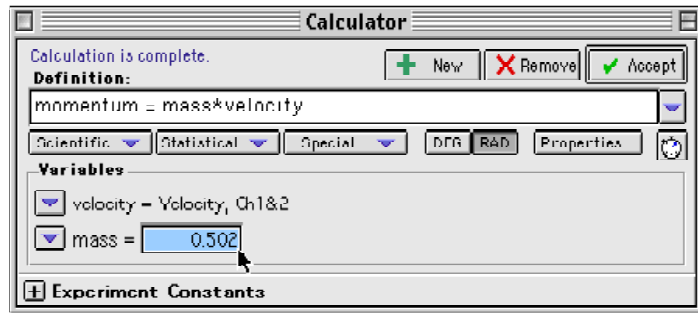
Record your results in the Lab Report section.

Optional

1.   Use the Calculator to make a calculation for linear momentum with units of kg m/sec.

•   In *DataStudio*, click the 'Calculate' button (🔲 Calculate) in the main toolbar.

    The Calculator window will open. The window shows the calculation for Momentum that was created as part of this activity.

    If the mass value for your cart is different than 0.502 kg, highlight the "0.502" in the 'mass' window and type in the mass of your cart.

    Click the 'Accept' button to save your change.

    Close the Experiment Calculator window. Display the momentum calculation by dragging a Graph display icon to the calculator.

•   In *ScienceWorkshop*, to create a calculation for momentum, click the Calculator button

    (🔲) in the Experiment Setup window.

    The Experiment Calculator window will open.

    Enter the mass of the cart and then '*' for multiplication.

    From the Input menu select Digital 1, Velocity.

    Enter a Calculation Name, Short Name, and Units.
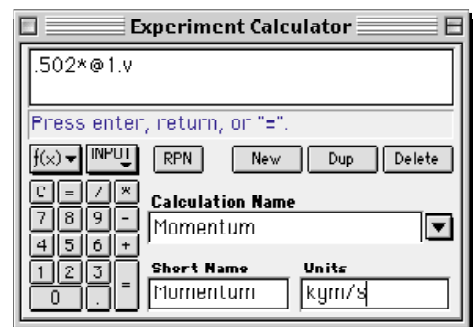
    Click the **equals** button (🔲) or press <ENTER> or <RETURN> on the keyboard.

    Close the Experiment Calculator window. Display the momentum calculation in the Graph display by selecting Calculations from the Data Input menu.

Lab Report - Activity P11: Collision – Impulse and Momentum

What Do You Think?

How is the force felt during a collision related to the duration of the collision?

Assuming that the change in velocity is the same for both collisions, if a collision takes more time, the force felt should be less since change in momentum = F_{net} change in time.

Data Table

Item	Value
Mass of cart	0.494 kg
Impulse (from integration)	0.3715 N*s
Velocity before collision	0.4116 m/s
Velocity after collision	-0.3867 m/s
Momentum before collision	0.2033 kg m/s
Momentum after collision	-0.1910 kg m/s
Change in momentum	0.3944 kg m/s

Questions

1. Why is it desirable to have the same initial speed for each data run?

The impulse, Δp, depends on v_i and v_f. If v_i remains constant, it is easier to observe similarities and differences in net force and Δt for the various trials.

2. How will raising the end of the Dynamics Track give the cart the same acceleration each time?

The acceleration, change in speed divided by change in time, of the cart is the same because the horizontal component of the force due to gravity that accelerates the cart down the track is the same for a given angle of track elevation.

3. For your data, how does the change in momentum compare to the impulse?

Answers will vary. For the example above, the change in momentum is slightly greater than the impulse. (a percentage difference of 5.8%).

4. What are possible reasons why the change in momentum is different from the measured impulse?

Answers will vary. The force exerted on the cart during the collision is not the only force that acts on the cart. There is a small amount of friction that will also change the momentum of the cart as it moves along the Dynamics Track.

5.   Compare the impulse and force for an abrupt (hard) and a cushioned (soft) collision. Use words and also sketch the force vs. time graphs.

The force vs. time plot for a softer collision will appear more spread out in time with a lower net force, while an abrupt collision will result in a force vs. time peak that is narrow in time and high in net force. If the change in momentum is the same for two different types of collisions, the areas under the force vs. time curves will be the same.

6.   Use the above comparison to explain why airbags in cars can help to prevent injuries to the occupants during a frontal collision.

In a collision, the change in momentum will be the same with or without airbags for example from 30 mph to zero in some amount of time. An airbag can lengthen the time of impact for the passenger, reducing the forces on the occupants of the car, and hopefully reducing injury.

Time Estimates	Preparation: 30 min	Activity: 50 min

Objectives

Students will be able to…

- use the Force Sensor to measure the force during a collision

- use the Motion Sensor to measure the motion of a cart during a collision

- use the Graph display to determine the area under the curve of force versus time

- compare the change in momentum to the integral of force vs. time

Notes

1. Make sure that the 'impact' end of the Dynamics Track is firmly braced so it will not slide during the collision. Make sure that the Force Sensor is securely fastened to the bracket, and the bracket is firmly mounted to the Dynamics Track.

2. Don't raise the Motion Sensor end of the Dynamics Track too high. The faster the cart moves, the more likely that it may move to one side or the other during the collision. A smooth but slow collision is better than a fast, jerky one.

3. Remind the students about the minimum distance between the cart and the Motion Sensor. The minimum distance is dependent upon the motion sensor used. Refer to the information in your Motion Sensor manual.

4. If you do not have the Accessory Bracket with Bumpers, the experiment can still be performed. Leave the hook on the Force Sensor. Cut a small slit in a rubber stopper, and place the rubber stopper over the hook. Mount the Force Sensor to the cart and create a barrier at the end of the track for the stopper to hit. Make sure that only the stopper comes into contact with the barrier.

5. If you do not have the Motion Sensor, Photogates or the Rotary Motion Sensor can be used to measure the initial and final velocity of the cart.

6. If velocity data does not correspond well to the Force Sensor data, increase the trigger rate for the Motion Sensor. Double click on the Motion Sensor icon in the Experiment Setup window to access the trigger rate.

Optional

- Add additional mass to the cart. Remember to measure and use the new mass value for the momentum calculations.

- Replace the magnetic bumper with one of the spring bumpers or with the "no-bounce" rubber bumper. Compare the force vs. time graphs.

- Try an inelastic collision. Put the clay holder on the front of the Force Sensor. Mold a small amount of soft clay onto the clay holder so that the cart will stop when it collides with the clay.

- Remove the Force Sensor from the bracket and mount the Force Sensor on top of the cart. Turn the bracket around so that the end of the Force Sensor can collide with the end stop on the force sensor bracket. Repeat the experiments, with the Force Sensor on the cart instead of on the bracket.

DataStudio Sample Data

Note: DataStudio and ScienceWorkshop results were obtained during separate data runs and can not be compared to each other.

In the following example, the area under the force versus time curve is 0.37 N*s. The velocity before the collision is 0.195 m/s. The velocity after the collision is –0.177 m/s.
Note that the time axes are not the same for the force and velocity graphs.
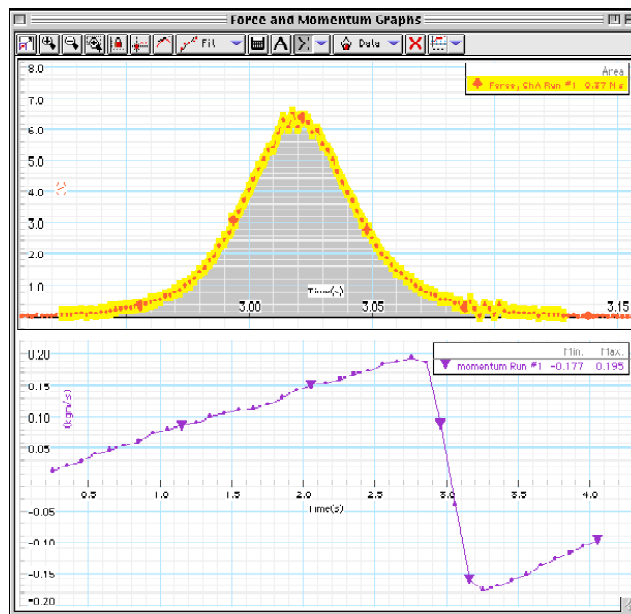
ScienceWorkshop Sample Data

In the following example, the area under the force versus time curve is 0.37 N*s. The velocity before the collision is 0.203 m/s. The velocity after the collision is –0.191 m/s.