Impulse and Momentum (Motion Detector)

The impulse-momentum theorem relates impulse, the average force applied to an object times the length of time the force is applied, and the change in momentum of the object:

$$\overline{F}\Delta t = mv_f - mv_i$$

Here, we will only consider motion and forces along a single line. The average force, $\overline{F}$, is the *net* force on the object, but in the case where one force dominates all others, it is sufficient to use only the large force in calculations and analysis.

For this experiment, a Dynamics Cart will roll along a level track. Its momentum will change as it collides with a hoop spring. The hoop will compress and apply an increasing force until the cart stops. The cart then changes direction and the hoop expands back to its original shape. The force applied by the spring is measured by a Dual-Range Force Sensor. The cart velocity throughout the motion is measured with a Motion Detector. You will then use data-collection software to find the impulse to test the impulse-momentum theorem.

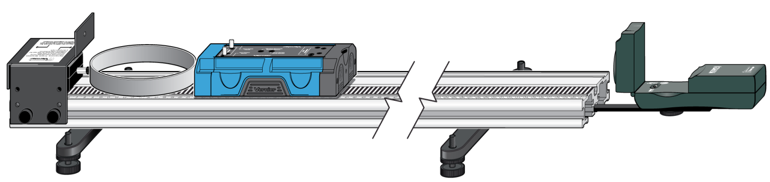


Figure 1

OBJECTIVES

- Measure a cart's momentum change and compare it to the impulse it receives.
- Compare average and peak forces in impulses.

MATERIALS

LabQuest
LabQuest App
Vernier Motion Detector
Vernier Dual-Range Force Sensor
Vernier Dynamics Track
Vernier Dynamics Cart
Vernier Bumper and Launcher Kit
Motion Detector Bracket

PRELIMINARY QUESTIONS

1. In a car collision, the driver's body must change speed from a high value to zero. This is true whether or not an airbag is used, so why use an airbag? How does it reduce injuries?

2. Two playground balls, the type used in the game of dodgeball, are inflated to different levels. One is fully inflated and the other is flat. Which one would you rather be hit with? Why?

PROCEDURE

1. Measure the mass of the cart and record the value in the data table.

2. Attach the Motion Detector and bracket to one end of the Dynamics Track (see Figure 1).

3. Set the range switch on the Dual-Range Force Sensor to 10 N. Replace the hook end of the Dual-Range Force Sensor with the hoop spring bumper. Attach the Dual-Range Force Sensor to the bumper launcher assembly as shown in Figure 2. Then attach the bumper launcher assembly to the end of the track opposite the Motion Detector.

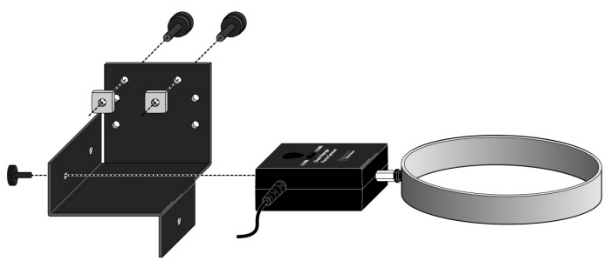
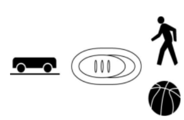


Figure 2 Connect the Dual-Range Force Sensor to the bumper launcher assembly.
***Note**: Shown inverted from how the sensor and assembly are attached to the track.*

4. Place the track on a level surface. Confirm that the track is level by placing the low-friction cart on the track and releasing it from rest. It should not roll. If necessary, adjust the track to level it.

5. Connect the Dual-Range Force Sensor to LabQuest. Set the Motion Detector sensitivity switch to Track. Connect the Motion Detector to a digital (DIG) port of LabQuest. Choose New from the File menu.



6. Zero the Dual-Range Force Sensor and then reverse its sign.
   a. Remove all force from the Dual-Range Force Sensor.
   b. Choose Zero ► Force from the Sensors menu.

   c. Choose Reverse ► Force from the Sensors menu to change the sign. Reversing the sign sets up the sensor so force readings are positive when there is an impact.

7. On the Meter screen, tap Rate. Change the data-collection rate to 250 samples/second and the data-collection duration to 5 seconds. Select OK.

Part I Elastic collisions

8. Practice releasing the cart so it rolls toward the hoop spring, bounces gently, and returns to your hand. The Dual-Range Force Sensor must not shift, and the cart must stay on the track. Keep your hands away from the space between the cart and the Motion Detector.

9. Position the cart so that the front of the cart is approximately 50 cm from the spring. Start data collection, then roll the cart as you practiced in the previous step.

10. Study your graphs to determine if the run was useful.
    a. Inspect the force data. If the peak exceeds 10 N, then the applied force is too large. Roll the cart with a lower initial speed.
    b. Confirm that the Motion Detector detects the cart throughout its travel and that you can see a region of constant velocity before and after the impact. If necessary, repeat data collection.

11. Once you have made a run with good position, velocity, and force graphs, analyze your data. To test the impulse-momentum theorem, you need the velocity before and after the impulse. To find these values, work with the graph of velocity *vs.* time.
    a. Change the y-axis of the position graph to Velocity.
    b. Tap and drag to select an interval corresponding to a time before the impulse, when the cart was moving at approximately constant speed toward the Dual-Range Force Sensor.
    c. Choose Statistics ► Velocity from the Analyze menu. Read the average velocity before the collision (v_i) and record the value in the data table.
    d. Choose Statistics ► Velocity from the Analyze menu to turn off statistics.
    e. Repeat parts a–c of this step to determine the average velocity just after the impulse, when the cart was moving at approximately constant speed away from the Dual-Range Force Sensor. Record this value in the data table.

12. Now you will calculate the value of the impulse. Use the first method if you have studied calculus and the second if you have not.

    Method 1 Calculus version

    Calculus tells us that the expression for the impulse is equivalent to the integral of the force *vs.* time graph, or

$$\overline{F}\Delta t = \int_{t_{initial}}^{t_{final}} F(t)\,dt$$

Calculate the integral of the impulse on your force *vs.* time graph.

a. Tap and drag across the region that represents the impulse (begin at the point where the force becomes non-zero).

b. Choose Integral ► Force from the Analyze menu.

c. Read the value of the integral of the force data, the impulse value, and record the value in the data table.

Method 2 Non-calculus version

Calculate the impulse from the average force on your force *vs.* time graph. The impulse is the product of the average (mean) force and the length of time that force was applied, or $\overline{F}\Delta t$.

a. Tap and drag across the region that represents the impulse (begin at the point where the force becomes non-zero).

b. Choose Statistics from the Analyze menu.

c. Record the value for the average (mean) force in the data table.

d. Read the duration of the time interval. To determine this value, note the number of points used in the average (N), and multiply by 0.004 s, the time interval between points. Record this product, Δt, in your data table.

e. From the average force and time interval, determine the impulse, $\overline{F}\Delta t$, and record this value in your data table.

13. Repeat Steps 9–12 two more times to collect a total of three trials; record the information in your data table.

Part II Inelastic collisions

14. Replace the hoop spring bumper with one of the clay holders from the Bumper and Launcher Kit. Attach cone-shaped pieces of clay to both the clay holder and to the front of the cart, as shown in Figure 3.

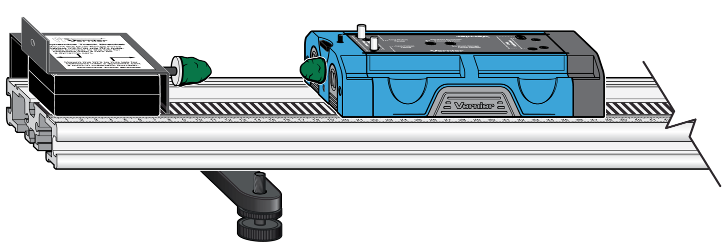


Figure 3

15. Remove all force from the Dual-Range Force Sensor and then choose Zero ► Force from the Sensors menu to zero the Dual-Range Force Sensor.

16. Practice launching the cart with your finger so that when the clay on the front of the cart collides with the clay on the Dual-Range Force Sensor, the cart comes to a stop without bouncing.

17. Position the cart so that the front of the cart is approximately 50 cm from the spring. Start data collection, then roll the cart so that the clay pieces impact one another.

18. Study your graphs to determine if the run was useful.
    a. Inspect the force data. If the peak exceeds 10 N, then the applied force is too large. Reshape the clay pieces and roll the cart with a lower initial speed.
    b. Confirm that the Motion Detector detects the cart throughout its travel and that you can see a region of constant velocity before and after the impact. If necessary, reshape the clay pieces and repeat data collection.

19. Once you have made a run with good position, velocity, and force graphs, analyze your data. To test the impulse-momentum theorem, you need the velocity before and after the impulse.
    a. Change the y-axis of the position graph to Velocity.
    b. Select the interval corresponding to the time before the impact, and choose Statistics ► Velocity from the Analyze menu. Record the average velocity in the data table.
    c. Choose Statistics ► Velocity from the Analyze menu to turn off statistics.
    d. Select the interval corresponding to the time after the impact, and choose Statistics ► Velocity from the Analyze menu. Record the average velocity in the data table.

20. Now you will calculate the value of the impulse. Similar to Step 12, use the first method if you have studied calculus and the second if you have not.

    Method 1 Calculus version

    Calculate the integral of the impulse on your force *vs.* time graph.

    a. Tap and drag across the impulse, then choose Integral ► Force from the Analyze menu.
    b. Record the impulse value in the data table.

    Method 2 Non-calculus version

    Calculate the impulse from the average force on your force *vs.* time graph.

    a. Select the impulse, choose Statistics from the Analyze menu and record the average force in the data table.
    b. Read the length of the time interval. To determine this value, note the number of points used in the average (N), and multiply by 0.004 s, the time interval between points. Record this product, Δt, in your data table.
    c. From the average force and time interval, determine the impulse, $\overline{F}\Delta t$, and record this value in your data table.

21. Repeat Steps 17–20 two more times to collect a total of three trials; record the information in your data table. **Note**: You will need to reshape the clay pieces before each trial.

DATA TABLE

Mass of cart	kg

Method 1 Calculus version						
Trial	Final velocity v_f (m/s)	Initial velocity v_i (m/s)	Change of velocity Δv (m/s)	Impulse (N·s)	Change in momentum (kg·m /s) or (N·s)	% difference between Impulse and Change in momentum
Elastic 1						
2						
3						
Inelastic 1						
2						
3						

Method 2 Non-calculus version								
Trial	Final velocity v_f (m/s)	Initial velocity v_i (m/s)	Change of velocity Δv (m/s)	Average force $\overline{F}$ (N)	Duration of impulse Δt (s)	Impulse $\overline{F}\Delta t$ (N·s)	Change in momentum (kg·m /s) or (N·s)	% difference between Impulse and Change in momentum
Elastic 1								
2								
3								
Inelastic 1								
2								
3								

ANALYSIS

1. Calculate the change in velocities and record the result in the data table. From the mass of the cart and the change in velocity, determine the change in momentum that results from the impulse. Make this calculation for each trial and enter the values in the data table.

2. If the impulse-momentum theorem is correct, the change in momentum will equal the impulse for each trial. Experimental measurement errors, along with friction and shifting of the track or Dual-Range Force Sensor, will keep the two from being exactly the same. One way to compare the two is to find their percentage difference. Divide the difference between the two values by the average of the two, then multiply by 100%. How close are your values, percentage-wise? Do your data support the impulse-momentum theorem?

3. Look at the shape of the last force *vs.* time graph. Is the peak value of the force significantly different from the average force? Is there a way you could deliver the same impulse with a much smaller force?

4. Revisit your answers to the Preliminary Questions in light of your work with the impulse-momentum theorem.

EXTENSION

The Bumper and Launcher Kit includes two different hoop springs, with one stiffer than the other. Repeat your experiment with the spring you have not yet used. Predict how the results will be similar and how they will be different.