

Impulse and Momentum

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:

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

For this experiment, a dynamics cart will roll along a level track. Its momentum will change as it reaches the end of an initially slack elastic tether cord, much like a horizontal bungee jump. The tether will stretch and apply an increasing force until the cart stops. The cart then changes direction and the tether will soon go slack. The force applied by the cord is measured by a Force Sensor. The cart velocity throughout the motion is measured with a Motion Detector. Using LabQuest to find the average force during a time interval, you can test the impulse-momentum theorem.

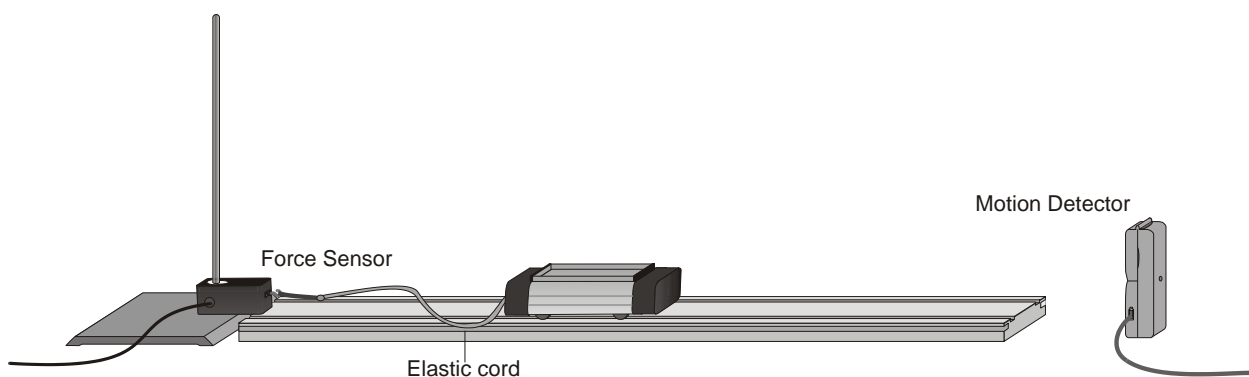


Figure 1

OBJECTIVES

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

MATERIALS


LabQuest	clamp
LabQuest App	elastic cord
Motion Detector	string
Vernier Force Sensor	500 g mass
dynamics cart and track	

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. You want to close an open door by throwing either a 400 g lump of clay or a 400 g rubber ball toward it. You can throw either object with the same speed, but they are different in that the rubber ball bounces off the door while the clay just sticks to the door. Which projectile will apply the larger impulse to the door and be more likely to close it?

PROCEDURE

1. Measure the mass of your dynamics cart and record the value in the data table.
 2. 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.
 3. Attach the elastic cord to the cart and then the cord to the string. Tie the string to the Force Sensor a short distance away. Choose a string length so that the cart can roll freely with the cord slack for most of the track length, but be stopped by the cord before it reaches the end of the track. Clamp the Force Sensor so that the string and cord, when taut, are horizontal and in line with the cart's motion.
 4. Place the Motion Detector beyond the other end of the track so that the detector has a clear view of the cart's motion along the entire track length.
 5. Set the range switch on the Force Sensor to 10 N. Connect the Force Sensor to LabQuest. Set the Motion Detector switch to Track. Connect the Motion Detector to DIG 1 of LabQuest.
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6. Zero the Force Sensor.
 7. On the Meter screen, tap Rate. Change the data-collection rate to 50 samples/second and the data-collection length to 3 seconds. Select OK.
 8. Practice releasing the cart so it rolls toward the Motion Detector, bounces gently, and returns to your hand. The Force Sensor must not shift and the cart must stay on the track. Arrange the cord and string so that when they are slack they do not interfere with the cart motion. You may need to guide the string by hand, but be sure that you do not apply any force to the cart or Force Sensor. Keep your hands away from between the cart and the Motion Detector.
 9. 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 is flattened, then the applied force is too large. Repeat data collection with a lower initial speed.
 - b. Confirm that the Motion Detector detected the cart throughout its travel. If there is a noisy or flat spot near the time of closest approach, then the Motion Detector was too close to the cart. Move the Motion Detector away from the cart, and repeat your data collection.
 - c. To repeat data collection, return to Step 9.
 11. Once you have made a run with good position 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 your stylus across the approximately constant- and negative-velocity region before the impulse.
 - 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 bounce (v_f) and record this positive value in the data table.
12. Now select a portion of the force graph to determine the value of the impulse.
- 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. The impulse is the product of the average (mean) force and the length of time that force was applied, or $\overline{F}\Delta t$. Record the value for the average (mean) force in the data table.
 - c. Read the length of the time interval. To determine this value, note the number of points used in the average (N), and multiply by 0.02 s, the time interval between points. Record this product, Δt , in your data table.
13. Perform a second trial by repeating Steps 9–12, and record the information in the data table.
14. Change the elastic material attached to the cart. Use a new material, or attach two elastic bands side by side.
15. Repeat Steps 9–13, recording the information in the data table.

DATA TABLE

Mass of cart	kg
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Trial	Final Velocity v_f (m/s)	Initial Velocity v_i (m/s)	Change of Velocity Δt (m/s)	Average Force F (N)	Duration of Impulse Δt (s)	Impulse (N·s)
Elastic 1						
1						
2						
Elastic 2						
1						
2						

Trial	Impulse $F\Delta t$	Change in momentum	% difference between Impulse and Change in momentum
Elastic 1	(N·s)	(kg·m /s) or (N·s)	(N·s)
1			
2			
Elastic 2			
1			
2			

ANALYSIS

1. Calculate the change in velocities and record in the data table. From the mass of the cart and change in velocity, determine the change in momentum as a result of the impulse. Make this calculation for each trial and enter the values in the second data table.
2. If you used the average force (non-calculus) method, determine the impulse for each trial from the average force and time interval values. Record these values in the data table.
3. 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 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, and then multiply by 100%. How close are your values, percentage-wise? Do your data support the impulse-momentum theorem?
4. 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?
5. Revisit your answers to the Preliminary Questions in light of your work with the impulse-momentum theorem.
6. When you use different elastic materials, what changes occurred in the shapes of the graphs? Is there a correlation between the type of material and the shape?
7. When you used a stiffer or tighter elastic material, what effect did this have on the duration of the impulse? What effect did this have on the maximum size of the force? Can you develop a general rule from these observations?