Experiment

10A

Impulse and Momentum

INTRODUCTION

You are no doubt familiar with everyday uses of the term *momentum*; e.g., a sports team that has begun to exert superiority over an opponent is said to have gained "momentum." However, in physics, this term has a precise definition: momentum, *p*, is the product of the mass and velocity of an object, $p = mv$.

You have learned that a net force is required to change the *velocity* of an object. In this experiment you will examine how the *momentum* of a cart changes as a force acts on it. This will enable you to determine the relationship between force, the length of time the force is applied, and the change in the momentum of the cart.

OBJECTIVES

In this experiment, you will

- Collect force, velocity, and time data as a cart experiences different types of collisions.
- Determine an expression for the change in momentum, Δp, in terms of the force and duration of a collision.

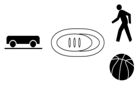
MATERIALS

Vernier data-collection interface	Motion Detector bracket
Logger *Pro* or LabQuest App	Vernier Bumper and Launcher Kit
Vernier Motion Detector	standard cart
Vernier Dual-Range Force Sensor	string
Vernier Dynamics Track	elastic cord (optional)

PRE-LAB 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. Suppose airbags were not vented to allow the gas inside to escape, but remained inflated (like a balloon). Would they be as effective in protecting a passenger in a collision?

PROCEDURE

1. Attach the Motion Detector to the bracket that will allow you to position it near one end of the Dynamics Track.
2. If your motion detector has a switch, set it to Track. 
3. Adjust the leveling screws on the feet as needed to level the track. To make sure the track is level, give the cart a gentle push. It should reach the opposite end of the track without a noticeable change in velocity.
4. Connect the motion detector and the Dual-Range Force Sensor (DFS) to the interface and start the data-collection program. Increase the data-collection rate to 500 samples/second[1]. The duration of the experiment can be reduced to 5 seconds.
5. Make the necessary adjustments so that two graphs: force *vs.* time and velocity *vs*. time appear in the graph window.

Part 1 Elastic collisions

6. Replace the hook end of the force sensor with the hoop spring bumper.[2] Attach the force sensor to the bumper launcher assembly as shown. Then attach the bumper launcher assembly to the end of the track opposite the motion detector.

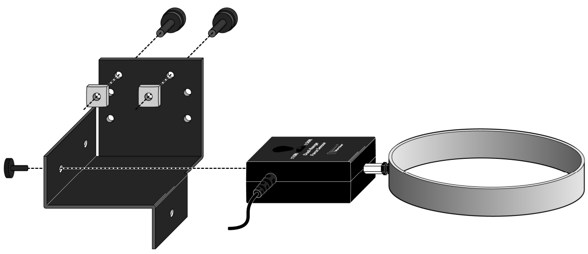


Figure 1

Note: *Shown inverted for assembly.*

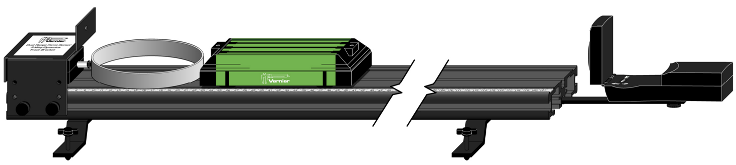


Figure 2

7. Practice launching the cart with your finger so that when it collides with the hoop spring bumper, it slows to a stop and reverses direction smoothly. An abrupt collision will not yield satisfactory data.

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[1] 250 samples/second for LabPro

[2] If this type spring is not available, your instructor will show you how to use an alternate arrangement to collect the data for this experiment.

8. Position the cart at least 20 cm from the motion detector[3], then zero both the motion detector and the force sensor.

9. Start data collection. When you hear the motion detector clicking, launch the cart toward the hoop spring bumper. Be sure to catch the cart once it has returned to its starting position. Because both force and velocity are vector quantities, check to see if the signs of force and velocity match your experimental setup. If necessary, reverse the direction of one or both sensors.

10. Collect data for at least three elastic collisions, varying the mass of the cart. Be sure to store the data for each run.

Part 2 Inelastic collisions

1. 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.

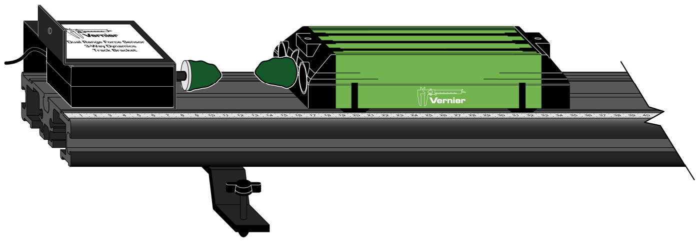

Figure 3

2. Set the switch on the force sensor to the 50 N position; reset the data-collection parameters as you did in Step 4.

3. Practice launching the cart with your finger so that when the clay "nose" on the front of the cart collides with the clay on the force sensor, the cart comes to a stop without bouncing. A collision that is too jarring will not yield satisfactory data.

4. Position the cart at least 20 cm from the motion detector, then zero both the motion detector and the force sensor.

5. Collect data as before for at least three inelastic collisions, varying the mass of the cart. Be sure to store the data for each run.

EVALUATION OF DATA

Part 1 Elastic collisions

1. On the velocity *vs.* time graph, select the interval corresponding to the period of time when the spring was acting on the cart. LabQuest App automatically selects the same interval on both graphs when you drag the stylus across an interval on one of the graphs. However, in Logger *Pro*, you first have to select both graphs and group them (x-axes). Next, turn on the Examine tool for each graph. Then, make the v-t graph the active window and drag the cursor across the appropriate interval.

[3] If you are using an older motion detector without a switch, the cart needs to be at least 45 cm from the detector.

In either program, when you choose Statistics from the Analyze menu, you will have the velocity of the cart just before and just after the collision with the spring.

2. From the mass of the cart and its change in velocity, $v_f - v_i$, determine the change in momentum, Δp, of the cart.

3. As you learned in kinematics, the area under a curve often has physical significance. In the case of the *F-t* graph, the area of the interval you selected is the product of the average force and the time during which the spring was interacting with the cart. You can determine this area by choosing Integral from the Analyze menu. In your class discussion you will give a name to this quantity.

4. Compare the value (both magnitude and sign) of the quantity you determined in Step 3 with the change in momentum of the cart.

5. Perform similar analyses for your remaining elastic collisions. Determine the % difference between the impulse, $F\Delta t$, and the change in momentum, Δp, for each of the collisions. Compare your findings to those of others in your class. What can you conclude about these quantities?

Part 2 Inelastic collisions

1. As you did in Step 1 of Part 1, select the interval corresponding to the period of time from slightly before to slightly after the collision. Due to the shorter duration of this type of collision, you should zoom in on this portion of both graphs. Note any differences in the shape of the *F-t* graph for this type of collision. Try to account for this difference.

2. Because some bouncing is unavoidable, you should discuss how to select an appropriate interval of the *F-t* graph for your determination of the impulse. Assume the final velocity of the cart is zero.

3. As you did with the elastic collisions, determine the % difference between the impulse, $F\Delta t$, and the change in momentum, Δp, for each of the inelastic collisions. Compare your findings to those of others in your class. What can you conclude about these quantities?

4. From Newton's second law, derive the equation you have determined from the analysis of your data. Compare the fundamental units for both impulse and change in momentum.

EXTENSIONS

1. When you catch a fast-moving baseball, it hurts less when your hand "gives" a little than if you hold your hand stiff. Explain why this is so in terms of impulse and change in momentum.

2. Now cars are made to crumple during a collision. Explain how this works in terms of impulse and change in momentum.

3. Suppose you had used a stiffer spring in the experiment. Describe how the shape of the force *vs.* time graph would differ from that which you observed.