Experiment
10B

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	standard cart
Logger *Pro* or LabQuest App	Cart Picket Fence
Vernier Photogate and bracket	string
Vernier Dual-Range Force Sensor	(optional) Vernier Bumper and Launcher Kit
Vernier Dynamics Track	(optional) elastic cord

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 a Photogate to the Dynamics Track using the bracket. Position the photogate about 30 cm from one end of the track[1]. Place the cart picket fence on the cart, as shown in Figure 2.

[1] Locate the photogate so that the cart picket fence has passed completely through the gate before the cart makes contact with the spring.

2. 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.

3. Connect the photogate and the Dual-Range Force Sensor (DFS) to the interface and start the data-collection program.

4. Set up data collection.

   Using Logger *Pro*

   a. Use time-based data-collection mode. Change the data-collection rate to 500 samples/second (250 samples/second if using a LabPro) and the data-collection length to 5 seconds.
   b. Choose Set Up Sensors ►Show All Interfaces from the Experiment menu.
   c. Click the image of the Photogate and choose Gate Timing.

   Using LabQuest as a standalone device

   a. Tap Mode. Select Time Based data collection. Set the data-collection rate to 500 samples/second and the duration to 5 seconds.
   b. In the same mode dialog, scroll down to the Photogate Mode section and expand the section by tapping on the arrow.
   c. Choose Gate Timing. The default flag size of 5 cm is correct.
   d. Select OK to accept these settings.

   With either program, make the necessary adjustments so that two graphs, force *vs.* time and velocity *vs.* time, appear in the graph window.

Part 1 Elastic collisions

5. 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 in Figure 1. Then attach the bumper launcher assembly to the end of the track as shown in Figure 2.

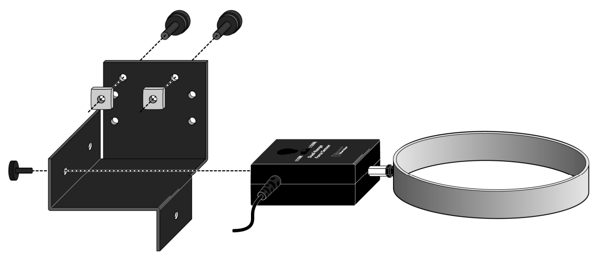

Figure 1

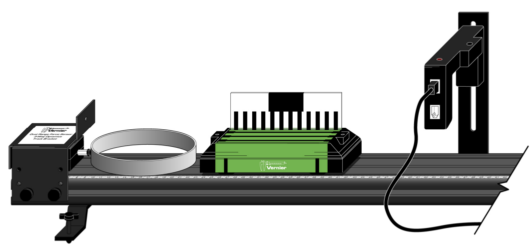

Figure 2

Note: Shown inverted for assembly.

6. 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.

[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.

7. Zero the force sensor. Adjust the position of the photogate so that the 5 cm flag on the picket fence clears the photogate before the cart touches the hoop spring bumper.

8. Start data collection, then launch the cart toward the hoop spring bumper. In LabQuest App, you must stop data collection to see the graphs.

9. 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.

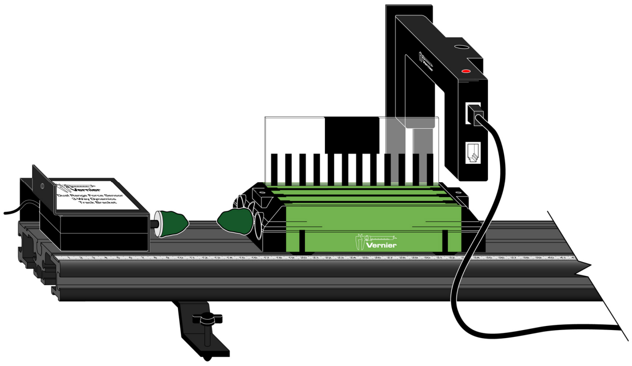

Figure 3

2. 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.

3. Set the switch on the force sensor to the 50 N position, reset the data-collection parameters as you did in Step 4, then re-zero the force sensor. Begin collecting data, then gently launch the cart through the photogate.

4. 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. Re-shape the clay on both the force sensor and the front of the cart after each collision.

EVALUATION OF DATA

Part 1 Elastic collisions

1. In Logger *Pro*, use the Examine tool to determine the initial and final velocities of the cart as it passed through the gate. In LabQuest App, you will see two points on the velocity *vs.* time graph. Select the region of the graph containing these points and choose Statistics from the Analyze menu. The maximum and minimum values are the initial and final velocities.

2. Determine the change in velocity, $v_f - v_i$, of the cart. Keep in mind that one of these values must be negative. From Δv and the mass of the cart, determine its change in momentum, Δp.

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 region corresponding to when the cart was in contact with the spring 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. In Logger *Pro*, use the Examine tool to determine the initial velocity of the cart as it passed through the gate. The final velocity of the cart is zero. In LabQuest App, you will see a single point on the velocity *vs.* time graph. Place the cursor on this point and read the value of the velocity.

2. Assuming the final velocity is zero, determine the change in velocity, $v_f - v_i$, of the cart. From this value and the mass of the cart, determine the change in momentum, Δp, of the cart.

3. 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.

4. 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?

5. 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 in terms of impulse and change in momentum.

2. Now cars are made to crumple during a collision. Explain 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.