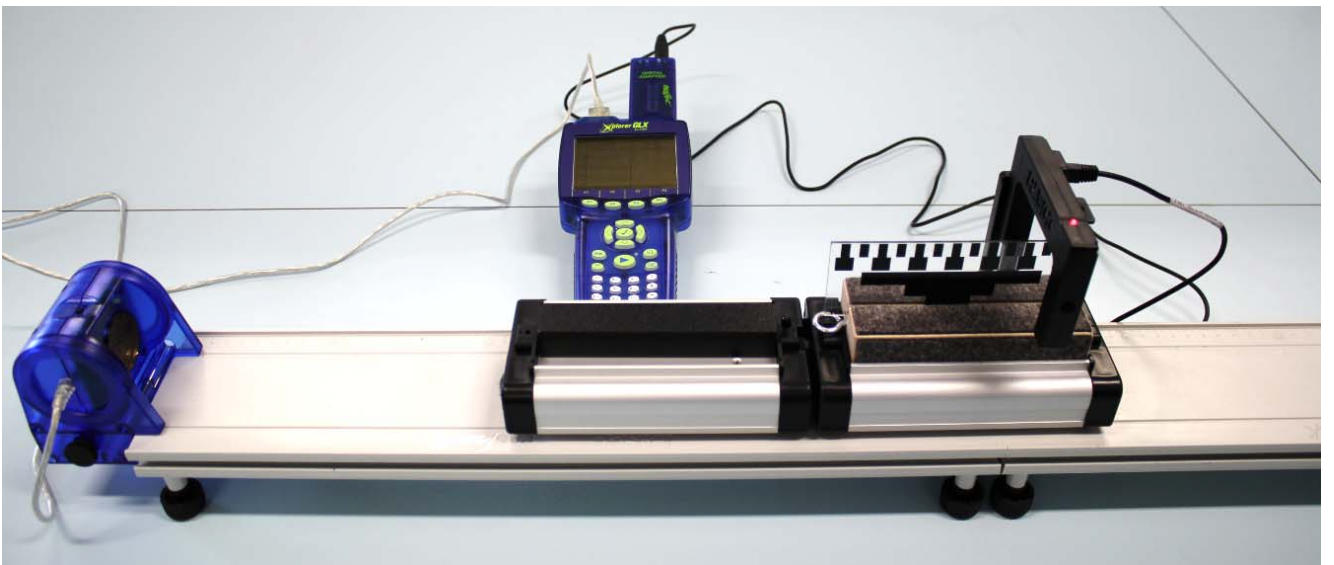


## EXPERIMENT 6

# Impulse and Conservation of Momentum

PREPARED BY PASCO SCIENTIFIC AND JOHN LONG FOR THE UNIT TEAM



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## Aim

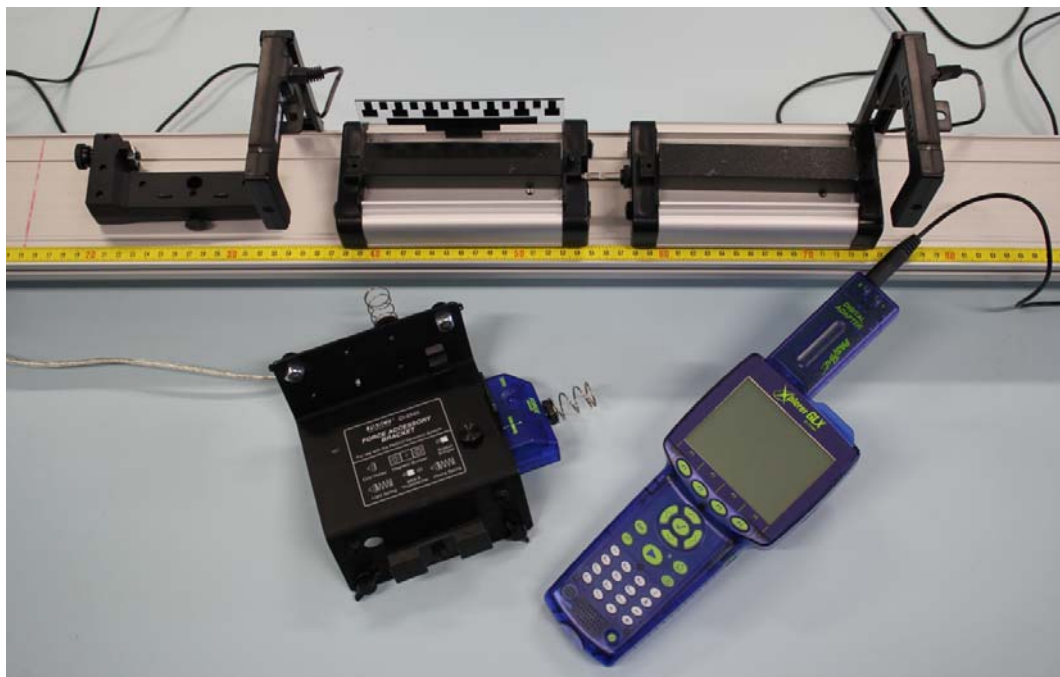
The aim of this experiment is to observe collisions between moving objects and to verify the principles of impulse, conservation of momentum, and conservation of energy.

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## Materials and Equipment

### ***For each student or group:***

- |   |                                   |
|---|-----------------------------------|
| ◆ GLX data logger                         | ◆ Dynamics track                  |
| ◆ Force sensor with bumper                | ◆ Dynamics track rod clamp        |
| ◆ Motion sensor or photogate              | ◆ Force accessory bracket         |
| ◆ Balance, (1 per class), 1200-g capacity | ◆ Large base and support rod      |
| ◆ 2 dynamics carts                        | ◆ Photo-gate and mounting bracket |
| ◆ Digital adaptors                        | ◆ Assorted weights                |



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## Background

First study sections 9-6, 9-7, and 9-9 the text by Halliday, Resnick and Walker.

Vehicle airbags, and the large yellow barrels full of sand called Fitch barriers near highway exits, are credited with saving thousands of lives and reducing injuries to car occupants. Two important physics phenomena that occur during a collision are the change in momentum and the impulse imparted on the vehicle and its occupants.



Left: Fitch barriers on a road. (<http://en.wikipedia.org/wiki/File:FitchBarrels2008.jpg>)

Right: air bags in a car. (<http://ask.cars.com/2011/12/do-all-new-cars-have-airbags.html>)

The change in momentum can be calculated by subtracting the momentum before a collision from the momentum after a collision:

$$\Delta p = mv_f - mv_i \quad (1)$$

Where  $\Delta p$  is the change in momentum,  $m$  is the mass,  $v_f$  is the final velocity, and  $v_i$  is the initial velocity. Remember that momentum and velocity are vectors.

Impulse is equal to the area under a graph of force versus time showing the force associated with the collision. Impulse  $I$  is also related to  $\Delta p$  through the impulse-momentum equation:

$$I = \Delta p = m\Delta v \quad (2)$$

When objects collide, whether locomotives, shopping carts, or your foot and the sidewalk, the results can be complicated. Yet even in the most chaotic of collisions, as long as there are no net external forces acting on the colliding objects, one principle always holds and provides an excellent tool for understanding the dynamics of the collision. That principle is called the conservation of momentum. For a two-object collision, momentum conservation is easily stated mathematically by the following equation.

$$m_1 v_1 + m_2 v_2 = m_1 v_1' + m_2 v_2'$$

In this case,  $m_1$  and  $m_2$  are the masses of the two objects in the collision. The initial speeds are  $v_1$  and  $v_2$ , respectively. The respective final speeds are  $v_1'$  and  $v_2'$ .

If net external forces are ignored, the sum of the momenta of two carts prior to a collision (left side of equation) is the same as the sum of the momenta of the carts after the collision (right side of equation).

**Inelastic collisions:** For two carts in an *inelastic* collision, the momentum after is the product of both masses and their shared velocity. Momentum is conserved, but kinetic energy is not conserved.

$$m_1 v_1 + m_2 v_2 = (m_1 + m_2) v'$$

$v_1$  = initial V Cart 1

$v_2$  = initial V Cart 2

$v'$  = shared V

**Elastic collisions:** For two carts in an *elastic* collision, both momentum and kinetic energy are conserved. Thus,

$$\frac{1}{2} m_1 v_1^2 + \frac{1}{2} m_2 v_2^2 = \frac{1}{2} m_1 (v_1')^2 + \frac{1}{2} m_2 (v_2')^2$$

In the special case where  $m_1$  is moving and  $m_2$  is at rest ( $v_{2i}=0$ ), combining conservation of energy and conservation of momentum leads to

$$v_1' = \frac{m_1 - m_2}{m_1 + m_2} (v_1) \text{ and}$$

$$v_2' = \frac{2m_1}{m_1 + m_2} (v_1).$$

If  $m_1 = m_2$ , then  $v_1' = 0$  and  $v_2' = v_1$ .

### Relevant Equations

$$\Delta p = mv_f - mv_i$$

Impulse = Area under Force versus Time graph

$$I = \Delta p = m\Delta v$$

$$m_1 v_1 + m_2 v_2 = m_1 v_1' + m_2 v_2' = p_{\text{total}}$$

$$\frac{1}{2} m_1 v_1^2 + \frac{1}{2} m_2 v_2^2 = \frac{1}{2} m_1 (v_1')^2 + \frac{1}{2} m_2 (v_2')^2$$

### Safety

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**Add this important safety precaution to your normal laboratory procedures:**

- ♦ Be careful with the carts. Do not let them fall from lab stations.
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## Procedure

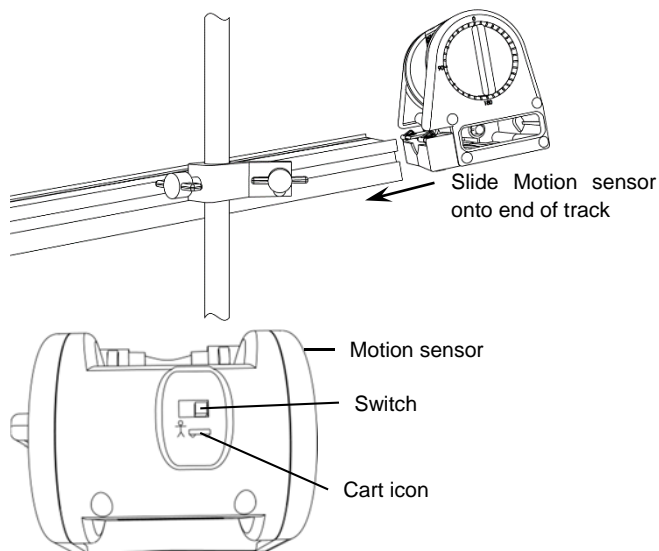
### Part A: Impulse and momentum

#### Set Up

- A1. Attach one end of the dynamics track to the large base and support rod using the dynamics track rod clamp, inclining the track just slightly (approximately  $10^\circ$ ).

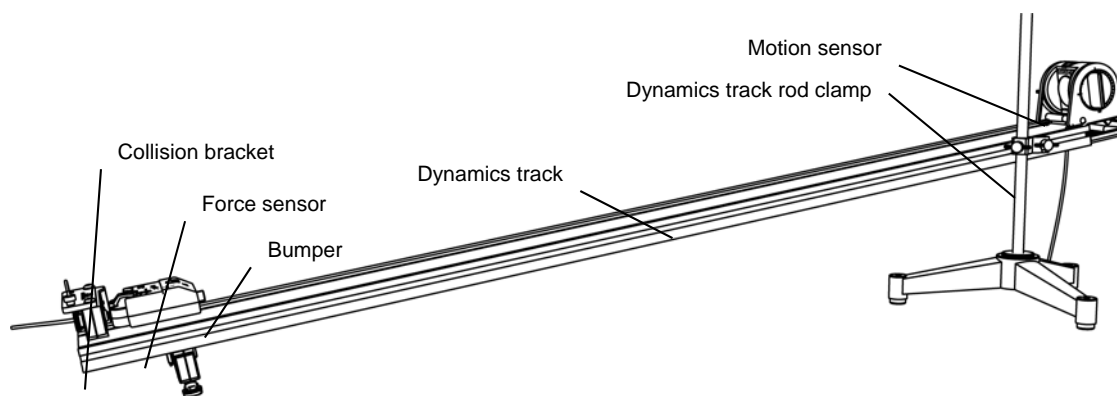
**WARNING:** Angles greater than  $10^\circ$  may cause the cart to collide too hard with the force sensor which may permanently damage the sensor.

- A2. Mount the motion sensor to the raised end of the track with the sensing element on the sensor pointing down the length of the track. Make certain the switch on the top of the sensor is set to the cart icon.



- A3. Screw in the rubber bumper to the front of the force sensor and then attach the force sensor to the discover collision bracket using the large thumbscrew on the bracket.
- A4. Mount the force sensor with collision bracket combo to the lower end of the track with the force sensor pointed up the inclined track.





- A5. Connect both the motion and force sensors to the data collection system.
- A6. On the data collection system, create two graphs: graph 1 = Force (Inverted) on the  $y$ -axis and Time on the  $x$ -axis, graph 2 = Velocity on the  $y$ -axis and Time on the  $x$ -axis.
- A7. Change the force sensor sample rate to 500 Hz and the motion sensor sample rate to 40 Hz.

### **Collect Data**

- A8. Measure the mass of the cart and record the value here.
- Mass of cart = \_\_\_\_\_
- A9. Press the zero button on the top of the force sensor.
- A10. Place the cart on the track (plunger end pointing away from the collision bracket) approximately 15 cm in front of the motion sensor holding it in place.
- A11. Begin data recording, then release the cart to roll freely down the slightly inclined track.
- A12. After the cart collides with the bumper on the force sensor, immediately stop data recording.
- A13. Repeat the previous steps two more times releasing the cart at different distances from the force sensor.
- A14. Save your data on the data collection system.

### **Data Analysis**

- On the Velocity versus Time graph, identify the velocity of the cart just before (initial velocity) and just after (final velocity) the collision for each trial, and then record each value in Table 1.

**Note:** Make sure the signs of the velocity are correct.

2. On the Force versus Time graph, find the area under the curve to determine the impulse from the moment just before the collision to the moment just after the collision for each trial. Record each value in a table.

**SUGGESTED TABLE: VELOCITY, IMPULSE, AND CHANGE IN MOMENTUM DATA**

	Initial Velocity (m/s)	Final Velocity (m/s)	Impulse (N·s)	$\Delta p$ (kg·m/s)
<b>Trial 1</b>				
<b>Trial 2</b>				
<b>Trial 3</b>				
<b>Average</b>				

3. Calculate the change in momentum  $\Delta p$  for each trial and record the resulting values in a table.

### ***Impulse with a soft bumper***

Change the bumper on the force sensor from the solid bumper to the bumper with the soft spring. Repeat the experiment and data analysis. Compare the impulse and the maximum force in the collision in this case with the data for the solid bumper.



Soft-spring bumper installed on the collision bracket and force sensor.



### Analysis Questions

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1. How do the measured values for impulse compare to the calculated values for change in momentum?
2. What are some factors that may have caused error in your measured values, and how could these have been avoided?
3. How is the momentum of the cart before and after the collision related? Was there energy lost in the collision? If so, where did the energy go?
4. How do the results with the solid bumper compare with those with the spring bumper?

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## Part B: Inelastic Collisions

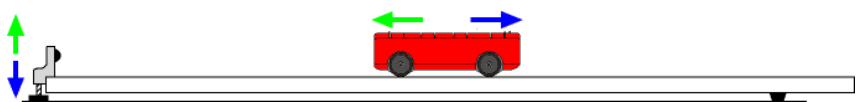
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### Prediction

How will the total momentum of two carts moving before a collision compare to the amount of momentum of the two carts after an inelastic collision?

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### Setup

1. Set up the PASCO GLX data-logger.
  2. Connect a Motion Sensor into the first port on the GLX and place it at one end of a track. Connect a photo-gate at the other end of the track and also to the second port of the GLX. For the motion sensor, use the sensors menu to set the data collection to 50 samples per second. For the photo-gate, use the sensors manual to set the flag length to 10 cm. Set both “time in gate” and “velocity in gate” to visible. Set both “time between gates” and “velocity between gates” to not visible.
  3. Place the track on a horizontal surface. To level the track, place a cart on the track and see if the cart rolls one way or the other. Use the leveling screws adjust until the track is level and the cart will not roll one way or the other on its own.
- Note: It is very important that the track is level to get the best results.
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4. Label one cart "Cart 1" and label the other "Cart 2". Measure the mass of each cart in kilograms and record their values.
  5. Put the Range Setting on the motion sensor to 'Cart'. Put a picket fence on cart 2 and adjust the vertical position of the photo-gate to trigger when the long flag (10 cm) passes in front of the detector beam.





6. Place Cart 1 on the left side of the track and place Cart 2 on the right side. Be sure that the Velcro ends of the carts are facing each other so that the carts stick together when they collide

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## Procedure

- NOTE: The procedure is easier if one person handles the carts and a second person handles the GLX.
- Set the GLX graph to display velocity versus time. Then set the table display to display “velocity in gate” and “time in gate.”
  - Push ‘Start’. Gently push cart 1 and let it roll towards cart 2.



Continue collecting data until the carts have collided, stuck together near the middle of the track, and continued through the photo-gate.

3. Push 'Stop'.
4. Repeat the experiment at least two more times.
5. Find the average velocity of each cart just before impact and the shared velocity after they collide. Include a measure of the uncertainty.
6. Determine the momentum of each cart before and after the collision and its associated uncertainty.
7. Use the Law of Conservation of Momentum to see if momentum was conserved.
8. Repeat the entire experiment for two more conditions:
  - $\text{mass}_1 \approx 1.5 \text{ mass}_2$
  - $\text{mass}_2 \approx 1.5 \text{ mass}_1$

**Data Table**

Cart	Mass (kg)	Average Initial Velocity (m/s)	Average Momentum Before (kg m/s)	Total average Momentum Before
1				
2				
	Mass (kg)	Average Final Velocity (m/s)	Average Momentum After	
Cart 1 + 2				

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## Part C: Elastic Collisions

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### Prediction

How will the total momentum of two carts moving before a collision compare to the amount of momentum of the two carts after an elastic collision?

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### Procedure

Turn one collision cart around so that the built-in magnets in the carts repel each other. This will allow elastic collisions to take place. With  $m_1 = m_2$ , allow an elastic collision to take place, where  $m_2$  is stationary. Observe and measure the respective speeds before and after the collision.

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### Analysis Questions

1. How does the momentum before the collision compare to the momentum after the collision?
  2. What factors do think may cause there to be a difference between the momentum before and the momentum after collision?
  3. Do your observations in the elastic collision match your prediction on what should happen?
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### Reference

Halliday, D., Resnick, R. and Walker, J. (2011), *Fundamentals of Physics*, 9th edn (extended), John Wiley & Sons, New York.

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