

External Forces and the 3rd Law

Equipment

1	Dynamics System	ME-6955
2	Force Sensor	PS-2189
1	Motion Sensor	PS-2103A
2	Compact Cart Mass	ME-6755
	Elastic Cord	(in ME-8998)
	Braided String	SE-8050
Required but not included:		
	Balance	SE-8723

Introduction

In the first part of the experiment (shown above), the forces are examined that are exerted on the two sensors by the connecting string. In the second part of the experiment, the external force, exerted by hand on the elastic cord, is compared to the internal forces created by the tension in the string.

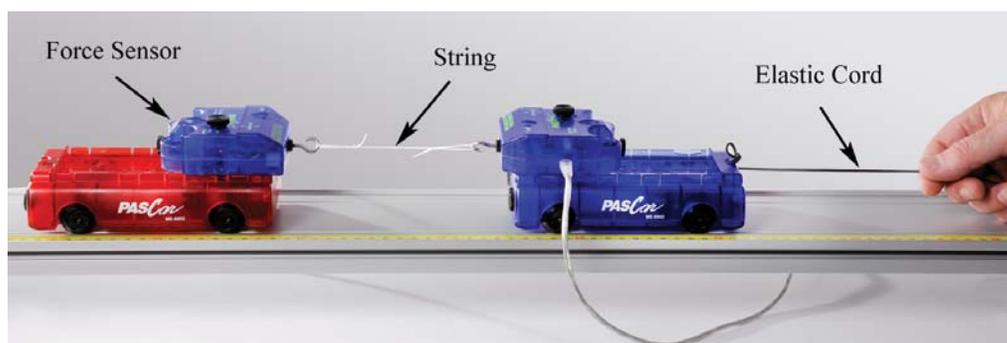


Figure 1: The two carts are accelerated to the right by pulling on the elastic cord.

Setup

1. Set up the track as shown in Figure 2 with feet and endstop. Note the orientation of the yellow rule: The Motion Sensor will be on the zero end.
2. Place the carts on the track and level the track enough so that the carts don't begin to roll.
3. Connect the Motion Sensor to the PASPORT input P1. Attach it to the track and adjust the alignment knob on the side of the Motion Sensor so that it points parallel to the track. Make sure the switch on the top of the Motion Sensor is set to "cart."
4. Using long thumbscrews, attach the Force Sensors to the carts as shown in Figure 3. Note the orientation of the two carts (see Figure 2): It is best to have them both facing the

direction as shown, so that the magnets in the ends of the carts do not interact.

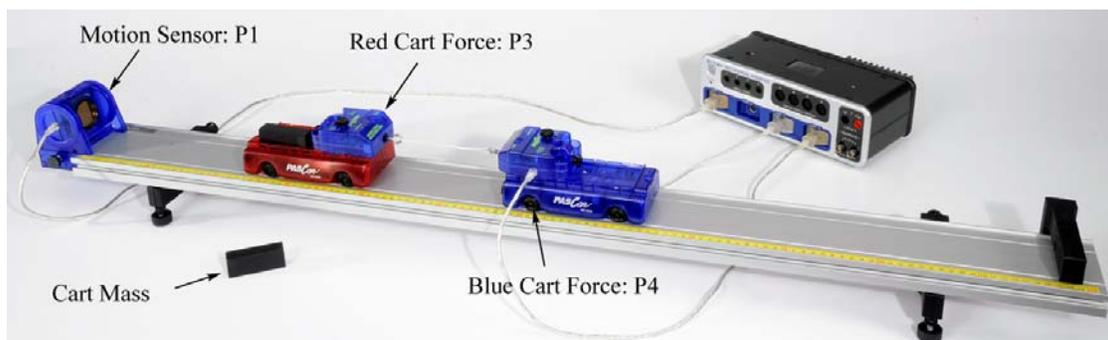


Figure 2: Setup for measuring Action-Reaction pairs



Figure 3: Attaching Sensor to cart

5. Use the Balance to record the mass of Cart + Force Sensor for both carts.
6. Plug the Force Sensor on the red cart into input P3 and the Force Sensor on the blue cart into input P4. Position the cords so they have as little effect as possible.
7. In PASCO Capstone, set the Common Sample Rate to 40 Hz. Create a graph of Position vs. Time. Then add a plot area by clicking on the Add New Plot Area button on the graph toolbar. Select the Velocity on the vertical axis in the new plot area.
8. Change the Sampling Mode from Continuous to Fast Monitor.
9. With nothing touching the hooks on the Force Sensors, press the "ZERO" buttons on the Force Sensors. Position the red cart about 30 cm from the Motion Sensor and click on Monitor.
10. Move the cart away from the Motion Sensor about 30 cm and then back. Check the Position and Velocity graphs to ensure that you are getting good, smooth, continuous data. Click on Stop.

11. Cut a piece of string about 25 cm in length. Tie non-slip loops on each end, with the final length of the string about 10 cm to 15 cm. This string connects the two Force Sensors, as shown in Figure 1.
12. Cut a piece of elastic cord about 30 cm long. Attach one end to the blue cart as shown in Figure 1.
13. Practice (without recording data) pulling on the carts with the elastic cord. Start with the back end (nearest the Motion Sensor) of the red cart at the 15 cm mark. In the following sections, this will always be the starting position.
14. Hold the elastic cord to put a small amount of tension in the string connecting the two sensors without causing them to accelerate yet. Then pull on the cord, accelerating the carts. Pull in such a way that the string stays in tension as far as possible.

Procedure: Action-Reaction Pairs

1. Change the Sampling Mode from Fast Monitor to Continuous.
2. Create a graph of Force P3 vs. time. Click on the Data Selector on the Force axis, select "Add Similar Measurement" and select ForceP4. Then select a QuickCalc of negative force. This will make the force values positive.
3. Click on Recording Conditions on the Sampling bar at the bottom of the page. Create a Start Condition based on the Position, "is above" 0.20 m. Then create a Stop Condition based on the Position, "is above" 0.50 m
4. Position the back of the red cart at the 15 cm mark. Click on Record. Data collection will NOT start until the cart reaches a position of 20 cm, due to an initial starting condition. You can stop recording at any time, but there is an automatic stop condition that stops the recording when the cart reaches 50 cm.
5. Pull on the elastic cord, accelerating the carts.
6. Get one good run of data. Open the Data Summary and re-name this run "Action-Reaction". You can also change the color of each trace, so that the Red Cart Force Sensor data is red and the Blue Cart Force Sensor data is blue. This makes it easier to keep track.
7. Examine the two curves to see if the forces exerted are the same. You will probably have trouble seeing the two sets of data at the same time. The best way is to toggle back and forth between the two data sets. In the Graph Legend, click on the icon under "F P3" to highlight that data. Then click on the icon under "F P4" to highlight that data. Go back and forth and see if you can detect any difference.
8. Are the action/reaction forces equal in magnitude (size)?

- Place both Cart Masses in the red cart and repeat the procedure. Place both Cart Masses in the blue cart and repeat the procedure. Are the action/reaction forces still equal in magnitude?

Internal vs. External

Setup

- Move the Force Sensor on the blue cart to the opposite end as shown in Figure 4. Do not just turn the cart around because the magnets in the ends of the carts would interact.
- The string connecting the carts should now be fastened to the thumbscrew on the back of the Force Sensor on the blue cart (see Fig. 4) and the Elastic Cord is connected to the Force Sensor hook.
- The black Cart Mass is shown in the photo to make the string show up better, but start with no masses in the trays.
- You will pull on the Elastic Cord to accelerate the carts in the same manner as before. However, the Force Sensor on the blue cart will now measure the External Force you apply to the system. The Force Sensor on the red cart will measure the tension in the string as before.

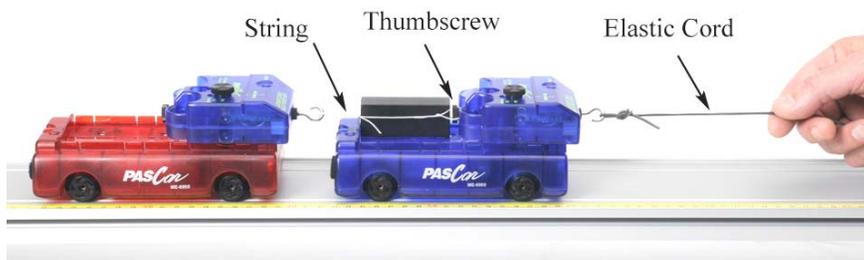


Figure 4: Setup for measuring internal and external forces

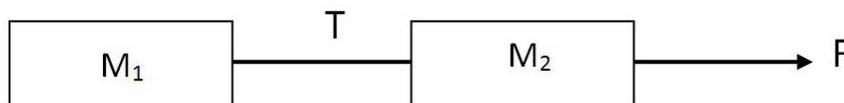


Figure 5: Force Diagram

Theory

An external force, F , is applied to the two mass system (as shown in Figure 5) causing an acceleration, a . The two masses are connected by a string with tension, T . Applying the 2nd Law to the system yields

$$F = (M_1 + M_2)a \quad (1)$$

The two masses can also be treated separately. What is the direction that the internal force, T, exerts on M₁? On M₂?

Applying the 2nd law to M₁ yields

$$T = M_1 a \quad (2)$$

and applying the 2nd law to M₂ yields

$$F - T = M_2 a \quad (3)$$

Show that equation (2) and Equation (3) combine into Equation (1).

Procedure: Equal Mass Carts

1. Position the back of the red cart at the 15 cm mark. Click on Record. There are the same start and stop conditions as before. Pull on the elastic cord, accelerating the carts.
2. Get one good run of data. Open the Data Summary and re-name this run "External Force". You can also change the color of each trace, so that the Red Cart Force Sensor data is red and the Blue Cart Force Sensor data is blue. This makes it easier to keep track.
3. Examine the two curves to see if the forces are the same. Should they be? Why are these not Action-Reaction pairs?
4. Pick a point in time and measure both forces using the Multi-Coordinates tool from the graph tool palette. For example, the peak force makes a convenient location, but you can pick any point where you have good data. Record your values.
5. Use Equation (1) to calculate the theoretical acceleration, a, and record the value.

Analysis

1. Use Equation (2) to calculate a theoretical value for T. Record your value and compare to the measured value using the % error calculation

$$\% \text{ error} = \frac{\text{Measured} - \text{Accepted}}{\text{Accepted}} \times 100$$

2. On the force graph, add a plot area by clicking on the Add New Plot Area button on the graph toolbar. Select the Velocity on the vertical axis in the new plot area.
3. Use the Slope tool (graph tool palette) on the velocity graph to measure the acceleration during the same time period as before and compare.

Procedure: Unequal Mass Carts

1. Add both masses to the blue cart and repeat. Get one good run of data and rename this run Unequal Mass.
2. Pick a point in time and measure both forces.
3. Use Equation (1) to calculate the theoretical acceleration, a , and Equation (2) to calculate a theoretical value for T . Record your values and compare.
4. Use the Slope tool (graph tool palette) on the velocity graph to measure the acceleration and compare.