

## Force and Acceleration

### Introduction

A Smart Cart is accelerated by the tension in a string that goes over a pulley and has mass hanging at its other end. The Smart Cart's sensors are used to measure both the force and acceleration of the cart. A force vs. acceleration graph is then used to determine an experimental value of the cart's mass, which is compared to the mass found by direct measurement.

### Equipment

Qty	Items	Part Number
1	Smart Cart (Blue; including Hook)	ME-1241
1	Dynamics Track Feet (Pair)	ME-8972
1	Dynamics Track End Stops (Only 1 needed)	ME-8971
1	1.2m Starter Dynamics Track	ME-9493
1	Elastic Bumper (Elastic & 1 pair brackets needed)	ME-8998
1	Super Pulley with Clamp (from ME-3420)	ME-9448B
1	Mass and Hanger Set	ME-8979
1	String	SE-8050
Required, but not included:		
1	Balance	SE-8723
1	PASCO Capstone Software	

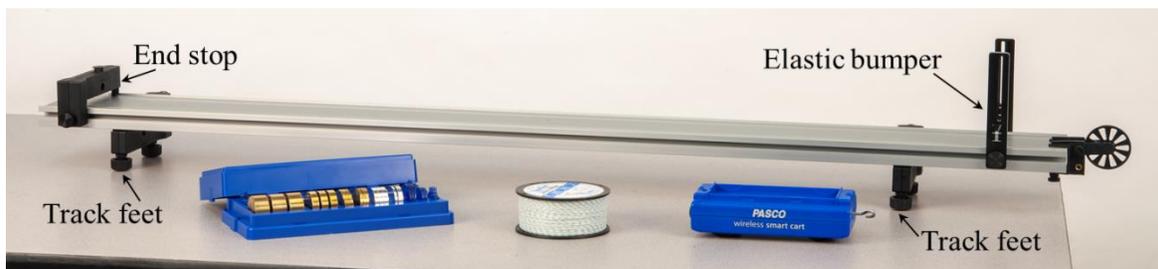


Figure 1: Experimental Setup

## Setup

1. As shown in Figure 1, set up the track with feet underneath at both ends. On the upper side of the track, attach an end stop at one end, and an elastic bumper with the elastic band in the upper notches (see Figure 2) at the other end.
2. Adjust the feet to make the track level. To test the level: Give the cart a little push in one direction to see if it coasts to a stop or accelerates. Then push it in the opposite direction to see if the cart coasts to a stop equally in both directions.
3. As shown in Figure 3, set up the pulley, hook, string, and hanging mass as follows:

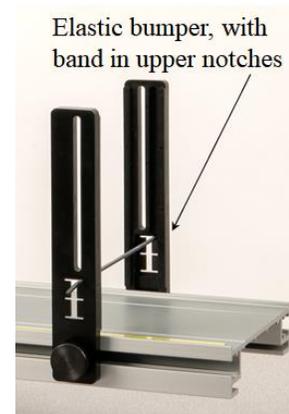


Figure 2: Elastic Band in Upper Notches

Clamp the pulley onto the end of the track where the elastic bumper is. Position the track so the pulley is just beyond the edge of the table. Make sure the pulley is attached to the clamp using the upper set of holes in the clamp.

Attach the Hook to the front of the Smart Cart.

Tie a loop in each end of a string about 1 meter long. Attach one loop to the hook on the cart, and pass the string under the elastic band and over the pulley. Attach a mass hanger to the other end of the string so it hangs below the pulley.

Adjust the level of the pulley so the string from the cart to the pulley is horizontal.

Make sure the string is passing below the elastic band and not touching it.

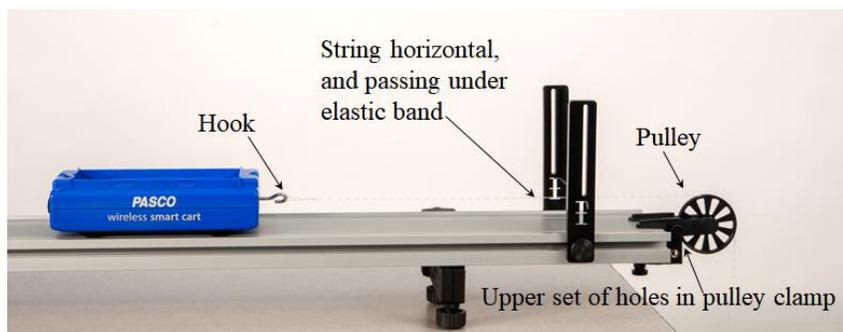


Figure 3: Pulley, Hook, and String

4. Turn on the Smart Cart, and then wirelessly connect it via Bluetooth in Capstone. In the lower toolbar, select Smart Cart Position Sensor and change the sample rate to 40 Hz. Do the same for the Smart Cart Force Sensor sample rate.
5. In Capstone, create a graph of Force vs. Time.

6. To zero the force sensor:

Remove the string from the cart's hook. In the lower toolbar in Capstone: Select the Smart Cart Force Sensor, and then Zero the force sensor.

Start recording. The force graph should read nearly zero since the string is removed. If not nearly zero, then stop recording, re-zero, and restart recording.

7. On the graph, add a second plot area and create a graph of Velocity vs. Time.
8. Create a table and create two new user-defined data sets: "F" with units of N, and "a" with units of  $\text{m/s}^2$ .

## Procedure

1. Recording conditions: In Capstone, on the lower toolbar, open Recording Conditions. Create a Start Condition: Position in meters is above 0.05. Create a Stop Condition: Position is above 0.40.

With these settings, after you click record, the actual recording of data begins only when the cart reaches 0.05 m, and ends when the cart reaches 0.40 m. This will result in graphs that are easier to analyze.

You can adjust the Recording Conditions as needed to suit your experiment.

2. The mass hanger has a mass of 5 grams. Add another 5 grams to the hanger to make the hanging mass total 10 grams.
3. Back the cart up, away from the pulley, and hold it there at rest. As shown in Figure 4, the hanging mass should now be just below the pulley, not touching the pulley, and not swinging noticeably.

Make sure the cart, once released, will be able to move a distance of at least 0.40 m before hitting the elastic bumper. If not, either adjust your setup, or adjust the Stop condition to a smaller position value in Recording Conditions.



Figure 4: Hanging Mass Before Release

4. Start recording, and then release the cart. Once the cart has traveled 0.05 m, recording will start. At 0.40 m it will automatically stop recording. After this, try to gently stop the cart before it hits the elastic bumper.
5. The force should be approximately constant, but an occasional large “bump” in the graph may occur. The velocity graph should be approximately linear and increasing in value. If your graphs are not like this, re-zero the force sensor and try again.
6. Click on the force graph to select it. Turn on statistics on the toolbar and select the mean. If you need more digits visible in the mean value tool, you can switch to tabular format and change the properties. Record the mean value for this graph as the first value of “F” in the table.
7. Click on the velocity graph. Turn on curve fit on the toolbar and then select a linear fit. On the linear fit, the “r” value (the “correlation coefficient”) gives you a good idea of how close your data is to exactly linear. A nearly perfect line has  $r = 1.000$ . How close to linear is your graph?
8. The acceleration of the cart is equal to the rate of change of its velocity. On the graphs, that means: At any time, the slope of the velocity graph should be equal to the value of the acceleration. Record this slope as the first value of “a” in the table.
9. Add mass to the hanger, and repeat the procedure to record graphs for this setup with hanging masses of 20 g, 30 g, 40 g, and 50 g (total, including the 5-gram hanger).
10. Use the graphs to find values of “F” and “a” for each case, and record these in the table.

## Force vs. Acceleration

1. In Capstone, create a graph of F vs. a. It may make the graph easier to read if you open its properties and change the data appearance to not show run symbols or connecting lines, and make the data points larger.
2. Click on the F vs. a graph, and turn on curve fit on the toolbar. Select a Linear fit.
3. Ideally, this graph should be linear, since the net force applied to an object is directly proportional to its resulting acceleration. How close to linear is your graph?

Note: The tension force magnitude F is approximately equal to the net force magnitude for the cart. We are ignoring frictional effects.

4. What physical property does the slope of the Force vs. Acceleration graph represent?  
Hint: What are the units of the slope?
5. If “F” is net force, and “a” is acceleration, what is the missing term in this equation?  
What is the name of this equation?

$$F = (?) a$$

6. Record the slope with units.
7. Use a balance to find the actual mass of the cart, and compare to the slope of the linear fit.

## Further Study

1. Review the table of Force and Acceleration values. The force  $F$  is the tension in the string. In theory, because the system is accelerating, the tension is less than the weight of the hanging mass.

For example, for the run with a 50-gram hanging mass, calculate the weight of the hanging mass. Remember weight =  $mg$ , where  $g$  is  $9.8 \text{ m/s}^2$ . How does the tension  $F$  for this run compare to the tension?

2. Ignoring frictional effects, the theoretical acceleration for this system is found from the equation:

$$a = \frac{\text{weight of hanging mass}}{\text{total mass of system}} = \frac{m_{\text{hanging}} \cdot g}{m_{\text{hanging}} + m_{\text{cart}}}$$

Calculate the theoretical acceleration for the run with the 50-gram hanging mass.

3. Compare the measured acceleration for this run (from the table of Force and Acceleration values) to the theoretical value using the percent error calculation:

$$\% \text{ Error} = \frac{\text{Measured} - \text{Theoretical}}{\text{Theoretical}} \cdot 100$$

Was your measured value higher or lower than the theoretical value? What might account for this?