

## Testing a Scientific Theory

Equipment Needed	Qty	Equipment Needed	Qty
Photogate/Pulley System (ME-6838)	1	String (SE-8050)	1
Mass and Hanger Set (ME-8967)	1	Universal Table Clamp (ME-9376B)	1
Dynamics Cart (inc. w/ Track)	1	1.2 m Track System (ME-9429A)	1

### Background

Newton described the relationship between acceleration, force, and mass as follows:

*The acceleration of an object is directly proportional to and in the same direction as the net force, and inversely proportional to the mass of the object:*

$$\vec{a} = \frac{\vec{F}_{net}}{m}$$

where  $\vec{a}$  is the acceleration,  $\vec{F}_{net}$  is the net force, and  $m$  is the mass.

Applying Newton's Second Law to the static setup used in this activity for an object accelerated by the weight of a hanging mass, neglecting friction, the acceleration of the object and hanging mass can be written as:

$$\vec{a} = \frac{\vec{F}_{net}}{m} = \frac{m_{hanging}}{m_{object} + m_{hanging}} \vec{g}$$

In order to test the theory, we can either do a number of random measurements with different masses of cart and hanger, or systematically study the dependence of  $a$  on these masses. The latter approach is clearly preferable, and we will focus on this approach. The theory we are trying to prove or disapprove suggests the following series of measurements:

- Keep  $m_{object} + m_{hanger}$  constant and change  $m_{hanger}$ . The measured acceleration  $a$  is expected to be proportional to  $m_{hanger}$ .
- Keep  $m_{hanger}$  constant and change  $m_{object} + m_{hanger}$ . The measured acceleration  $a$  is expected to be proportional to  $1/(m_{object} + m_{hanger})$ .

**For You To Do**

For this activity, use a smart pulley to measure the acceleration of a cart on which a constant force is acting. By varying the mass of the cart and the mass of the hanger we will test the predictions made on the basis of Newton's force laws. We will change the mass of the hanger and the mass of the cart in a systematic manner, guided by the theory we are trying to prove or disprove.

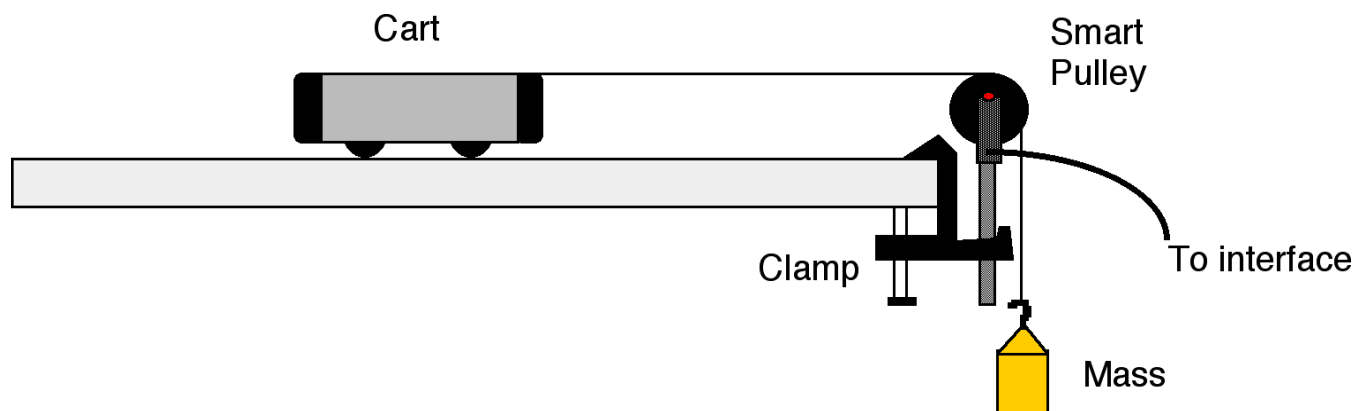
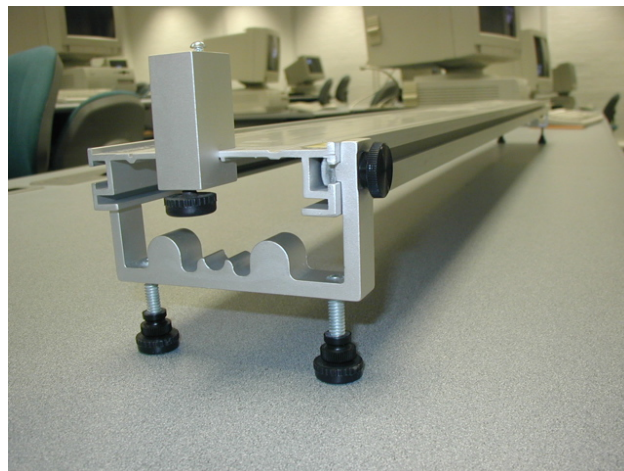
**PART I: Computer Setup**

1. Make sure that the *ScienceWorkshop* interface is connected to the computer and turned on (look for the green light on the front panel of the interface).
2. Connect the stereo phone plug of the “smart” pulley to Digital Channel 1 of the interface.
3. Download the setup file *TestingATheory.cap.zip* for this measurement from the Physics 141 web site (select Laboratories -> Lab 2 from the toolbar). The setup file will be downloaded as a zip file. It should be expanded automatically.
4. Open the *Capstone* program by clicking on the icon in the Dock.
5. After the program opens, select the “Open Experiment” option from either the top toolbar or the “File” menu and navigate to your desktop to open the document entitled *TestingATheory.cap* that was downloaded from the Physics 141 web site.
6. The *Capstone* document opens with a Graph display that shows the measured velocity versus time.
7. Before proceeding, select “Save As” from the file menu to ensure that you can save the data you will collect. Use a new filename that clearly identifies this file as belonging to you (e.g. I may use the filename *TestingATheoryFW092809.cap*.)
8. **Make sure that you save your work frequently so that you do not lose any large amount of data if computing problems occur.**
9. Note: The spoke arc length for the pulley is set at 0.015 m. If you are using a different pulley, change the spoke arc length by selecting “Hardware Setup” from the left toolbar, clicking on the picture of the photogate and then clicking on the photogate with pulley “Properties” symbol. A window will open that will allow you to change the “Spoke Arc Length.” Note that the arc length is measured in meters. Enter the correct value for the arc length of the pulley you are using and click OK.



## PART II: Sensor Calibration and Equipment Setup




1. You do not need to calibrate the sensor.
2. Connect one support leg to either end of the track (see the picture on page 3).
3. Place the Dynamics Track on a horizontal surface. Level the Dynamics Track by placing a cart on the Dynamics Track. If the cart rolls one way or the other, use the adjustable feet at one end of the Dynamics Track to raise or lower that end until the Dynamics Track is level and the cart does not roll one way or the other
4. Attach a pulley to the right end of the Dynamics Track using the table clamp.
5. Carefully measure and record the total mass of the cart in the Laboratory Data section.
6. Place the cart on the Dynamics Track. Use a string that is 10 cm longer than the length needed to reach the floor when the cart is next to the pulley. Attach one end to the cart.
7. Add 20 or 30 grams of mass to the mass hanger.
8. Carefully measure and record the total mass of the mass and mass hanger in the Lab Data section.
9. Attach the mass hanger to the other end of the string by wrapping the string four or five turns around the notched area of the mass hanger. Put the string in the pulley's groove and adjust the height of the pulley so the string is parallel to the Dynamics Track.

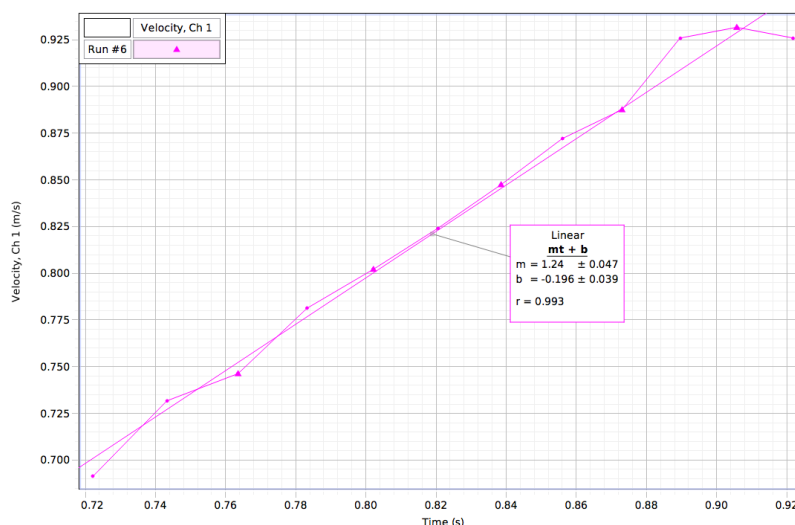


**PART III: Data Recording**

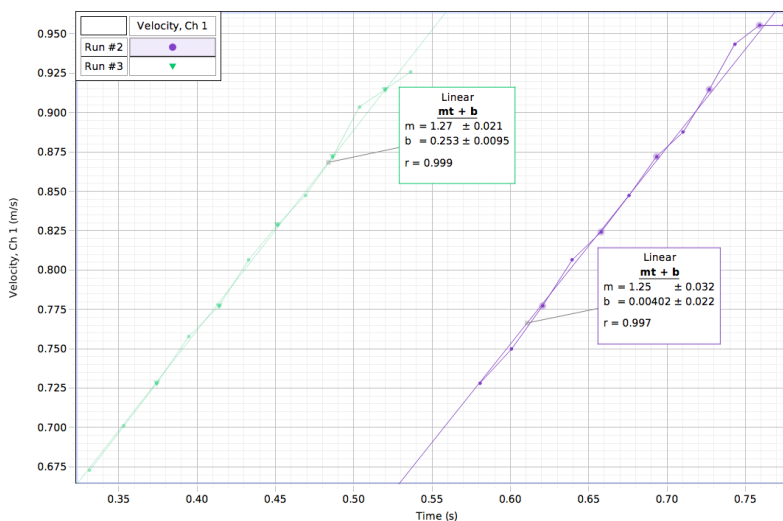
1. Pull the cart toward the left end of the Dynamics Track. Do not let the mass hanger bump into the pulley.
2. Start recording data and then release the cart.
3. Stop recording data before the cart reaches the pulley.
4. Stop the cart before it collides with the pulley.
5. Use the "fit" tool in *Capstone* to do a linear fit to the velocity vs time graph in order to extract the acceleration (for details on the fitting procedure, please refer to the section "Analyzing the Data"). Record the acceleration in the Data Tables.
6. In order to determine the error in the acceleration we measure, repeat the same measurement four more times.
7. We now start a series of measurements where we keep  $(m_{\text{object}} + m_{\text{hanger}})$  constant and change  $m_{\text{hanger}}$ . Start by putting extra mass on top of the cart and no mass on the hanger. Determine the acceleration of the cart and record the acceleration in the Data Tables. Repeat the measurement four more times, each time moving some of the mass on the cart to the hanger.
8. We now start a series of measurements where we keep  $m_{\text{hanger}}$  constant and change  $(m_{\text{object}} + m_{\text{hanger}})$ . Start by putting extra mass on top of the cart and a little mass on the hanger (about 10 - 20 grams). Determine the acceleration of the cart and record the acceleration in the Data Tables. Repeat the measurement four more times, each time removing some of the mass on the cart.

**Analyzing the Data**

1. Determine the experimental acceleration for each of the data runs.
2. Click on the Graph display to make it active. Find the slope of the velocity vs. time plot, the average acceleration of the masses.
3. In *Capstone*, select Run #1 from the Data Menu () in the Graph display. If multiple data runs are showing, click on the runs so that the check mark disappears next to the runs that you do not want to see. There should only be a check mark next to Run #1. Click the "Scale to fit" button () to rescale the Graph axes to fit the data. Next, click the 'Fit' menu button () . Select 'Linear'. Note: if you try to apply a linear fit and a message appears saying "curve fit status value contains an unexpected value," then either try to change the initial guesses for m and b in the curve fit editor (located on the left toolbar) or use the weighted linear fit.
4. Record the slope of the linear fit in the Data Tables in the Lab Report section. This is the measured acceleration.



5. Using the first series of measurements, where the masses are kept constant, determine the overall error in the procedure that you used. In order to estimate this error, follow the following procedure:
- Extract the slope and its error for each of the five measurements of this series.
  - Examine the errors in the slope for each of these measurements. Are they similar? If so, you can obtain your best estimate for the slope and its standard deviation from the "normal" average and the "normal" standard deviation. If the errors vary significantly, you will need to use the weighted average and the weighted standard deviation. The following Figure shows the results of two measurements with the same mass configuration. As you can see, the variations in the values of the slope are significantly larger than the error in the procedure used to extract the slope.



- We will use this standard deviation as the error for all our measurements of  $a$ . Although the proper procedure would be to repeat the measurements for each mass combination a number of times and extract a standard deviation as outlined in b for each mass combination, this would make the experiment too time consuming.
6. Process the data of the other runs in a similar manner.

**Laboratory Data Sheet - Testing a Scientific Theory****Data Table 1: Determine the error in our procedure.**

<b>Run</b>	<b><math>M_{\text{cart}}</math> (kg)</b>	<b><math>M_{\text{hanger}}</math> (kg)</b>	<b><math>a</math> (m/s<sup>2</sup>)</b>

Using the data in the table determine your best estimate for the acceleration and its standard deviation. Indicate what procedure you used to obtain these values.

$a =$  \_\_\_\_\_

$\sigma_a =$  \_\_\_\_\_

Procedure used: \_\_\_\_\_

Data Table 2: Constant Total Mass

Run	$M_{\text{cart}}$ (kg)	$M_{\text{hanger}}$ (kg)	$M_{\text{cart}} + M_{\text{hanger}}$ (kg)	$a$ (m/s <sup>2</sup> )

**Note:** the results of the analysis carried out using the data shown in Table 1 can be entered in the first row of this table.

Use a graphing program (such as Igor) to make a graph of the measured acceleration as function of  $M_{\text{hanger}}$  to determine if the acceleration depends linearly on  $M_{\text{hanger}}$ . Such a graph should be included in your lab report.

Data Table 3: Constant Hanger Mass

Run	$M_{\text{cart}}$ (kg)	$M_{\text{hanger}}$ (kg)	$M_{\text{cart}} + M_{\text{hanger}}$ (kg)	$a$ (m/s <sup>2</sup> )

Use a graphing program (such as Igor) to make a graph of the measured acceleration as function of  $1/(M_{\text{cart}} + M_{\text{hanger}})$  to determine if the acceleration depends linearly on  $1/(M_{\text{cart}} + M_{\text{hanger}})$ . Such a graph should be included in your lab report.



**Questions**

1. Make a comparison between the predicted acceleration and the measured acceleration for each of the measurements carried out in this experiment.

Run	$M_{\text{cart}}$ (kg)	$M_{\text{hanger}}$ (kg)	$a_{\text{measured}}$ (m/s <sup>2</sup> )	$a_{\text{theory}}$ (m/s <sup>2</sup> )	% Differ

Note: % Differ =  $100 (a_{\text{measured}} - a_{\text{theory}}) / a_{\text{theory}}$ .