Name _____ Date _____

Developing 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

Background

The acceleration of an object depends on the net applied force and the object's mass. In an Atwood's Machine, the difference in weight between two hanging masses determines the net force acting on the system of <u>both</u> masses. This net force accelerates both of the hanging masses; the heavier mass is accelerated downward, and the lighter mass is accelerated upward.
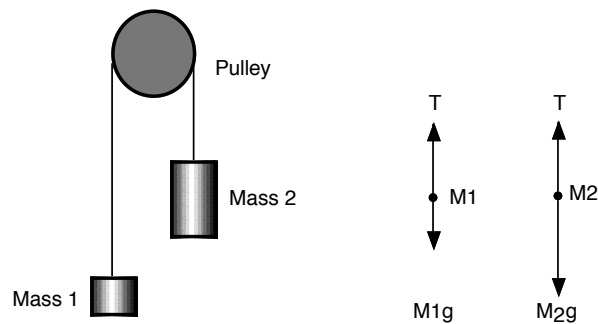
Based on the above free body diagram, T is the tension in the string, $M_2 > M_1$, and g is the acceleration due to gravity. Taking the convention that up is positive and down is negative, the net force equations for M_1 and M_2 are:

$$T_1 - M_1 g = M_1 a$$
$$T_2 - M_2 g = M_2(-a)$$

In this experiment we will measure the acceleration of the masses, and develop a theory that describes our observations.

Assuming we do not have a theory for this experiment, we can develop a theory based upon our own observations. In order to determine what our theory may look like, consider the following:

- We assume that the measured acceleration depends on the mass of M_1 and M_2: $a = f(M_1, M_2)$.

- Based on experience we expect that the acceleration is 0 m/s^2 when $M_1 = M_2$. We thus expect that the theory we are trying to develop depends on $(M_1 - M_2)$.

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- We expect that the measured acceleration depends also on the gravitational acceleration g.

- Combining the last two points, we may consider some of the following "theories":

$$a = k \frac{\left(M_1 - M_2 \right)^{\alpha}}{M_1^{\alpha}} g \quad \text{or} \quad a = k \frac{\left(M_1 - M_2 \right)^{\alpha}}{M_2^{\alpha}} g \quad \text{or} \quad a = k \frac{\left(M_1 - M_2 \right)^{\alpha}}{\left(M_1 + M_2 \right)^{\alpha}} g \quad \text{or} \quad ....$$

where k and α are dimensionless constants. Note: when considering possible dependencies of f we need to make sure that the units are correct. This is one of the reasons that the power of the argument in the denominator is the same as the power of the argument in the numerator (the ratio is now unit less).

- The possible functions may provide the experimenter with helpful suggestions on how to vary the various parameters (e.g. measure a while keeping $(M_1 - M_2)$ constant, measure a while keeping $(M_1 + M_2)$ constant, etc.).

For You To Do

Use the Photogate/Pulley System to measure the motion of both masses as one moves up and the other moves down. Use *Capstone* to record the changing speed of the masses as they move. The slope of the graph of velocity vs. time is the acceleration of the system.

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 *DevelopATheory.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 *DevelopATheory.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 *DevelopATheoryFW092809.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. Mount the clamp to the edge of a table.

3. Place the "smart" pulley in the clamp so that the rod is horizontal (see Figure).

4. Use a piece of string about 10 cm longer than the distance from the top of the pulley to the floor. Place the string in the groove of the pulley.

5. Fasten a mass hanger to each end of the string by forming a loop at the end of the string and tying it back on itself to 'knot it' or by wrapping the string about 5 times around the notch in the mass hanger.

6. You can now place different masses on each hanger. Be sure to include the 5 grams from the mass hanger in the total mass for each side. You may want to use the convention that $M_1 > M_2$.

7. Move the M_1 mass hanger upward until the M_2 mass hanger almost touches the floor. Hold the M_1 mass hanger to keep it from falling. Turn the pulley so that the Photogate beam is unblocked (the
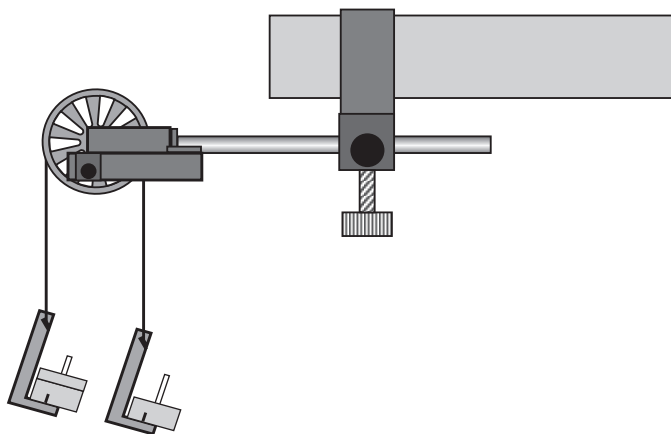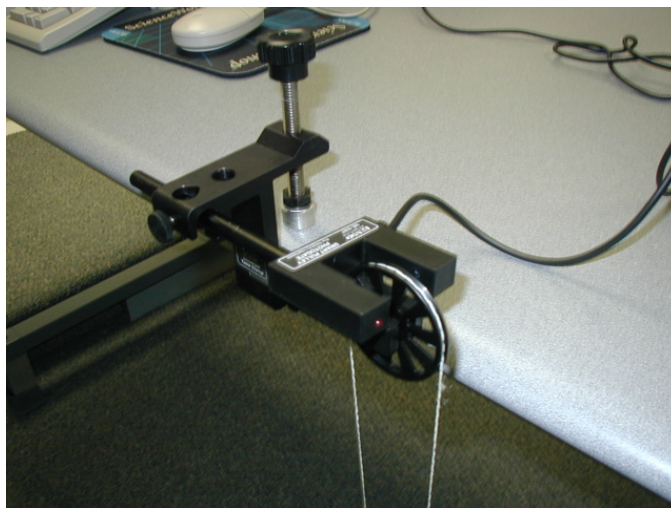
red light-emitting diode (LED) on the
photogate does not light).

PART IIIA: Data Recording – Constant Total Mass

1. Start recording data.

2. Release the M_1 mass hanger and let it fall.

3. Stop recording just before the M_1 mass hanger reaches the floor.

4. Do not let the upward moving mass hit the Pulley.

5. "Run #1" will appear in the Data list (you can replace "Run #1" with a short text that contains information about the run; e.g. "M1 = 55, M2 = 45").

6. 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.

7. Repeat this measurement 4 more times in order to obtain a good estimate of the error of this measurement. We will use this error for all of our other measurements.

8. For Run #6, move a mass (e.g. 10 grams) from the M_1 mass hanger to the M_2 mass hanger. This process changes the net force without changing the total system mass. Record the new total mass for each hanger with masses in the Data Table in the Lab Report section. Allow the mass to fall. Begin data recording. Stop recording data just before the hanger reaches the floor. Determine the acceleration from the velocity vs time graph, and record is in the Data Tables.

9. Repeat the above step to create three more mass combinations. For each run, the net force changes but the total mass of the system remains constant. Determine the acceleration from the velocity vs time graph, and record it in the Data Tables.
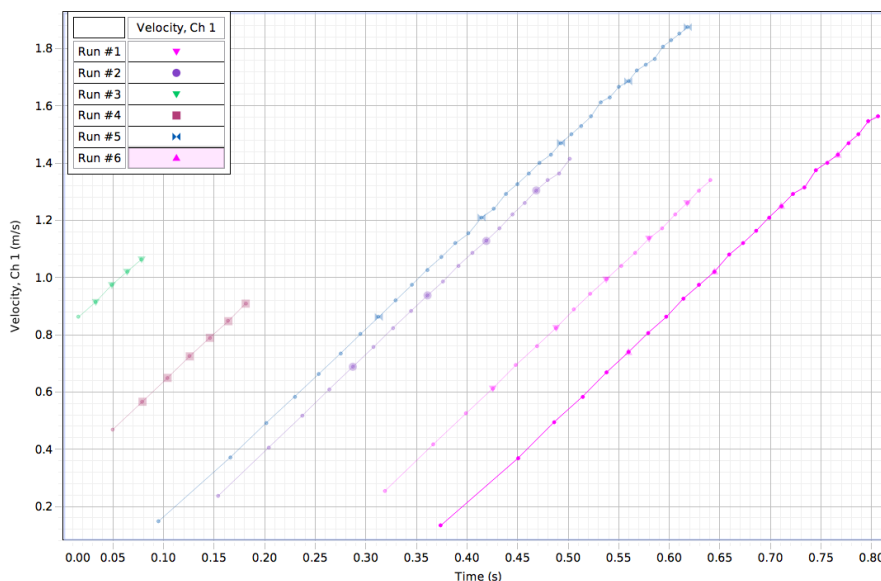
An example of the type of data you may collect in this measurement if the data collection is stopped before mass _M_1 hits the ground.
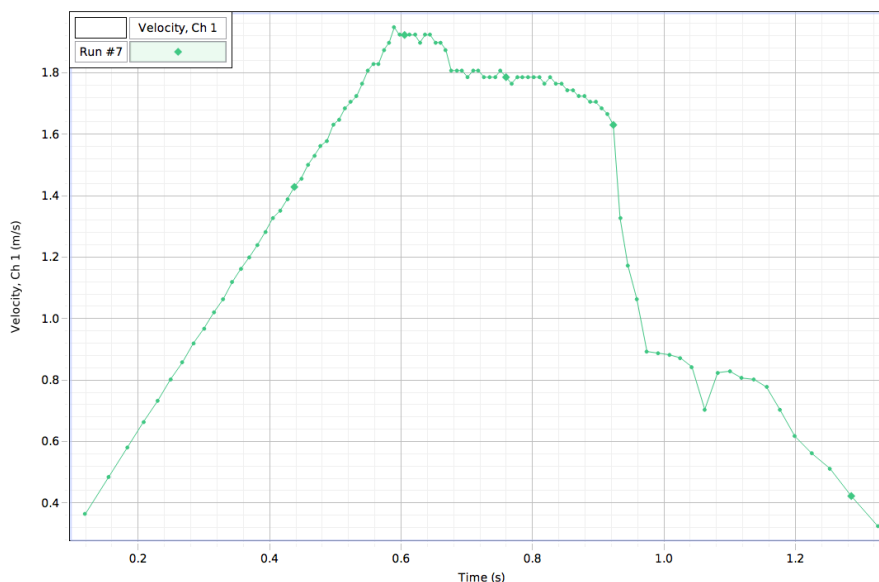
An example of the type of data you may collect in this measurement if the data collection is not stopped before mass _M_1 hits the ground. In this case, make sure that you only include the data range with the positive slope in your fit.

PART IIIB: Data Recording – Constant Net Force

1. Arrange the masses as they were for Run #1. Now, change the total mass of the system but keep the net force the same. To do this, add exactly the same amount of additional mass to both mass hangers.

2. Make sure that the difference in mass is the same as it was for the beginning of Part IIIA.

3. Add approximately 10 grams to each mass hanger. Record the new total mass for each hanger with masses in the Data Table in the Lab Report section. Release the M_2 mass hanger and let it fall. Start data recording. Stop recording just before the M_2 mass hanger reaches the floor.

4. Repeat the above step to create three more data runs. For each data run, the net force remains the same, but the total mass of the system changes.

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:

    a. Extract the slope and its error for each of the five measurements of this series.

    b. 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.
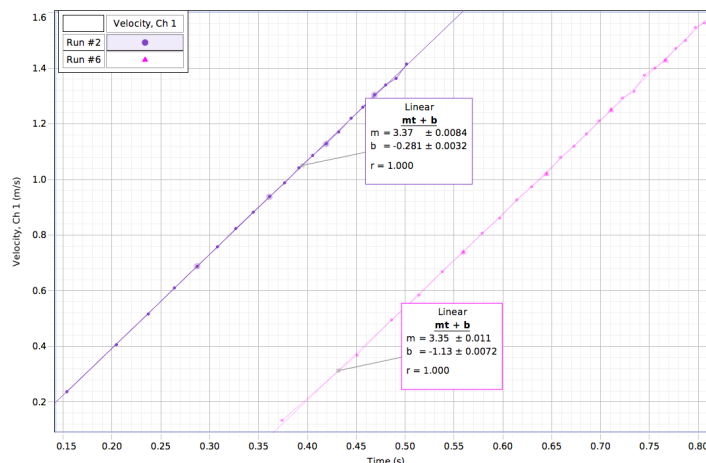
Example of the results of linear fits to the data collected in this experiment. Both data sets were taken with the same mass combination, and we note that the slopes differ significantly more from each other than the error in the slope of each measurement.

    c. 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.

Laboratory Data Sheet - Developing a Scientific Theory

What Do You Think?

What is a real world application of Atwood's Machine?

Data Table 1: Determine the error in our procedure.

Run	M_1 (kg)	M_2 (kg)	a (m/s^2)

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 = _____

σ_a = _____

Procedure used: _____

Data Table 2: Constant Total Mass

Run	M_1 (kg)	M_2 (kg)	$M_1 - M_2$ (kg)	$M_1 + M_2$ (kg)	a (m/s^2)

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 $(M_1 - M_2)$, $(M_1 - M_2)^2$, etc., to determine how the acceleration depends on $(M_1 - M_2)$. Such a graph should be included in your lab report.

Data Table 3: Constant Mass Difference

Run	M_1 (kg)	M_2 (kg)	$M_1 - M_2$ (kg)	$M_1 + M_2$ (kg)	a (m/s^2)

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 $(M_1 + M_2)^{-1}$, $(M_1 + M_2)^{-2}$, etc., to determine how the acceleration depends on $(M_1 + M_2)$. Such a graph should be included in your lab report.

Questions

1. Using the results of the analysis carried out in connection with the data shown in Data Tables 2 and 3, propose the functional dependence of the acceleration on the masses.

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

Run	M_1 (kg)	M_2 (kg)	$a_{measured}$ (m/s^2)	a_{theory} (m/s^2)	% Differ	$a_{theory}/a_{measured}$

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

3. Based on the comparison made in 2) adjust your theory if required. What is your final "theory"? For all the parameters in your theory (k and α) provide your best estimate of their value and the error in their value.