Newton's 2nd Law

Introduction:

In today's lab you will demonstrate the validity of Newton's Laws in predicting the motion of a simple mechanical system. The system that you will investigate consists of a car moving on a frictionless horizontal surface (a car riding on a low friction track) connected to a small hanging mass by a massless inelastic string which passes over an ideal pulley.

In the space below apply Newton's 2nd law to determine the motion of the car and the tension in the rope attached to the car. Use the framework we have developed in class and the following variables: for the car's mass m_1, the hanging mass's mass m_2, the acceleration due to gravity *g*, the acceleration of the car *a*, and the tension in the rope F_T. Your end results should only be interms of m_1, m_2, and *g*.

Important to simplify your analysis you should keep the sum $m_1 + m_2$ kept constant during this experiment. *Hint:* What role does the pulley play? Can you draw an equivalent situation without the pulley?

How the computer (and you) will calculate the acceleration:

The acceleration is (for small time intervals) given by

$$a = \frac{v_2 - v_1}{\Delta t},$$

where Δt is the duration of the time interval and v_1 and v_2 are the velocities at the beginning and end of the interval respectively.

Therefore, if we can determine the velocity at two points and the time interval between the points, we can calculate the acceleration. These two velocities can be determined using the two photogates positioned along the track and connected to the computer through the Pasco interface. The photogates detect when the infrared beam that passes from one side of the photogate to the other is blocked. During the experiment you will release the car from a point before the first photogate. The "flag" on top of the car will block the beam and you will configure the computer to record three time intervals; t_{gate1}, t_{gate2}, and deltaT ; the time the flag interrupts the beam at each photogate (gates 1 and 2) and the time interval from when the flag starts to interrupts the photogate 1 until it starts to interrupts photogate 2. Using the length of the flag, L, we can compute an average speed, $v_{avg} = L/t$, for the car as it passes through each photogate. If the car has constant acceleration, this average speed is the same as the instantaneous speed that the car has at the time half-way through the gate.

Collect the Data:

1. Turn on the interface box (switch in the back) and turn on the computer and monitor. Open Data Studio and select Create Experiment.

2. Click on **File** on the top menu bar, select open activity, and open file Newton 2nd Law.

3. Measure the length of the flag on your car (don't forget uncertainty). Record the value below:

4. In the Experiment Setup window, there is a drawing of two photogates. Click on the first one, select the constants tab and enter the length of the car's flag **(in meters).**. Click on the second photogate image and follow the same procedure to set the length of the car's flag for the second photogate. You need not enter any value in the "Space between Gates" box it is not need for this lab. Minimize the Experiment Setup window.

5. Your screen should have two digital displays: one for the time in Gate 1 and one for the time in Gate 2. Gate 1 is the farthest from the pulley and Gate 2 is the closest to the pulley. There should also be a table with columns for Mass, tGate1, tGate2.

6. Attach two 20 gram masses to the car and use a 10 gram mass as the hanging mass. Position the car about 15-30 cm before the first photogate. **Be careful that you do not pass the car through the photogates when you position it.**

7. Click Start . If need be, adjust the display so that you can see the time displays and the columns for Mass, tGate1 and tGate2 in the table.

8. Release the car and catch it before it rebounds back through the photogates turn.

9. When you are happy with your measurement click Keep (where Start had been) and then enter the value for the hanging mass in kg when prompted. **Do not click the red square yet.** The data must all be taken in one run.

10. Now use one of the 20 gram masses as the hanging mass and put the other 30 grams on the car. Position the car **making sure you don't go through the photogates**. Release the car to capture the second measurement and click Keep. Record the new hanging mass when prompted.

11. Continue to collect data for hanging masses of 30 g, 40 g, and 50 g, making sure that you transfer mass between the car and the hanging mass so that the sum of their masses remains constant.

12. After the last set of values click the red square to stop. All of your data should be in the table.

Save the Data:

1. Save your results in a file with the name NewtonYourNames and print out your table.

Analyze the Data:

The times collected above are the raw data. We first use the times to calculate velocities and then use the velocities to calculate acceleration. To this end we will construct a new table that contains: mass, vInGate1, vInGate2, deltaT, and the acceleration. Step by step instructions are as follows.

1. To create a new table, drag a new table from the display window to the mass data set in the data window. The moment at which the measurement was made is irrelevant so unselect the clock symbol at the top left of your new table. Add vInGate1 by dragging that data from the data window to the right side of the table. Add vInGate2 and deltaT in the same way.

2. You should still see the times spent in Gate 1 and Gate 2 for your 50g measurement displayed in the digital boxes at the top of the screen. Check by calculation that the velocities shown in the final row of the table using these two times are correct. (Note: the displays are showing rounded off values, so you might not get the "exact" same value, but convince yourself that the values for velocity are being calculated correctly.) Show your calculations below:

3. Using the uncertainty in your measurement of the length of the flag, propagate the uncertainty in the length to find the uncertainty in values of the velocities you calculated by hand. Show that calculation below:

4. Using deltaT and the velocity values, calculate the acceleration for the data in the last row of the table. Include the uncertainty in your answer, both absolute and relative. You will assume that this relative uncertainty is the same for each acceleration. Show your work below:

5. Now we will use the computer to calculate the acceleration. Click the calculate button at the top of the screen (near the Start button). In the Calculator window you will define the equation to calculate the acceleration and define the variables used in that equation. In the definition box type in the acceleration equation using variable names that make sense to you and press Enter. After you press enter each variable will appear below the equation with a triangle button. Under that button there is a pull-down menu that allows you to connect the variable to the relevant Data Measurement. **Important obscure fact:** you must click the clock like icon at the right side of the calculation window to actually use time measurements in a calculation. Click accept to carry out the calculation and close the Calculate window. The data window will now have the acceleration calculated in it. Drag the acceleration from the data window into the table to display it.

6. How does your acceleration value compare to the last one in the table?

7. Again, save your work so far. Also, make your new table active and then print it.

8. On page 1 of this lab you found how the acceleration, a, depends on m_1, m_2, and g. Since the system mass is constant, the graph of a versus m_2 (the hanging mass) should be a straight line. What should the slope of that straight line be? (See your work on page 1 of the lab.)

9. Because of this theoretical prediction we want to construct a graph of Acceleration vs. Hanging Mass, with the Acceleration on the vertical and Hanging Mass on the horizontal axis. To create this graph drag the graph icon from the display window to the Acceleration in the data window. You should now have an Acceleration vs Time graph. To switch Mass in for time double click the time label on the graph and select Mass. Rescale the graph so that both axes start at zero and all data is shown.

   Double click the middle of the graph to reach the Graph Settings window. Here you can remove the lines connecting your data points by unchecking the Connect Data Points option. It is also here that you can add error bars to your graph. To do so, check the box Show Errors and then select the Errors tab. Here you can use the relative uncertainty you calculated for acceleration above

   Click on OK at the bottom of the Graph Set up Window. You should now have your completed graph, properly labeled, with uncertainty indicated by error bars.

10. If your experiment agrees with the theory, the graph should be a straight line. Check this by doing a linear fit to the data which will yield the slope and intercept of the best-fit line. To carry out the fit, click the fit button at the top of the graph and select Linear Fit.
11. Write the equation of the best fit line, using the appropriate variables in place of x and y.

What value does our theory predict for the slope and y-intercept of this straight line?

Is the theoretical prediction consistent with your experimental observations? Be sure your discussion includes the uncertainty in your experimental result. You may assume the relative error in the slope of your best fit line is approximately equal to the relative error in the acceleration.

12. Save the File and print your graph.