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 cushion of air on an air track) connected to a small hanging mass by a massless inelastic string which passes over an ideal pulley.

Consider the analysis of this system's motion from a free-body diagram point of view. Let F_T be the tension in the string, m_2 the hanging mass, m_1 the mass of the car, and a be the magnitude of the acceleration of the hanging mass and the car. In the space below apply Newton's 2nd Law to find the tension F_T in the rope and the acceleration of the cart.

Important to simplify your analysis you should keep the sum $m_1 + m_2$ kept constant during this experiment.

<u>How the computer (and you) will calculate the acceleration:</u>

The acceleration is (for small time intervals) given by $a = (v_2 - v_1)/(t_2 - t_1)$. Therefore, if we can determine the velocity at two points and the time interval between the points, we can calculate the acceleration. There are two photogates positioned along the track that are connected to the computer through the interface. The car will be released from a point before the first photogate. Notice that there is a "flag" on top of the air car. The computer will record three time intervals; t_{gate1}, t_{gate2}, and t_{12} ; the time the flag interrupts the infrared beam at each photogate 1, photogate 2, and the time interval from when the flag starts to interrupts the photogate 1 until it starts to interrupts photogate 2. If the length of the flag, L, is known, we can compute an average speed, $v_{avg} = L/t$, for the car as it passes the location of 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. Double click on the Science Workshop icon to open it.

2. Click on **File** on the top menu bar, click on **open** and select the folder PHY151. Open file NEWTLAB.

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

4. Below the picture of the interface box, there is a drawing of two photogates. **Double click** on it. In the dialog box that results, enter the length of your flag as the "object length" **<u>(in meters).</u>** Do not enter any value in the "Space between Gates" box; you will not need to enter that for this lab. Then click on the OK button.

5. Now, to "clean up" you display area, click on the middle button on the right side of the title bar of the NEWTLAB. This should reduce the main window to just show the REC, MON, STOP, PAUSE button area.

6. Your screen should have two digital displays at the bottom: 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.

7. Attach two 20 gram masses to the air 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.**

8. Click on the REC button. A "Keyboard sampling" window will come up. Move the window so that you can see the time displays and the columns for Mass, tGate1 and tGate2 in the table. It is OK if it covers the REC, MON, STOP buttons.

9. Type in the hanging mass <u>in kg (0.01)</u> in the "Entry #1" area in the Keyboard Sampling window. **DO <u>NOT</u> press the ENTER key on the keyboard or click on the ENTER button in the Keyboard Sampling Window yet!**

10. Turn on the air blower, release the car and catch it before it rebounds back through the photogates turn off the air blower.

11. Click on the ENTER **button** in the **Keyboard Sampling** window (**NOT** the ENTER key on the keyboard). The displayed times that go with the typed in mass will be recorded and should now be displayed in the table.

12. 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**. Type in the new hanging mass as Entry #2 in the area in the Keyboard Sampling window (0.02). Turn the air on, release the car, turn air off. Click on the ENTER button in the Keyboard Sampling window.

13. Continue to collect data for hanging masses of 30 g, 40 g, and 50 g, making sure that the rest of the masses are on the car. Follow the same procedure as in 12 above: position the car, type in the mass value as an ENTRY (note that the program tries to pick up your pattern and anticipate your next Entry, so you may not have to type it in), air on, release the car, air off, click on the ENTER button.

14. After clicking on ENTER for the last set of values, click on STOP SAMPLING in the Keyboard Sampling window. You should see your RUN # appear in the DATA list. Also, your table should show the data for this run.

Save the Data:

1. Click on the **File** on the Menu Bar, and select **Save As**.

2. In the file name area give your file the name Newt2Sum.sws

3. Make the table active by clicking on it, click on **file**, select **print active display** to print the table.

4. Click on the left most button of those on the right side of the title bar of the table window. This will reduce the table to a bar at the bottom of the science workshop window.

Analyze the Data:

1. Click on **DISPLAY** on the top menu bar and select **New Table.** Move the table to the blank area of the screen. The table will have an "Index" column and a column for time in Gate1. Click on the large gray button at the top of this time column and select Mass. The first column should now have the hanging mass. Now go to the buttons above the Index column. Click on the 2^{nd} button down (the add-a-column button). Select Digital 1, Velocity in Gate 1. Do the Add-a-column again and select Digital 1, Velocity in Gate 2.

2. You should still see the times for interruption of Gate 1 and Gate 2 for your last data still displayed in the Digital boxes at the bottom of the screen. Check by calculation that the velocities shown in the last line of the table for 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 uncertainly in your measurement of the length of the flag, determine the uncertainly in the values of the velocities you checked. Show that calculation below:

4. Now using the "Add a Column" button, select Calculations, Time Interval. This will add the time interval from the first gate to the second to the table. Using this and the values of velocity, calculate the acceleration for the data in the last line of the table. Include the uncertainty in your answer, both as absolute and as percentage. You will use this percentage uncertainty to be the same for all of your values of acceleration. Show your work below:

5. Now click on the "Add a Column" button again, select Calculation, Acceleration. This should add a column with the accelerations calculated. How does your value compare to the last one in the table?

6. Again, save your work so far by clicking on **file** and then **save**. Also, make your new table active and then print it.

7. Since the system mass is constant, then by Newton's 2nd Law, the acceleration a is directly proportional to the net force, F_{tot}, so a graph of a versus F_{tot} should be a straight line. Also, since $F_{\text{tot}} = m_2 g$, then a graph of a versus m_2 should also be a straight line. What should the slope of that straight line be? (See page 1 of the lab.)

8. Click on the **Display** menu on the top bar and select **New Graph**. Move the graph to cover the table. Move the cursor to the bottom right corner of the graph window. When it turns into a double headed diagonal arrow, click and drag to make your graph a decent size (you can cover the digital displays).

   Since we want a graph of Acceleration vs. Hanging Mass, we want the Acceleration on the vertical and Hanging Mass on the horizontal. In the horizontal axis area, click on the large gray button that is on the left side and select Mass. In the vertical axis area, click on the large gray button near the top of the area and select Calculation, Acceleration. You should now have a graph of Acceleration versus Mass. Click in the areas by the scales for the vertical and horizontal axes. In the dialog boxes that appear make the min value zero for both and the max value large enough that all five of your data points fit comfortably in the graph area.

   There are several buttons in the bottom left of the Graph window, the Graph Tools area. Click on the bottom left button (it looks like a graph). This opens the graph set-up window. In the text box under NAME, type a title for your graph (it currently just says Graph Display). Also, make sure there is not a "check" selecting the "connected points". If there is, click on it to "uncheck" it.

   In that same window is an area called error bars. This allows you to show the uncertainty of a value on the graph. You have a percentage uncertainty in the vertical data, acceleration. Click on the box for vertical. An check should appear in the box. Click on the box in front of %. A check should appear in the box, indicating that the value is percent. Now put your value for percent uncertainty in the number area.

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

9. If your experiment agrees with the theory, the graph should be a straight line. You'll check this by doing a linear fit to the data to finding the slope and intercept of the best-fit line.

   In the Graph Tools (bottom left) click on the statistics button (the Σ). This opens up the statistics area to the right of the graph. Click in the horizontal axis area and readjust the max value so that all of your data is still in the graph area (make sure that the min is still zero).

   Now in the statistics area to the right of the graph, click on the button and select Curve Fit, Linear.

10. Write the best fit equation, using the appropriate variables in place of x and y.

What are the slope and y-intercept of this straight line?

What do we <u>theoretically</u> expect for the slope and y-intercept of this straight line?

Use the relative uncertainty in the acceleration as the relative uncertainty in the slope of the experimental line. Does your experimental data agree within uncertainty with the theoretical expectation?

11. Save the File and print your graph