.Lab #2 Graphical Analysis

Purpose: To investigate how graphs can be used to represent linear and non-linear relationships between various physical quantities, to learn how to input data into an Excel spreadsheet and to use the spreadsheet to draw graphs of data.

Equipment: Hooke's Law apparatus (suspended spring and mass set)
Simple pendulum apparatus
Meter stick
Stopwatch
Science Workshop 750 Interface (SWI)
Computer with DataStudio (DS) software

Discussion: Part 1, Linear Relations

Many basic experiments in physics, engineering, chemistry, or biology involve recording sets of values of two variables and analyzing these data to determine how one of the variables affects the other. One way to examine the relation between two variables is to plot a graph and then decide if a line or smooth curve may be used to represent all the data. Suppose, for example, you have collected several pairs of data for two variables x and y. A good example of simple linear data is obtained by measuring the displacement, or amount of extension, of a vertically suspended spring with a mass hanging from it. The weight of the mass provides the stretching force, which extends the spring. The displacement of the spring (the amount it is stretched) is the dependent variable (y), and the force (weight of the mass) is the independent variable (x). The dependent variable depends on the independent variable. Y depends on x. The amount of stretch depends on the weight of the mass (not the other way around).

In equation form, Hooke's Law, as applied to a spring, looks like this:

$$F = - k x \qquad (1)$$

Where F is the force on the spring (in newtons) and x is the displacement, or amount of stretch, of the spring (in meters). The constant k, is called the spring constant, or stiffness constant, and has units such as newtons per meter. It's a measure of how much force per unit length it takes to stretch the spring. A high spring constant characterizes what we call a "stiff" spring. The minus sign is due to the fact that the spring force on the mass (up) is opposite to the direction of stretch of the spring (down).

Procedure: Part 1

1. Suspend a spring from a ring stand bracket and record on paper the initial position, L_o, of the bottom coil with respect to a meter stick taped to the ring stand.

2. Hang a mass hanger (the mass of which is 50 grams) from the spring and record this amount of mass as well as the new position L of the spring's bottom coil with respect to the fixed meter stick. This is trial # 1.

3. Place a mass of 100 grams on the mass hanger. Again measure and record the new position of the bottom coil. Remember to also record the TOTAL mass for this trial (including the mass hanger).
4. Repeat this procedure in 100-gram increments for four more trials. You should then have six pairs of data.
5. Using excel, complete a smooth data table, like the one shown below, which calculates the displacement for each trial ($L-L_o$) and the force on the spring for each trial. (The force is the weight of the mass.)
   Note that each column in the spreadsheet has a heading giving the physical quantity, with units in parentheses. The numbers shown are just examples.

   Initial position of spring $L_o = .252\text{m}$

Trial No.	Mass (kg)	Force (N)	Length, L (m)	Displacement, $L-L_o$ (m)
-	0	0	.252	0
1	.05	.49	.269	.017
2	.15	1.47	.305	.053
3	.25	-	-	etc.
4	.35	-	etc.	
5	.45	etc.		
6	.55			

6. Using Excel's "Chart Wizard" feature, plot a graph of Displacement vs. Force, with the displacement as the dependent variable. Display the trend line and its equation. The slope of the trendline should be the reciprocal of the spring constant, k.

Discussion Part 2, Non-linear Relations:

A good example of two variables that are NOT linearly related is the relation between the length of a pendulum and its period. The equation that describes this relation is:

$$T = 2\pi (L/g)^{1/2} \qquad (2)$$

Where T represents the period, or time to complete one whole cycle, and L represents the length of the pendulum. Clearly, this is not a linear equation in T and L. But by squaring both sides of this equation we have

$$T^2 = (4\pi^2/g) L \qquad (3)$$

Note now that T^2 and L ARE linear, and the slope of the line will be $4\pi^2/g$.

Procedure Part 2:

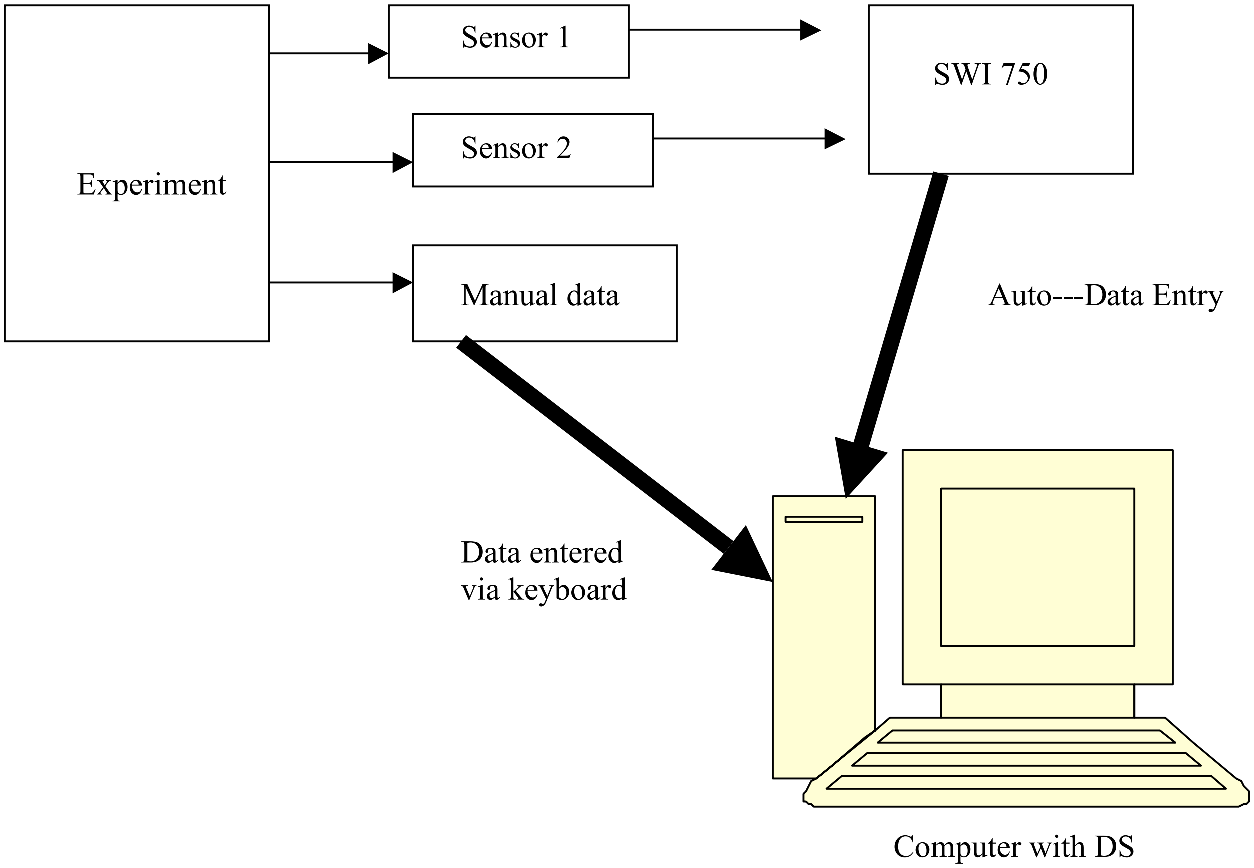
1. Suspend the metal bob from the ring stand bracket using a string length initially about 0.9 meters or so. Record your data table in exact length from the pivot point to the center of mass of the bob to the nearest mm using a meter stick.
2. Display the bob to one side of the vertical 5 or 10 degrees, release, and let swing.
3. Using a stopwatch, measure the period of the pendulum and record. To minimize measurement error due to hand-eye coordination, it is suggested that you measure, say, ten full cycles, and then divide the result by ten in order to get a more accurate period.
4. Shorten the length of the sting by 10 or 15 cm or so and repeat steps 2 and 3.
5. Repeat this process for several string lengths, working your way down to periods that are less than one second.
6. Create a spreadsheet in Excel similar to the one below, and then use Chart Wizard to graph T^2 vs. L. From the equation of the trendline, determine the value of g and compare to the accepted value of 9.80 m/s^2. Determine the percent error.

Trial No.	Length, L (m)	Stopwatch Period, T (s)	Stopwatch T^2 (s^2)
1	.906	1.853	3.4336
2	.789	1.674	-
3	-	-	-
-	-	-	
-	-		
-	-		
7	etc.		

Discussion Part 3:

Introduction to the DataStudio and ScienceWorkshop Interfaces

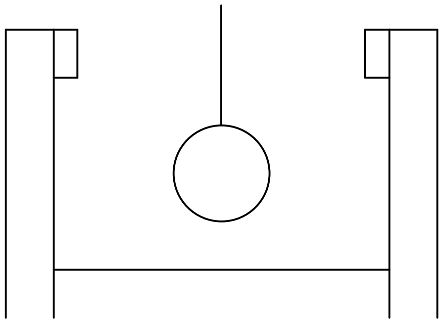
For many of the experiments during this semester, you will use a PC based automated measurements, data logging, analysis, and reporting interface called "DataStudio". The DataStudio (DS) software which controls the "Science Workshop 750 Interface" which is the black box on your desk, connected to the computer through a USB interface. The Science Workshop Interface (SWI) provides the hardware interface between your experiment and the computer, with the help of different sensors, such as voltage sensor, a photogate sensor, etc. The sensors help you make the measurements. The signals from the sensors are processed (converted to digital signals understood by the computer) by the SWI and sent to the computer. DS helps you to log, graph, and analyze the data, and also helps you to prepare your lab report. In some cases, you may do manual measurements, without using SWI controlled sensors. You can, in such cases, directly enter your measurement data into DS, and complete the analysis and reporting. The figure below gives a schematic representation of total system.



Procedure Part 3:

Setup:

1. Make sure that the SWI is connected to the computer and is on (Check the green light on the front panel)
2. Plug in the output of the photogate sensor to the DIGITAL CHANNEL 1 on the front panel of the SWI
3. Suspend the pendulum bob from the stand using the string and the clamp provided with the stand. The string length should initially be about a meter or so.
4. Position the photogate so that the pendulum bob is hanging between the arms of the photogate. Let the pendulum swing with a small amplitude in a vertical plane, and make sure that the plane of the photogate is perpendicular to the plane of the swinging pendulum, and the pendulum is swinging symmetrically on either side of the photogate. The bob should cut the beam of the photogate in each swing so that you can time the swing.



Run:

5. On your desktop, double-click the folder “PHYLab1” to open it. Then open the folder “Lab01”. In this, double-click the icon “Lab01Pendulum.ds” to start your experiment. The opening screen shows a “Data” display, a “Displays” display, a “Table 1” display, a “Experiment Setup” display, and a “Help” screen saying “The interface is ready for use”. Close the help screen by clicking on the X mark at its top right hand corner. The “Experiment Setup” display can be moved out of the way by clicking on the blue strip at the top and dragging it.
6. The “Experiment Setup” has a picture of the SWI showing the photogate connected to Digital channel 1. Table 1 will display the data form the first run of your experiment. The “Data” display shows the title of the experiment (Pendulum) and the number of runs you have made. The “Displays” display shows the display facilities that you are using in the current experiment. For example, here you are using a “Table” display, and “Table 1” is shown in the list of displays. In other experiments, you could use a “Graph” display, etc. You will use the “Table 1”, “Data”, and “Displays” displays, so if you wish, you can close the “Experiment Setup” display.
7. Set the pendulum to oscillate in a vertical plane with a small amplitude (pull the bob to one side by about 3 inches and let go). Watch the oscillations to make sure that the bob is not swinging in a horizontal ellipse or a circle. Once you are sure of that, you can start the timing. Let the pendulum continue to oscillate.
8. Locate the “Start” button on the tool bar at the top of the window on your screen. It has a green arrow on it, and there is a digital timer to its right. Click on the “Start” button. You will see the timer immediately. After each oscillation is complete, you will see a reading appear under “Time” and “Elapsed Time” in the Table 1 display. Successive readings will appear after each oscillation. At the bottom of the “Elapsed Time” column, you will see the Mean and Standard Deviation of the “Elapsed Time”, which is the time for one full oscillation. If you don’t see these, go to the top of the Table 1 display, locate the button marked. Click on the down arrow beside it and you will see a list of statistical functions available. Select Mean and Standard Deviation by clicking on them. A check mark will appear before each one. If any other functions have a check mark, deselect them by clicking on them.
9. After you have accumulated about a dozen readings, press the “Stop” button (The “Start” button would have changed to the “Stop” button) to stop the run

10. Leave the screen as it is, and start EXCEL. At the top of the spreadsheet, type "Lab01 Pendulum" and then enter the names of your team, and the date. You need to make an entry for the length of the pendulum on this spreadsheet. So under these entries, enter "Run 1", and under that, enter "Length (m)".
11. Carefully measure the length of the pendulum, from point of suspension to the center of the bob, and note the value in meters under Length. (University Physics students, measure the length 5 times, and get the mean and standard deviation of the 5 values using the AVERAGE and STDEV functions in Excel.) Under these values, you will directly import the data from run1 from the DataStudio screen.

Data exporting and importing:

12. First you have to export the data from DataStudio to a text file. Then you have to import the text file into Excel. So Go back to DataStudio-Lab01.
13. On the menu bar at the top, Click on "Display", and then on "Export Data". You will get a standard Windows "Save As" dialog box. Save the data file in the: Desktop\PHYLab\Lab01\StudentData\ folder, with a carefully selected name which should contain your initials followed by "Lab01Run1". Make sure that it is saved as a *.txt file. Click on Save.
14. Now go back to your Excel file. Under the value of the length of the pendulum click on a cell to highlight it. Go to the menu bar and click on Data>Get External Data>Import Text File. In the dialog box, double-click on the text file that you just saved, and "Text Import" dialog box appears. Click on Finish, and then click on OK to import the data. Notice that the mean and standard deviation do not get imported. You can just enter these values manually into your spreadsheet, or, ask Excel to again calculate these values.

Subsequent runs:

15. Go back to DataStudio. Shorten the length of the pendulum by 10 or 15 cm. Measure its length carefully. Make a second run, beginning with step 7.
16. Note: After Run 1, it is not necessary to import all the data into Excel. For each run, you only need the length of the pendulum, and the mean and standard deviation of the elapsed time. So from Run 2 onwards, you can just note the mean and standard deviation which you can see Table 1, and enter them into appropriate cells in Excel.
17. Repeat six runs with six different lengths of pendulum. Make sure that you change the length of the pendulum by more than 50% over all the runs.

Data Analysis:

1. Use the six sets of data in Excel for analysis.
2. Add a fifth and sixth column to your data table from Part II that are entitled Photogate Period (s) and Square of Photogate Period (s^2).
3. Now plot the square of the photogate period vs. the length, using the graphing facilities in Excel. From the slope, calculate g. In the results section of your report, compare this g-value with your stopwatch value and with the actual value.

4. **University Physics students:** Make sure of the significant figures. The error in g will depend on the errors in the length and time period. The relation is obtained as below:

   First, express *g* in terms of the measured quantities, the length of the pendulum *l* and the time period *T*:

   $$T = 2\pi\sqrt{\frac{l}{g}} \tag{2}$$

   Square both sides and rearrange:

   $$T^2 = 4\pi^2 \frac{l}{g} \tag{3}$$

   Now use calculus to find the error in *g* in terms of errors in *l* and *T*:

   $$\Delta g = 4\pi^2 \frac{\Delta l}{T^2} + 8\pi^2 \frac{l}{T^3}\Delta T \tag{4}$$

   The first term in equ, (4) is obtained by differentiating *g* with respect to *l*, assuming that *T* has no error, and is therefore constant. The second term is obtained by differentiating *g* with respect to *T*, assuming that *l* has no error, and is therefore constant. When you differentiate with respect to *T*, you will get a negative sign but you always add the contributions to errors form different sources. You can use equ. (4) to calculate the error in *g*. Δl and ΔT are the errors in *l* and *T*. You will have a different value for each of these form each run. But for the present, take the worst of these values.

Questions:

1. How do the measurements with the DS compare to your manual measurements? Describe in detail, in terms of precision, accuracy, ease, repeatability, time consumed, etc. Note, mere qualitative statements like, "This is more accurate" will not do. You must quantitatively compare the accuracies. Make sure that you distinguish clearly between accuracy and precision. Which of your experiments determining g was more accurate? Which was more precise? Why?