Lab 1: Introduction to Laboratory

Goals and Purpose

In this lab you will further your experience using Excel to analyze data graphically. In the pre-lab, you learned how to organize data in a spreadsheet and how to plot it. In this lab, you will analyze a plot by hand to determine the relationship between the plotted quantities. Then you will use Excel's built in features to do the same. By performing the analysis in both ways, you will discover the meaning of what the spreadsheet calculates and how it relates to the data.

Outline of the procedure

I. Preparing the Spreadsheet

- Log into the computer using the procedure described in Appendix B.
- You have been provided a set of data in an Excel spreadsheet. It is located on the Xenon server at **F:\USERS\LABS\PHY141\intro_data.xls**.

  Copy the spreadsheet file to the Desktop of the computer you are using.

- Open the file and add your name and your partner's name to the top of the spreadsheet page. Save a copy into your student directory on the **F:\STUDENTS** drive. You should find a sub-directory with your first initial and last name.

II. Description of the Data

The data in the spreadsheet represent what you might measure if you were doing a "thermal expansion" experiment. Most materials will increase in length when heated. The relationship is given by the equation

$$L = (L_0\alpha)T + L_0 \tag{1}$$

where α is called the "coefficient of thermal expansion", L is the length of the material at temperature T, and L_0 is the length of the material at absolute zero. The data may have been collected by heating a bar of metal to a given temperature and measuring the length, repeating the process for a wide range of temperatures. Note that the Kelvin scale is used where 0 K is absolute zero, 273.15 K = 0 °C, 373.15 K = 100 °C, etc.

A plot of L versus T (note that this means that L is on the y-axis and T is on the x-axis) should give you a relatively straight line, if equation (1) is correct, because it has the form

$$y = mx + b \tag{2}$$

where $y \to L$, $m \to (L_0\alpha)$, and $b \to L_0$. Such linear relationships will be a common theme in this lab course.

III. Plotting the Data and Analyzing by Hand

- Create a plot of L versus T in Excel using the same procedure as you did in the pre-lab. Make sure to label the axes with the variable name and the appropriate units. For this exercise, you do not have to include a title or caption, as you normally would. Add grid lines for both the *x*- and *y*- axes. To do this, under the **Chart** dropdown menu select *Chart Options*. Choose the *Gridlines* tab and select the minor axis gridlines for both axes.
- Adjust the range of the *y*-axis to start at 0.48 and end at 0.64. Make sure that the minor gridlines are something like one-fifth the value of the major gridlines.
- Print out a copy of the graph *for each lab partner*. Select printer *NSC135*, and your instructor will show you where to pick up your printed graph.
- You will now determine the relationship between L and T by determining the slope and intercept of a line that fits through the data. Since there is some scatter in the data (that is, the data are not exactly on any given line), there is some uncertainty about what the best-fit line would be.
- Instead, you will draw two lines that only approximate the trend in the data, one with the lowest feasible slope and one with the highest feasible slope. For each line, consider that the line should pass near every data point with approximately half the data points above the line and half below. This is a subjective process when done by hand. Take care, but realize that the "correct" lines are difficult to determine by hand. And be sure to extend each line to the vertical axis so that you can find the intercept. An example is illustrated in the figure below (Fig. 1)

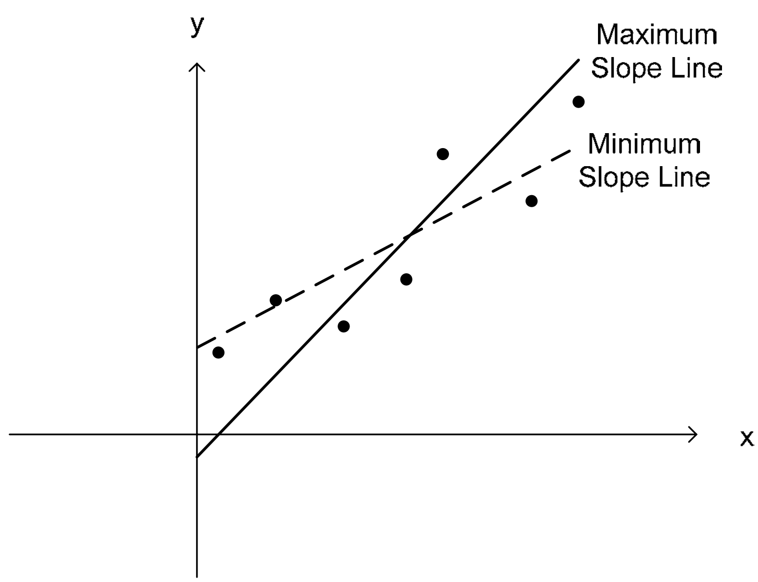

Figure 1. Drawing approximate maximum and minimum lines through data.

- Find the slope of each of the two lines you drew. Recall that slope is "rise over run" so you calculate

$$m = \frac{\Delta y}{\Delta x} = \frac{y_{end} - y_{start}}{x_{end} - x_{start}} \tag{3}$$

where the subscripts denote the starting and ending points of the lines you drew. What units does the slope have?

- Also find the intercepts by determining where each line intersects the vertical, or y-axis. What units does the intercept have? What physical quantity does it correspond to?
- You now have two different slope and intercept values for the data. Now you will approximate the slope and intercept of the best-fit line by taking the average of the two slope and intercept values. Calculate these values in Excel using the cells indicated in the spreadsheet. Be sure to include units for these quantities. When you do these calculations, DO NOT type numbers in when those numbers are already present in a cell on the spreadsheet. It I very easy to make mistakes this way. INSTEAD, type in the cell location (e.g., C10) to use that number in a calculation.
- The uncertainty, or error, in the slope is approximately given by the one-half of the difference between the two extreme slopes. Likewise for the uncertainty in the intercept. Calculate these uncertainties in Excel using the cells indicated in the spreadsheet for your results. By convention, uncertainties are always recorded as positive values.
- From your best-fit slope and intercept values determine α and L_0 for this material, using the cells indicated on the spreadsheet.
- The uncertainty in L_0 (indicated by the symbol σ_{L_0}) should be obvious to you from the previous step. However, the actual physical quantity that characterizes a particular material is the thermal expansion coefficient α, and its uncertainty (indicated by the symbol σ_α) is not obvious. Clearly it must depend on the uncertainty in the slope and intercept, but how? In the weeks ahead you will learn how to do this kind of calculation, which is called "error propagation." But in today's exercise, this calculation is done for you in the indicated cell. If you entered your values and errors for the slope and intercept correctly, then the uncertainty σ_α should appear. This is important to calculate, because it tells us how much confidence we should have in our experimental value of α.

IV. Analysis by Computer

Of course, analysis by hand is very subjective. Compare your results with your lab partners and with the other people at your table. You will find that your values likely disagree, though they should be fairly similar if you've been careful. We asked you to perform this analysis by hand so that you understand, to some extent, what the computer is doing when it finds slopes and intercepts and why there would be some uncertainty in these values.

Best-fit lines are better determined by computer. Excel uses a simple algorithm to fit a line to data, following standard statistical data analysis concepts. The procedure is called "Linear Regression" or just "Regression." It calculates the slope and intercept that minimize the overall distance between the data points and the fit line. You can find this data analysis tool under the "Tools→ Data Analysis" menu item. If it is not there, ask the instructor or lab assistant for help.

- Turn the minor and major gridlines off.
- Select the "Regression" data analysis tool.
- For the **y-range** data, highlight the data that is plotted on the vertical axis, in this case, the *L* data.
- For the **x-range** data, highlight the data that is plotted on the horizontal axis, in this case, the *T* values.
- Select **Output range** – click on the indicated cell in your Excel spreadsheet.
- After pressing **Enter**, a large table of values will be inserted into the spreadsheet where you have indicated in for the Output range. Label this table with a meaningful name such as "Results from best fit of L vs. T data"
- Most of the values in the table do not concern you. The ones to pay attention to are the "X Variable," (which is the slope) and "Intercept," (which is the y-intercept) entries under the column labeled "Coefficients." The column to the right of these values shows the "Standard Error" or "uncertainty" in the slope and intercept.
- How do the slope and intercept values as determined by the computer compare to your values? What about the uncertainties?
- Use the slope and intercept values to determine α and L_0 for this material. Be sure you put them in the indicated cells.
- Just as before, the uncertainty σ_α should be calculated automatically for you.
- What does this best-fit line look like and how closely does it follow the data? To find out, you will calculate what the fit says *L* should be for each value of *T*. In the "FitData" column create a formula that uses Equation (2) and the cell locations (e.g., J25) of the slope and intercept given by the regression analysis to calculate a value for *L* for each *T*.
- Add this FitData series to the graph. Since these are predicted data, not measured data points, you must change the representation from separate points to a line. Either double click on a best-fit data point or select **Format Data Series** for the best-fit data. Go to the *Patterns* tab and under *Line* select "Automatic". Then under *Marker* select "None".
- Examine the graph. Does the best-fit line look like it follows the trend in the data well? If not, check your calculations.
- Next, look at the FitLow and FitHigh columns. If you followed the instructions for the regression output, these columns have had their values calculated. They represent the lines whose slopes are two standard deviations above and below the slope of the best fit line. Plot these on the same graph. Make sure you have a legend on your graph with each of the data series labeled. It is possible that they are closer to the fit line than your hand-drawn lines are.

V. Turn In

Turn in your hand-analyzed plots (write your name on the top of the sheet), along with a copy of your computer-analyzed plot (properly formatted, of course). For the figure caption of the second plot, be sure to write in your calculated values for α and L_0. Print out and turn in this worksheet and your Excel spreadsheet. Staple all of the materials together in a logical order and turn them in prior to leaving lab.