Plotting with Graphical Analysis

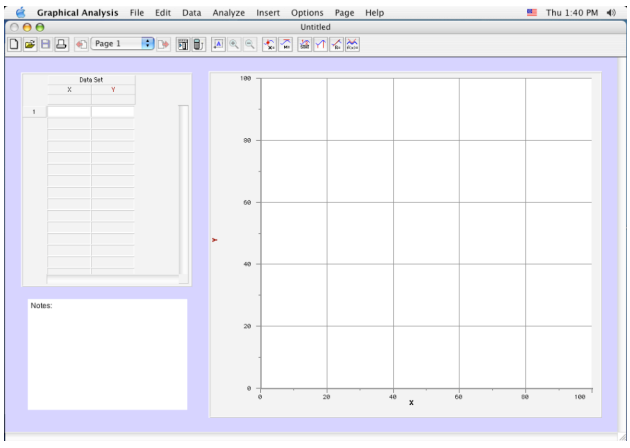
Many of the experiments in this course make use of graphing for analysis, and most will require you to fit a straight line to your measured data using the technique called *linear regression*. This is an opportune time for you to learn some computer graphing and analysis techniques that will make your life easier, allowing you to be neater and more accurate.

This write-up is not intended to be a full tutorial on using the Macintosh computer or on the program *Graphical Analysis*. Keep in mind that all you need for this course is a basic knowledge of *Graphical Analysis*. There are plenty of bells and whistles that can be used to improve the layout and look of your graphs, but they will not be required for this course. There's nothing particularly special about *Graphical Analysis* other than that it is loaded on the computers in the Physics labs and you can copy it if you wish. Other graphing programs with linear regression are just fine.

Graphical Analysis Summary

Starting *Graphical Analysis*:

Double click (two mouse clicks in rapid succession) on the *Graphical Analysis* icon. The opening screen will appear, then after a few seconds the view should switch to an empty data table with an empty graph (similar to figure).



Stopping *Graphical Analysis*:

To stop the program click on the **File** menu choice at the top, then drag the mouse down to highlight the bottom line, **Quit**. Release the mouse button, and the program will terminate. If you have any data entered you will be asked whether or not to save your file. More on saving and retrieving files later.

Note: In this document menu choices like that above will be indicated by **File/Quit**.

The Data Table:

Although you only see a few rows and columns, many more are available. Use **Data/NewDataSet** to create more data columns.

Data titles, labels, units: Give each of your data sets a title and all of your columns informative labels, so that you'll know what data or calculations they contain. Double click on "Data Set" to give it a name, for example "position vs time". To give a label to a column, double-click on the cell that is originally "X" or "Y". This will bring up a dialog box, and you can then type in a descriptive label, eg., "position". You can also type in the proper units, eg., "m". Your column labels will appear automatically on the graph as the axes labels.

(*Note:* Graphs are often described as "B vs. A." This means "vertical" vs. "horizontal" and you want graph B on the vertical axis and A on the horizontal axis.)

Entering and Editing Data:

To enter data into a cell, move the cursor to that cell and then click on it to select it. You'll see a box around the currently selected cell. Now type in your data, then press either "Enter", "Return," "Tab," or an arrow key. These differ by where the next selected cell appears. Practice using all of them to see what they do. "Return" moves to the cell to the right in the same row or if at the end of a row around to the start of the next row, and is effective for entering columns of data.

To change data, click on a cell and the current entry will be highlighted. Then type the new number, which will appear in its place, and

hit "Return" or "Enter." You can delete an entry entirely by selecting the cell, then pressing "Delete" or "Backspace."

Your data points will appear on the graph as you enter them with the number in the first column as the horizontal coordinate and the corresponding number in the second column as the vertical coordinate. The axis label and units that you entered at the top of the column will automatically appear. The points are connected by lines (see more on this below).

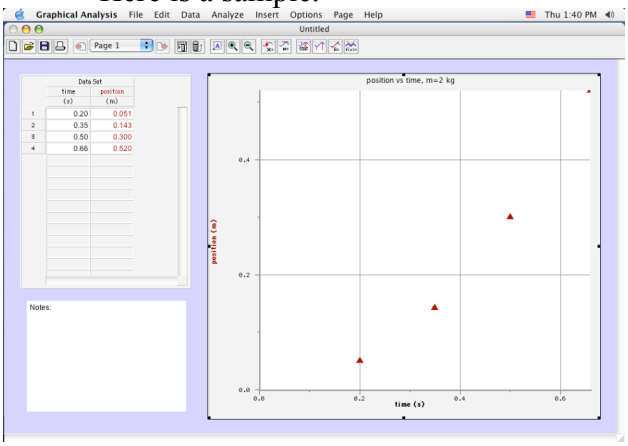
➤*Important note on computer notation:*

Graphical Analysis does not print subscripts or superscripts. So how can a number in scientific notation (e.g. 4.3×10^5) be entered without the superscript? The computer notation for this is 4.30e05, where the "e05" means "10 with an exponent of 5." (This might be familiar from your calculuator.) Don't confuse it with the number e=2.718, this use of the letter "e" is completely unrelated. For example, 2.55e-06 would mean 2.55×10^{-6}. You might see this notation when *Graphical Analysis* prints the linear regression equation on the screen, since the slope and intercept are often very big or very small numbers and scientific notation is needed.

Precision: By default, the data in the table is displayed with as many digits to the right of the decimal place as your most accurate data point. To change this you can select **Data/ColumnOptions**, then select Options and choose the number of decimal places or the number of significant figures in scientific notation to display.

Title: The last thing you need for a basic graph is a title. You can double-click somewhere in the main portion of the graph or select **Options/Graph Options….** A dialog box will appear allowing you to enter a title. You'll see other options in this box, such as error bars, etc. Try them out!

Here is a sample.



Graph Control:

Now you have a graph with all the data shown, the axes labeled with quantity and units (from the info at the top of the data columns), and an appropriate title. Some of the default settings are *not* optimal so to improve the graph, you will need to change some settings.

Lines: By default, data points are connected by line segments. This is almost always inappropriate. Double click somewhere in the graph or use **Options/Graph Options…** and uncheck the "Connect Points" box.

Scale: The minimum and maximum limits of the axis are selected by *Graphical Analysis* based on your data. These may be OK, but probably not. In general your data should include the origin. So you want the axes to start at x=0, y=0 but *Graphical Analysis* has probably started them at some other value. You can change these values by double clicking on an axis (the cursor will become a wiggly arrow) or use **Options/GraphOptions…**Axes Options.

Note: By now you should have noticed that *double* clicking on graph items is a standard way of selecting them for changes. Try it out!

Axes: To change either the horizontal or vertical axis, put the tip of the cursor arrow right on the axis and *double* click. This brings up a dialog box allowing you to change properties of the axis.

Grid: The default is a graph with grid lines. If you do not want grid lines, then select **Options/Graph Options…**Grid to turn the grid lines off. You can eliminate grid lines on every major tick mark, every minor tick mark, or both. Note that you'll need to do this on *both* of the axes to eliminate the full grid.

Symbol: You may not like the default symbol (triangle, circle, etc.) used for data points. To change it, double click on the label at the top of the appropriate data column. This brings up a dialog box, select the Options tab and pick a different symbol.

Misc: There are many more options for controlling a graph, but this is enough for now. You should try experimenting with other features that you see in dialog boxes to learn what they do. Or try double clicking on things to see what options you bring up. You'll always get a "Cancel" button, so you can see what options are available and then click Cancel to return to where you were without making any changes.

Changing what gets plotted: If you wish to change which quantities get plotted you can point to the axis label and a hovering "X" will appear, click once and a dialog box will allow you to choose which data set(s) goes on the axis.

More Advanced Techniques

The above procedures are the basic techniques of entering/editing data and producing a graph. In addition, you'll need to be able to do some calculations with your data, do linear regression, print both tables and graphs, and save your data and graphs for future use. These are described in this section.

Calculations with existing data:

After collecting data, you frequently need to add numbers together, multiply by constants, utilize functions, or perform other calculations. *Graphical Analysis* can do the straightforward calculations that we'll need in this course. To calculate new quantities that depend on the entries in other columns select **Data/New CalculatedColumn…** Be sure to give the new column a label before you forget what it is. In the dialog box you can access Functions or the Variables(Columns) from the menus. Now you can add, subtract, multiply, or divide the entries from different columns using the dialog box.

Functions: There many functions built into *Graphical Analysis,* some of them are: log, ln, exp (=e^x), sqrt, trigonometric functions: sin, cos, tan, etc.

➤The trigonometric functions expect arguments in radians. You can choose to use degrees by selecting **File/Settings for file…** and clicking degrees.

Example: Suppose you had a table with columns giving measured values of time (t) and position (x) and you want to calculate the acceleration, $a = 2x/t^2$ for each pair of points. Assume the data columns are labeled with "time" for t and "position" for x.

The following procedure will do this:

--**Data/NewCalculatedColumn…** will give a dialog box to specify the calculation.

--With the cursor in the equation box, type "2*", then Variables(Columns)/position.

--Now type "/", then Variables(Columns)/time, then "^2" (for squaring), giving: 2*"position"/"time"^2

--Click "Done". Now you have a new column with the acceleration.

Multiple Graphs:

You may sometimes need to plot two or more data sets on the same set of axes. Sometimes they all have the same set of x-values. For example, you might want to plot measured and theoretical position (possibly different y-values) at a fixed set of times (x-values). To do this, select **Graph Options/AxesOptions** and select as many columns as you want for y-values by checking the appropriate boxes. They'll all be graphed on a single set of axes with a different symbol for each.

NOTE: If your data sets have different x-values (e.g., different experimental runs) the x-column labels and units *must be the same*. For example you might have data set 1: columns

x, y and data set 2: columns x, y2. Then you would select y and y2 from the list.

Linear Regression (or Linear Least Squares Fitting):

After you're satisfied that the data is OK and is graphed the way you want, you're ready to apply linear regression, if it appears that the data is a straight line. Select **Analyze/Linear Fit** or use the Fit button  . A "best fit" straight line will appear on your graph, along with an equation for that line in a box. **You can read the slope and intercept directly from the equation,** thus eliminating the need to measure "rise-over-run" with a ruler. The equation for the line has been calculated from the data in your table, using the formulas given in the Introduction of this Lab Manual in the section entitled Least Squares. "Least squares" is the name of a statistical technique for choosing the line that represents the "best fit," and you'll learn where these formulas come from if you take a statistics class.

To see the uncertainties in the slope and intercept double click on the equation box and then check the "standard deviations" boxes.

After the equation there is the following "correlation=0.988." This is the "r^2 coefficient" or the "correlation coefficient," and it is a statistical measure of how good your assumption is that the data are really described by a straight line. Generally, you want r^2 to be > 0.90. If it's less, then you're probably not justified in fitting a straight line to your data. r^2=0 implies that the data are completely random and have no correlation at all.

You can remove the regression line from the graph, if you wish, by clicking at the upper left of the fitting equation box. You can also *move* the equation box to somewhere else on the graph if the default location is not convenient. To move it, click on it, keep the mouse button down, and *drag* the box to the desired location and release the mouse button.

Curve Fitting

The **Analyze** menu has other options. For example **Curve Fit…** finds the best fit of your data to nonlinear functions, such as polynomials. You may use the built-in functions or you can enter your own. Also, you can do the curve fit manually by adjusting the fit parameters or allow the program to do it automatically.

Printing and Saving

Once you've finished with a graph, you'll want to print it. You may also want to print the data table. Either or both can be taped into your lab report or lab notebook. You may also want to save your work for future use. Both of these are easy.

Printing:

To print just the data or the graph you can select **File/Print Data…** or **File/Print Graph…**.

If you've made more than one graph and would like to print them on a single page, be sure that neither graph is selected by clicking the mouse somewhere else. Now you can use **File/Print Graphs…**.

Saving Files:

If you're not finished working with a table or graph, or if you think you might want to return to it, save it. To save a data table, make it the active window and select **File/Save As…**. Now give your file a name and indicate which folder or location in which to save it.

Retrieving Files:

To return to a saved file, start *Graphical Analysis* normally, then when the empty data table appears, close it with the Close Box in the upper left. Don't save. After it's gone, choose **File/Open**. A dialog box will appear, similar to that used for saving files. A box at the top indicates the active location. Select the correct location and file.

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