Lab 1: 225L Graphical Analysis

Experiment for Physics 225 Lab at CSUF

What You Need to Know

Introduction:

Most of you have likely had to plot graphs sometime in your previous education. Graphs are an extremely useful way to display data, trends in the data, and help us to understand the nature of a process or proposed law. There are many different types of graphs, a sampling of which can be found under the insert menu item, charts, in the Excel spreadsheet.

In this first lab we will focus on two dimensional graphs, and the two most commonly used in science and engineering, Cartesian plots and log-log plots. The most common type of graph called a Cartesian plot is when both of the axis scales are linear (equally spaced divisions). This type of plot is useful for displaying data that have a linear relationship, or one that is nonlinear, where the data do not range over multiple orders of magnitude. Arguably the second most common graph used to display data and find trends is the log-log plot. This is where both axis scales are ruled proportional to the log of the number[1]. This type of graph is extremely useful in situations where one or both variables ranges over multiple orders of magnitude, and for extracting power law relationships and their exponents between variables.

Summary:

In today's lab, you will be making two graphs by hand, one on Cartesian graph paper and one on log-log graph paper which will be supplied. In addition, you will make two graphs on the computer using the Excel spreadsheet.

In the Cartesian graph section, you will plot the data given and determine the slope and intercept, assuming a linear relationship between the variables exists. You will also determine the slope and intercept using a best fit trendline and compare to the hand drawn graph results for the slope and intercept. A spreadsheet will be used to investigate the effects of random noise on the slope and intercept values.

In the log-log graph section, you will plot the data for the period of the planets vs. their semi-major axis distances (effectively their mean distance from the sun) to find the mathematical relationship between them. You will find the exponent of an assumed power law relationship between the variables for both the hand drawn graph and the computer graph with a least square fit trendline, and compare the two values.

The paper graphs should be stapled together and submitted with the names of all partners. The rest will be pasted into the digital report. The details of this exercise follow.

[1] The semi-log graph, where one axis is scaled linearly, and the other proportional to the log of the number, will not be covered in this lab.

What You Need to Do

Part 1: Cartesian Plots

You are given the following data of velocity v as a function of time t for an air track cart.

	no noise	noisy
t(s)	v (m/s)	v_n (m/s)
0.35	2.948	2.786
0.85	2.873	3.143
1.35	2.798	2.540
1.85	2.723	2.719
2.35	2.648	2.857
2.85	2.573	2.805
3.35	2.498	2.257
3.85	2.423	2.596
4.35	2.348	2.243
4.85	2.273	2.377

Figure 1 - Velocity as a function of time for air track cart

The second column in Table 1 are the exact or ideal values of v. The third column of the table labeled v_n, are one set of values with uniformly distributed random noise or error of up to ±10% added to the data of column 2. This is one of many possible sets of random noise values of v_n.

Hand Drawn Plot

A) Plot the column 3 data as a function of time (v_n, vs. t from Figure 1) by hand on Cartesian graph paper (v_n on the vertical scale, t on the horizontal scale). Yes draw it by hand on physical paper, your instructor will not accept an excel graph for this part, it is an educational requirement that you sketch and analyze at least one graph by hand. Use the following best practices:

   a. Draw data points with large markers so that they are easily seen (X is a good marker for hand graphs having relatively few data points. Computer graphs have many different markers to select from).

   b. Choose the vertical and horizontal scales on the hand drawn graph so that the data are spread out over most of the horizontal and vertical range of the plot area and the numbered values on the axis are convenient.

   c. Label the variables near their axis with their units in parenthesis, as shown on the example (computer drawn) graphs of the data in Figure 2. Assume constant acceleration so that $\mathrm{v} = \mathrm{v}_0 + at$, and draw the best "eyeball fit" straight line through your data.

An "eyeball fit" straight line to the data places the line so that about the same number of data points are above the line as are below the line, and the areas above and below the line to the data are approximately equal. This is a somewhat subjective procedure.

   d. Extend the line to the y axis so that you can determine the *y* intercept from your plot.

B) Determine *a* and v_0 from the slope and *y* intercept of your graph and write their values (with units) on the graph and in Table 2 which follows.

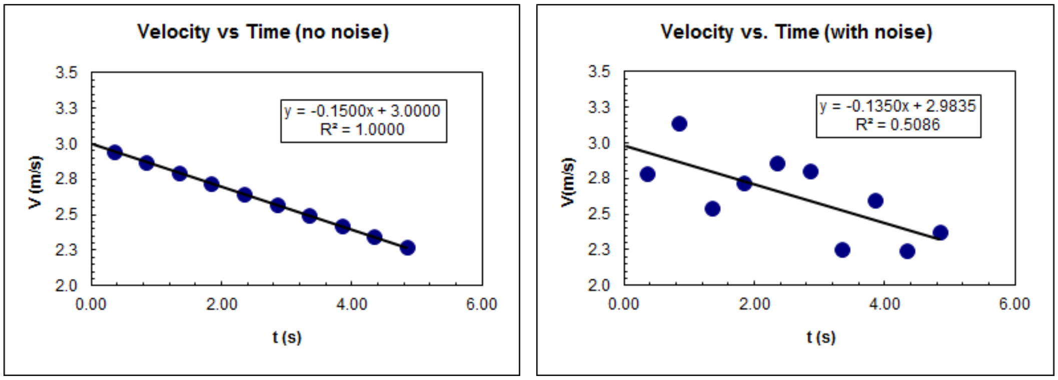


Figure 2 – Excel plot of Velocity vs. time for the data in Table 1.

a. The slope *m* in the linear equation $y = mx + b$ is determined by choosing 2 points (x_1, y_1) and (x_2, y_2) on the line that are conveniently separated and using the equation $m = \Delta y / \Delta x = (y_2 - y_1)/(x_2 - x_1)$.

Example graphs in Figure 2 show the labeling and choice of axis scales to display data over most of the plot area. Note that the best fit, "least squares" straight line equation is given in the inset, as well as R^2, which is the coefficient of determination, and a measure of the goodness of the fit. The closer R^2 is to one, the better the fit of the model curve to the actual data.

Checkpoint 1:

Of the plots in Figure 2, which one has a more linear relationship? Support your answer with a number from the charts.

C) Write your names on the physical graph paper, you'll turn it in at the end of the lab with your report.

Excel Plotting

A) Begin by opening the 225 student excel spreadsheet using MS excel on our computers from the Supporting Files section of the website.

Note you'll be using the different tabbed sheet found in the student spreadsheet for this lab. They may not be visible if you don't have the excel window maximized, but they should be at the bottom, shown in Figure 3.

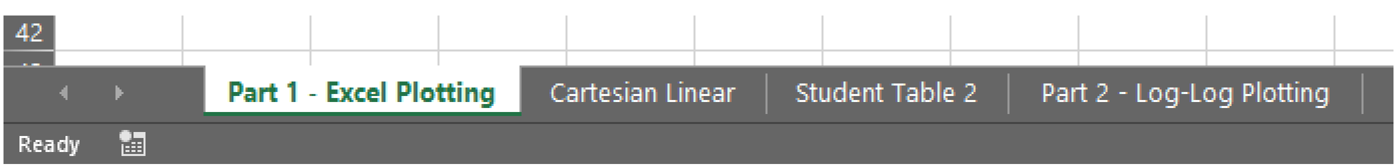


Figure 3 – Excel Tabs location.

A) Enter the (t, v_n) data points in 2 adjacent columns in the Part 1- Excel Plotting of the Excel spreadsheet.

B) Make a similar plot (scatter plot with no lines connecting the data points) for the data in the Excel spreadsheet and pass a linear trend line through the data.

If you are unfamiliar with excel and need assistance in this step, see *Appendix A: Making and formatting a linear chart with excel*

C) Format your plot properly with the following:

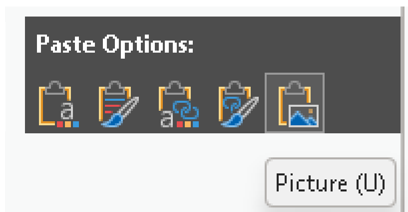
a. Display the graph equation and the R^2 value on the graph, which are options in the trendline box that pops up when you specify trendline.

b. Format the trend line label so that it has 4 decimals (this is under format trendline label when you right click on the trendline and number format). The default does not usually have enough significant figures to get an accurate value of the slope and intercept.

c. Be sure to title the graph, and label the axis with title and units in parenthesis, as in the examples in Figure 2.

D) Copy and paste your graph into your report.

Figure 4 – MS Word Paste Menu



Note for your graph, when you paste it don't ctrl-v, right click and select the paste as picture option as shown in Figure 4, this will avoid any formatting issues.

Part 1- Excel Plotting Completed Graph

Question 1:

Compare the difference between your "eyeball fit" to the data, slope and intercept, and your trendline fit values from Excel for the same set of data. Which one do you have more confidence in?

Effect of deviation and noise on the determination of fit parameters

Next you will use the Cartesian linear tab worksheet to see how different amounts of deviation or noise in the data affect the slope and intercept values by entering in the same and different values for the noise amplitude.

A) Enter your eyeball fit slope and intercept values from Part 1 – Hand Drawn into the first row of Student Table 2 (in the Student Table 2 tab).

Student Table 2

Effect of different noise amplitude on determination of slope and intercept

					no noise value $a(m/s^2)$	no noise value $v_0(m/s)$
	Enter your numbers in highlighted cells				**-0.15**	**3**

	Noise Amplitude	Slope $a(m/s^2)$	Intercept $b = v_0$ (m/s)	Coeffic of Det. R^2	%dev from no noise Δa	%dev from no noise Δv_0
eyeball fit	**0.1**			NA	-100.0000	-100.0000
	0.1	-0.1402	2.8872	0.7492	-6.5038	-3.7611
	0.1	-0.1900	3.0856	0.8543	26.6750	2.8536
	0.1	-0.0929	2.7627	0.4953	-38.0953	-7.9111
	0.1	-0.1665	3.0055	0.6696	10.9838	0.1844
	0.1	-0.1334	3.0378	0.6093	-11.0744	1.2604
	0.05	-0.14278315	2.97100571	0.80857552	-4.8112	-0.9665
	0.05				-100.0000	-100.0000
	0.05				-100.0000	-100.0000
	0.08				-100.0000	-100.0000

Figure 5 – Student Table 2

A) Enter the noise Amplitude values from the first column in Student Table 2 into the Noise Amplitude cell at the top of the Cartesian Linear tab in excel. You should notice all the graphs and v_n data change.

For example, you'll first enter 0.05 as shown in Figure 6.

Figure 6 – Where to adjust noise amplitude.

	A	B	C	D	E	F	G
1							
2			**v0 (m/s)**		**a (m/s²)**		**Noise amplitu**
3		enter->	3	enter->	-0.15	enter->	0.05
4			(3 default)		(-.15 default)		(0.1 default)

B) Copy and use the paste special (right click -> select number formats and values option) to paste the 3 new values for a, v_0 and R^2 in Cells L6-N6 in the Cartesian linear tab into the corresponding rows in the Student Table 2 sheet tab

Note it does not work if you just use paste, since it copies the cell formulas from the Cartesian linear sheet and not the numerical values.

Figure 7 – Where the values to copy are.

K	L	M
Best Fit Trendline parameters		
Slope	**Intercept**	**Coeff. of Det.**
a (m/s²)	**v0 (m/s)**	**R^2**
-0.0934	2.7820	0.5695

C) Type the next value in the amplitude column into the Cartesian Linear tab, and continue until you fill out the remainder of Student Table 2. Be sure to do at least 2 of each noise value, do all 5 if your instructor requests it.

Note if the number is the same just type it or paste it into the cell again and press enter, the sheet will recalculate, emulating a repeated experiment with the same deviation present.

D) Copy and paste your completed table into your lab report.

Part 1- Completed Student Table 2

Checkpoint 2:

A higher Noise Amplitude corresponds to more deviation from experimental sources. What trend do you notice between the Noise amplitude size and the coefficient of determination?

Checkpoint 3:

Is there a consistent trend between the Noise Amplitude and the deviations? (The last two columns)

Notice for the 0.1 noise amplitude the slope and intercept vary considerably between different random configurations with the same noise amplitude. The slope varies from the no noise value between about -36% to +27%, and the intercept varies considerably less, from about -8% to about +2.9%. This shows that the determination of the slope can be much less accurate than the noise percentage, which was no more than +/- 10% in the table, and the accuracy of the intercept determination is comparable to the noise amplitude. There are mathematical equations for how the noise in the data affect the determination of the parameters, but these are beyond the present introduction to the effects of noise and error on the determination of parameters.

Question 2:

What can you conclude about the possible accuracy of the determination of the slope and intercept vs. the variation of the noise for these other cases?

Part 2 – Linearization and Log-Log Plotting in excel

Sometimes a relationship is nonlinear, or covers a large scale. Linearization can help us extract data, and Log-Log plots are useful for representing data over larger scales.

A) Repeat the excel plotting exercise in part 1 for the first two columns of the solar system data on the sheet 2 tab of the spreadsheet, just up until you have a nicely formatted graph to view the data. You'll come back and manipulate this graph more later.

You should notice that this is a nonlinear data set. You're still plotting an exponential relationship, specifically it's theoretically:

$$T = a^{3/2}$$

One of Kepler's laws from later in your course.

So we have two options, we can either plot this relationship on a different type of graph (log-log) or Linearize the data.

Linearization

Linearization is the process of "massaging" an equation to the linear form

$$y = mx^1 + b$$

In our example if we generalize Kepler's law a bit we currently have

$$y = Ax^{3/2} + b$$

Checkpoint 4:

Compare the generalized equation to Kepler's law above. What are y, A, and b equal to?

This is nonlinear, as you see when you graphed your data. So do some algebra to turn it into something with one exponent.

Question 3:

Apply Logs to both sides of the equation with $b = 0$ and use the properties of logs to get this into linear form.

$$y = bx^{3/2}$$

Your answer to question 3 should be

$$\log(y) = \frac{3}{2} * \log(x) + A$$

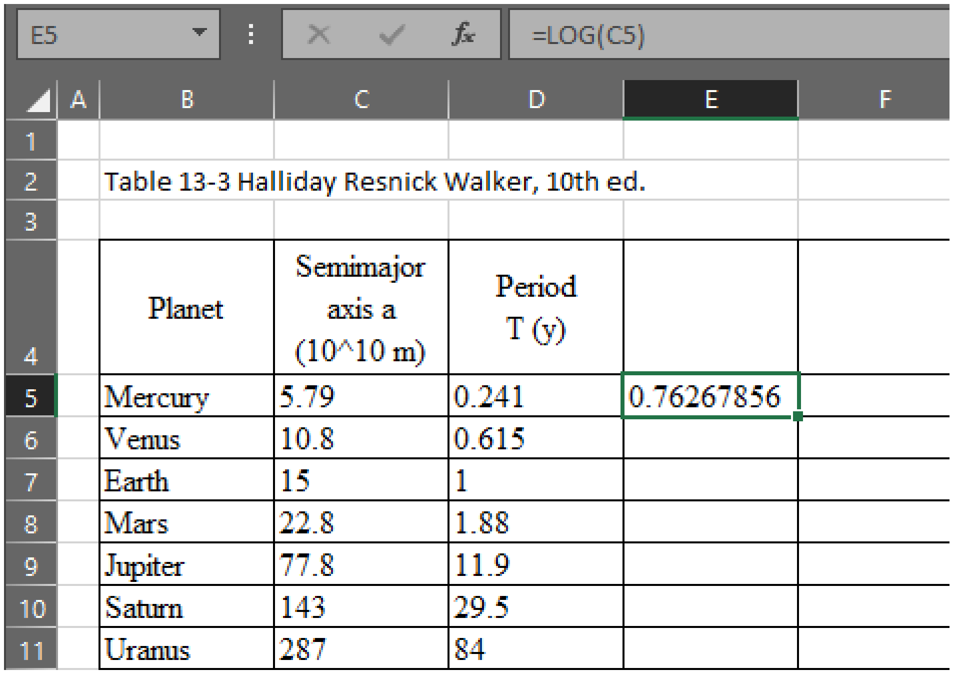
So if we graph $y\ axis = \log(y)$, $x\ axis = \log(x)$ we are plotting the equation

$$y\ axis = \frac{3}{2}\ x\ axis + A$$

Which is a linear equation!

A) Use an excel equation in Column E to calculate the log(semimajor axis a) for each value.
   a. Start by typing =log(and learn how it works. Check Figure 8 for help.

b. Once your sheet computes the first value in cell E5, click the solid box in the bottom right corner and drag it down, or double click it so that it fills the entire column. Shown in Figure 8.



	A	B	C	D	E	F
1						
2		Table 13-3 Halliday Resnick Walker, 10th ed.				
3						
4		Planet	Semimajor axis a (10^10 m)	Period T (y)		
5		Mercury	5.79	0.241	0.76267856	
6		Venus	10.8	0.615		
7		Earth	15	1		
8		Mars	22.8	1.88		
9		Jupiter	77.8	11.9		
10		Saturn	143	29.5		
11		Uranus	287	84		

Figure 8 – Excel Equation

c. Don't forget to label your column in the top cell! (Not shown in figure 8)

B) Use an equation in Column F to compute the log of the period. (Tip you can move the solid box sideways too)

C) Insert a chart of your two log computation columns and follow Part 1 – Excel Plotting until you have a nicely formatted chart with a LINEAR! Trendline.

Notice here your graph should now be linear since you're plotting a Linearization of your original data. If its still not linear, call over your instructor.

D) Paste this graph into your report.

Part 2- Linearized Graph

Question 4:

Compare the slope of your graph to the linearized version of Kepler's law and find a % difference. You may need to right click -> format trendline label, change to number, and show at least 6 decimals(a %0 difference will not be accepted, everyone is using the same data we know what it should be)

Checkpoint 5:

To check your understanding try to linearize the Energy equation $K = \frac{1}{2}mv^2$ if you have data for K and v. What would you plot on each axis to show a linear relationship?

Log-Log Axis

Alternatively in this scenario since we're just using a log transformation we can just plot the data on a different graph.

A) Go back to your nonlinear graph at the beginning of this section and this time change the graph axis scales to log-log (this is done by right clicking on the numbers below each axis and selecting format axis. Click logarithmic scale as one of the options on the window that pops up). See Figure 9.

Now your data APPEARS linear, so you can visually see if it's a good fit or not. Can we use a linear trendline though?

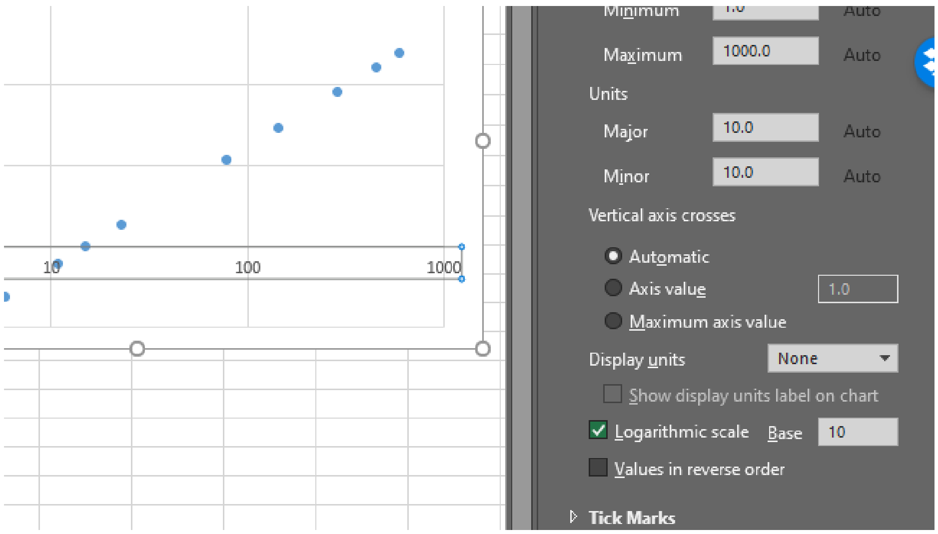


Figure 9 – Logarithmic Scale Checkbox

B) Add a linear trendline to the data if you haven't yet, it should now be very obvious this not a linear graph, the linear trendline not go through the center of the data.

C) Right click that linear trendline you made and go into "more trendline options". Click through the other fits until one goes right through all the data. (Or think about it and figure out what type of relationship you're plotting)

D) Add an equation and R^2 value. You may need to format the label to add decimals since it is very precise data.

E) Paste this log-log graph with the new nonlinear trendline into your report.

Part 2 – log-log axis graph with nonlinear trendline.

Question 5:

Compare the exponent in your fit graph to the exponent in Kepler's law and find a % difference. Again you may need to right click -> format trendline label, change to number, and add decimals until you get to the difference.

Conclusion

Follow the lab report guide to write a conclusion on this lab.

Submit any excel or graphical analysis data your instructor requests along with your report.

Conclusion

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Appendix A: Making and formatting a linear chart with excel

A) Make your graph with the following steps, but all the rules of a hand drawn graph from earlier still apply, make the data take the entire graph, pick good axis limits, axis and graph titles, etc.

a. Click and hold the first value in your x-axis column.

b. Drag to the bottom value of your y-axis column.

Note it helps to have x column first then y column since that's excels default order. You can switch them after you make the graph by clicking the data and moving the highlighted boxes, or right-clicking the graph, selecting "Select Data" and changing it there.

L(m)	sqrt(L)	T(s)
0.15	0.387	0.74
0.3	0.548	1.11
0.45	0.671	1.38
0.6	0.775	1.55
0.75	0.866	1.75
0.9	0.949	1.88

Figure 10 – Excel table highlighting

c. Once you have your two columns selected as shown, go to the top of the excel sheet and locate the "Insert" tab. (Office 365 word bar shown)

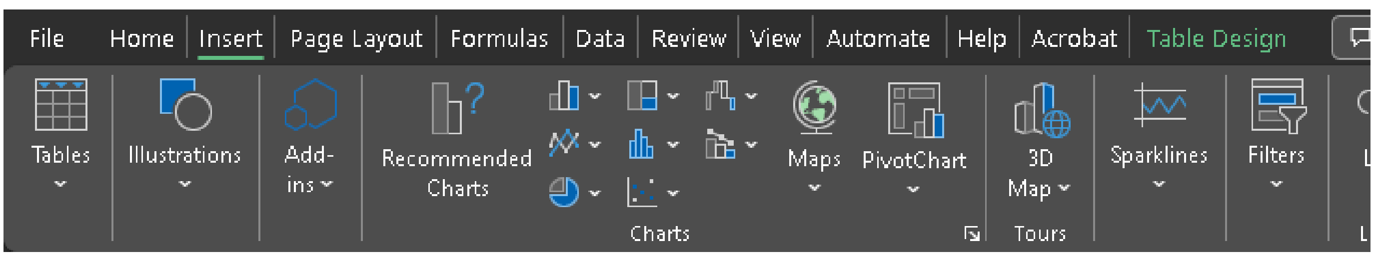
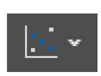


Figure 11 – MS Word top ribbon, showing insert

d. Then click the scatter chart icon  and select the first one, "scatter"

B) You should now have the simple scatter plot shown. From here you can adjust most everything by right clicking it, or adding missing things like axis labels from the + menu at the top right of the graph.

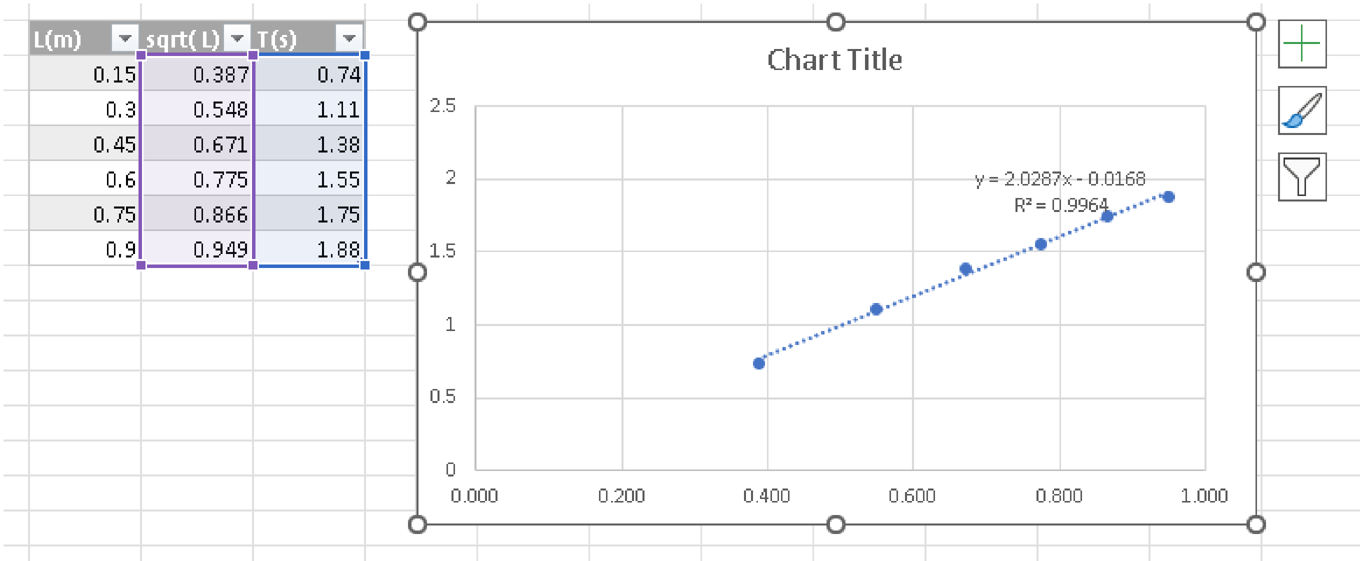


Figure 12 – Unformatted sample graph

C) In particular we need a trendline for slope and y intercept.

a. In the + menu click the arrow next to trendline, then select "More Options" .

b. In the "Format Trendline" menu check the bottom two boxes, Display Equation and Display R-squared value.

Excel just did the same thing you did by hand, but with a bit more precision and mathematics.

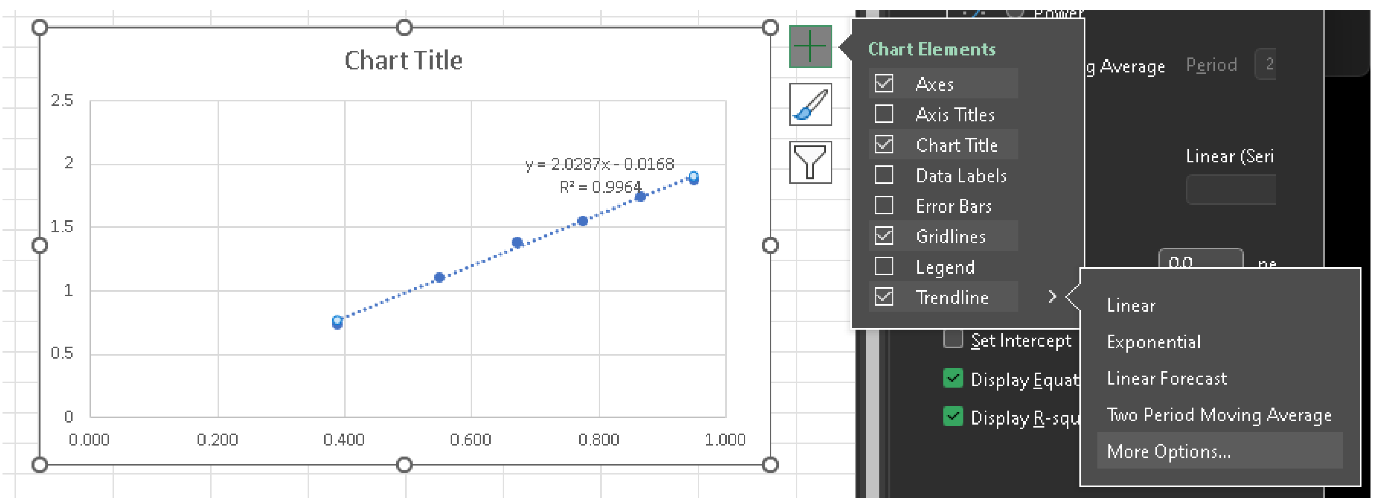


Figure 13 - + Menu in MS Word