GRAPHING

Objectives

1- To plot and analyze a graph manually and using Microsoft Excel.
2- To find constants from a nonlinear relation.

Exercise 1 - Using Excel to plot a graph

Suppose you have measured the speed ***v*** of an object as a function of time ***t***. Since you choose the values of time, ***t*** is the independent variable and ***v*** is a dependent variable. The data is shown in the table below:

t (s)	v (m/s)
0	20
5	30
10	40
15	50
20	60
25	70
30	80

Remember that you have studied in your physics course that ***t*** is related to ***v*** by the equation:

$$v = v_0 + a\,t$$

where a is the acceleration, t is time and v_0 is the initial velocity.

Plotting the data

You want to plot v versus t. This means that you want to plot v on the vertical axis and t on the horizontal axis.

1. Open Microsoft Office Excel 2007 and enter (or copy and paste) the data and then select it as shown in Figure 1.

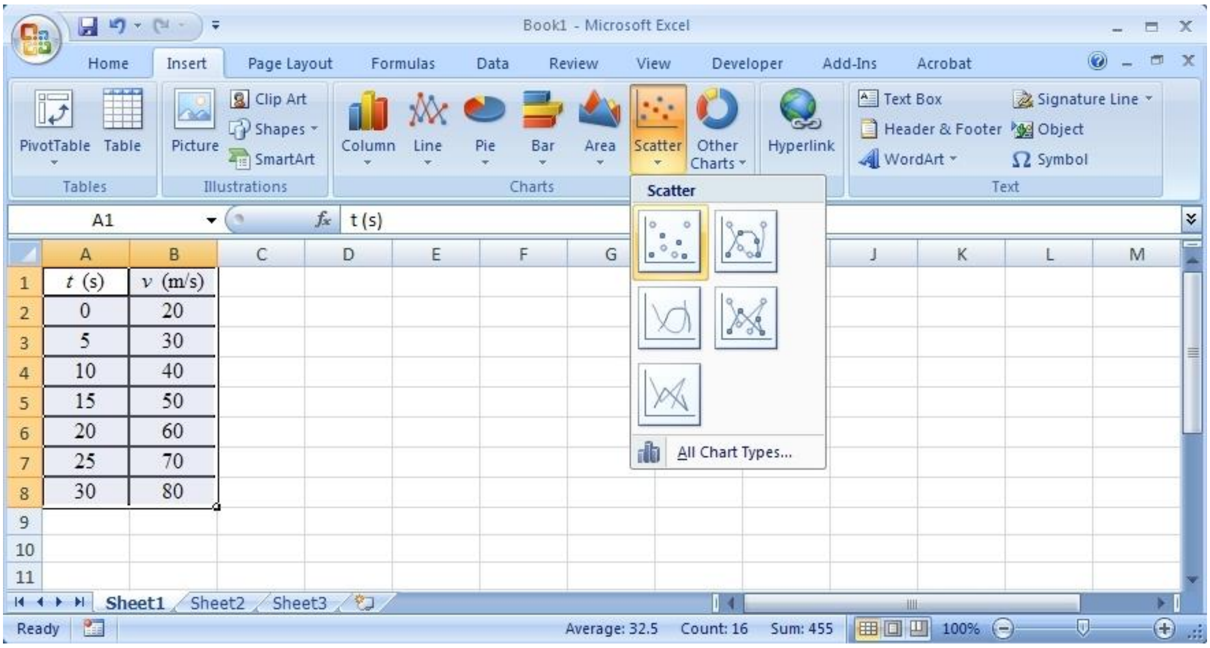


Figure 1

2. Click on ***Insert*** tab, then in the ***Charts*** group click on ***Scatter*** button and choose the first option. This will take you to ***Design*** tab. See Figure 2. Note that the tabs of **Chart Tools** (**Design**, **Layout** and **Format** tabs) become available only when you are working on the chart (graph).

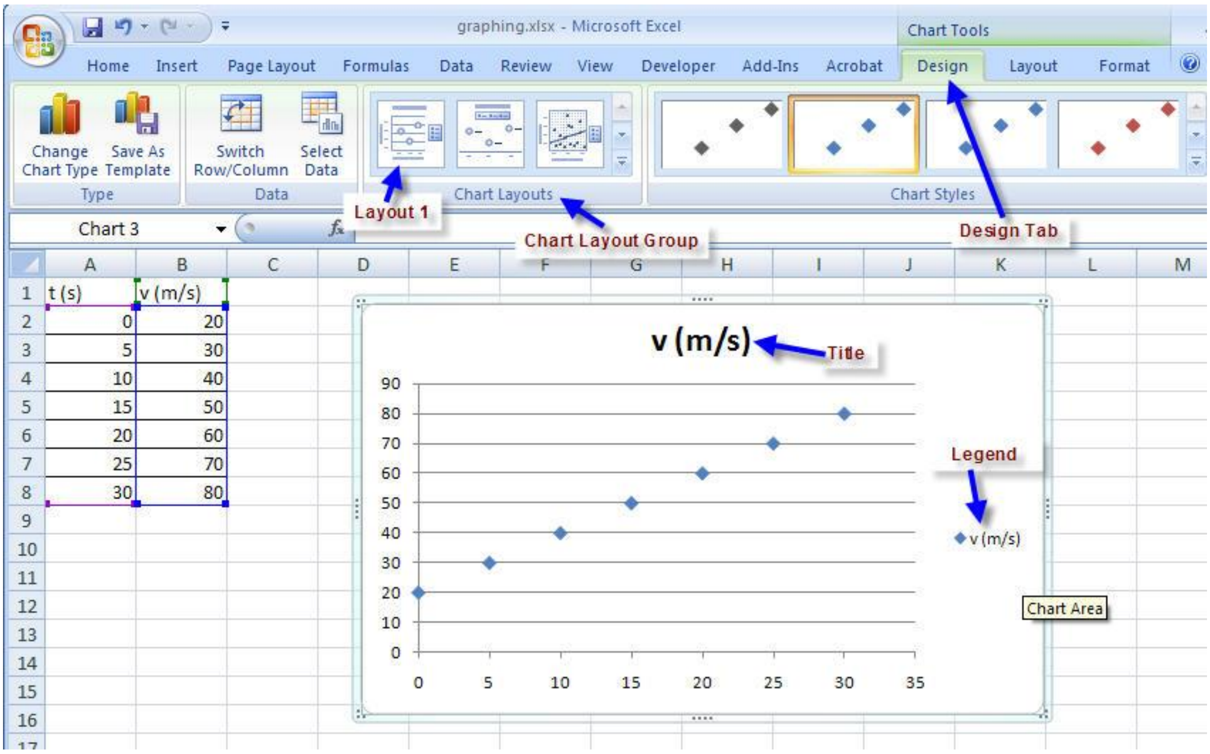


Figure 2

3. In the ***Chart Layouts*** group choose the first **Layout**. Change the chart title to *Exercise 1*, the x-axis title to *t (s)*, and the y-axis title to *v (m/s)*.

4. Add gridlines to the x-axis by right clicking on the x-axis numbers and choose ***Add Major Gridlines***.

5. Right click on the ***Legend*** entry and choose ***Delete***.

Finding the slope and the y-intercept

6. To fit your data to a straight line, right click on the data points in your plot and choose ***Add Trendline***.

7. Select ***Linear***, tick ***Display Equation on chart*** and close the ***Format Trendline*** window.

8. Move the equation up using the mouse, and you should get a graph as shown in Figure 3. Note that Excel takes the leftmost selected column (t) as the x-axis by default.

9. Write the equation that you got in step (8) in your notebook.

10. What is the slope of the straight line? What does it represent?
11. What is the y-intercept? What does it represent?

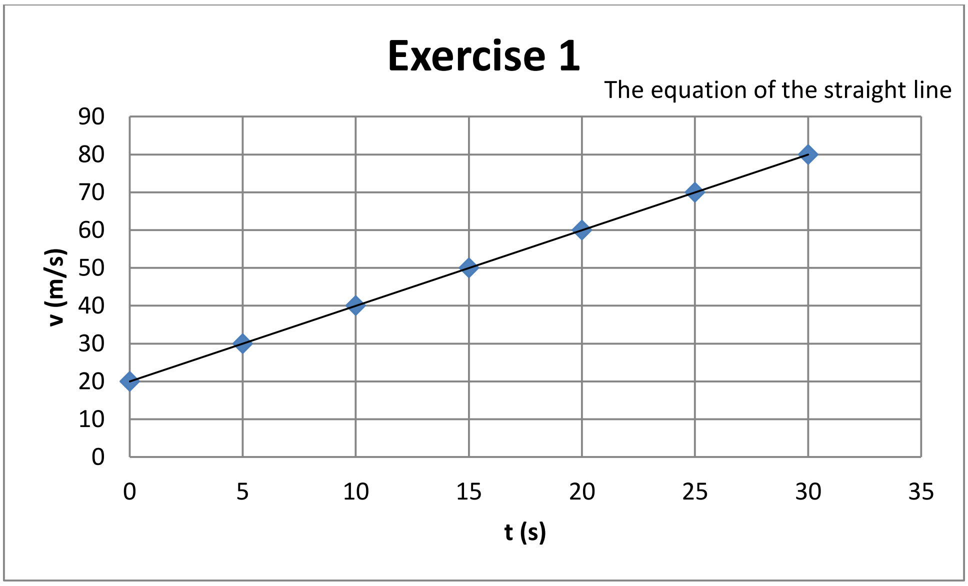


Figure 3

Exercise 2 – Plotting a graph manually

Use the data given in the table of Exercise 1 to plot v vs. t in your notebook. This means that you want to plot *v* on the vertical axis and *t* on the horizontal axis.
You may need to have a look at the appendix at the end of this write-up to get general advice on how to create a graph manually.

The slope is the change in *v* divided by the change in *t*.

$$slope = \frac{change\ in\ v}{change\ in\ t} = \frac{\Delta v}{\Delta t} = \frac{v_2 - v_1}{t_2 - t_1}$$

If you apply this formula to any two points on the line, you should get the slope of the straight line.

1. What is the slope of the straight line?

The y-intercept is where the line meets the vertical axis.

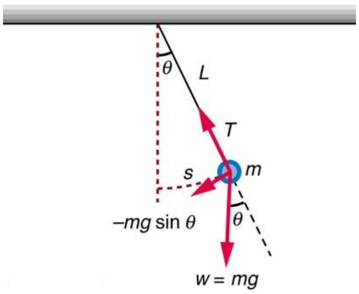
2. What is the y-intercept?

3. Compare your findings in exercise 2 with what you have found earlier in Exercise 1.

Exercise 3 - Finding constants from non-linear relations

In chapter 15 of your textbook, you will study the simple pendulum. The period T of a simple pendulum of length L is given by:

$$T = 2\pi\sqrt{\frac{L}{g}}$$



Where:
g is the free-fall acceleration (constant)
T is the period of oscillation (Dependent variable)
L is the length of the simple pendulum (Independent variable)

The relation between T and L is non-linear. The table below shows the data collected by a student for the dependence of T on L.

L (m)	T (s)
0.25	1.00
0.50	1.42
0.75	1.74
1.00	2.01
1.25	2.24
1.50	2.46

We will now use excel to make three plots. Copy the table in an excel sheet and then make the following plots and answer the questions in your lab notebook.

1. Plot T vs. L. Do you get a straight line? If you get a straight line, then find the slope and the value of g.
2. Add one column in the table for $\sqrt{\mathbf{L}}$ and plot T vs. $\sqrt{\mathbf{L}}$. Do you get a straight line? If you get a straight line, then find the slope and the value of g.
3. Add another column to the table for $\boldsymbol{T^2}$ and plot $\boldsymbol{T^2}$ vs. L. Do you get a straight line? If you get a straight line, then find the slope and the value of g.

Exercise 4 – More examples on non-linear relations

1. In physics 102, you will study the ideal gas law. The pressure P of an ideal gas in a container with variable volume V at constant temperature T is given by:

$$P = \frac{nRT}{V}$$

Where:

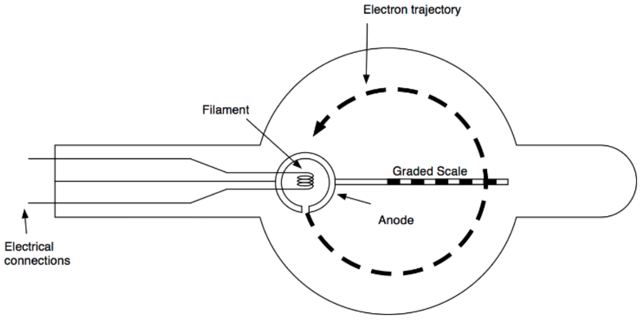
n is the number of moles (constant)
P is the Pressure (Dependent variable)
V is the volume of the vessel (Independent variable)
R is the universal gas constant (constant)
T is the temperature of the gas (constant)

The relation between P and V is non-linear. If you do an experiment and collect data for P and V and plot P vs. V, you will not get a straight line.

a) What should you plot in order to get a straight line?
b) What does the slope of the straight line represent?
c) What is the y-intercept?

2. In physics 102, you will study the effect of a magnetic field on a charged particle. The radius r of a beam of electrons circling in a region of an external magnetic field B is given by:

$$\frac{e}{m} = \frac{2V}{B^2 r^2}$$



Where:

r is the radius of the circular path of electrons (Dependent variable)
V is the accelerating voltage (Independent variable)

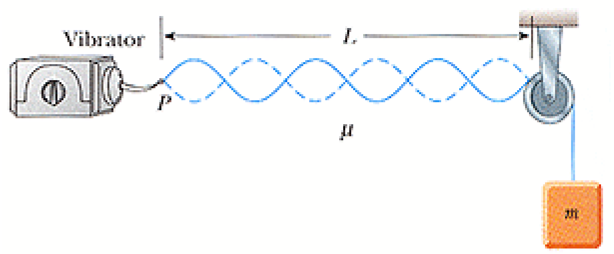
e is the charge of the electron (constant)
m is the mass of the electron (constant)
B is the external magnetic field (constant)

The relation between r and V is non-linear. If you do an experiment and collect data for r and V and plot r vs. V, you will not get a straight line.

a) What should you plot in order to get a straight line?
b) What does the slope of the straight line represent?
c) What is the y-intercept?

3. In physics 102, you will study waves on a string. The number of loops n in a vibrating string fixed at one end is given by:

$$n^2 = \frac{4L^2 f^2 \mu}{mg}$$



Where:

n is the number of loops (Dependent variable)
m is the hanging mass (Independent variable)
L is the length of the string (constant)
f is the frequency of oscillation (constant)
μ is the linear mass density (constant)
g is the acceleration due to gravity *constant)

The relation between n and m is non-linear. If you do an experiment and collect data for n and m and plot n vs. m, you will not get a straight line.

a) What should you plot in order to get a straight line?
b) What does the slope of the straight line represent?
c) What is the y-intercept?

4. You have seen in chapter 2 of your physics textbook that the displacement *y* of a particle falling freely is given by the following equation:

$$y = ½\, g\, t^2 + v_0\, t$$

where g is the free-fall acceleration, t is time and v_0 is the initial velocity. If you do an experiment and collect data for y and t and plot y vs. t, you will not get a straight line.

a) What should you plot in order to get a straight line?
b) What does the slope of the straight line represent?
c) What is the y-intercept?

Appendix: Manual Graphing

Objectives
To learn to quickly and accurately plot a graph; how to use graphical techniques to represent and analyze laboratory data.

Background
In PHYS 101-102 lab the student is often asked to plot a graph from the data he has gathered. Usually this graph is also the tool used to analyze the data. It is thus important for the student to have a good idea how to go about plotting a graph, and how a graph may be used to analyze data, particularly when the data satisfy a non-linear relation.

Steps in Plotting a Graph

1. What Is to Be Plotted?
When a student is told to plot, say, S versus *t*, it is important that he understands that this means: S is the *dependent* variable, plotted on the *"y"* or vertical axis; *t* is the *independent* variable, plotted on the *"x"* or horizontal axis. This is a *convention* (agreement) which should be memorized. (Students who are careless with this part of deciding how to go about making a graph often wind up in a confused mess!)

2. Choice of Scale
The *scale* for a variable is the number of centimeters of length of the graph paper given to a unit of the variable being plotted. For example, one might allow 1 cm for each 10 seconds of time. Note that in general the scales along the *x* and *y* axes may be different.
Two things need careful consideration before choosing the scales for a graph, the ranges of the variables, and convenience in plotting:
a) **range of the variable:** Suppose a student has some data for a variable S which ranges from 5 cm to 125 cm. He then should choose a scale which allows him to plot S values from zero to values somewhat greater than 125 cm.

Notice in this case that, unless told to do so by the instructor, he does not choose to *suppress the zero* and start the S scale from 5 cm. The reason is that later he may need to use the graph to find values *extrapolated* (continued) to the origin. Also, he allows space on the graph for values somewhat greater than the largest value in the data set (in our example, 125 cm). He does this because later some more data, with larger values, may be acquired, or he might need to extrapolate the graph to larger values.
Finally, the scale should be chosen to most nearly use the whole of the graph paper. Just because a simple choice (say, 1 cm to 1 second of time) makes a graph easy to plot, this should not be done if it results in a tiny graph "hiding" in a comer of the sheet of paper! Besides not looking "nice", such a graph is also inaccurate when used to analyze the data.

b) **convenience in plotting**: It turns out that scales of 1, 2, 5 and 10 (and multiples of 10 of these) per centimeter are easiest to use; a scale of 4 per centimeter is somewhat more difficult but can be used. Scales of 3, 6, 7, 9, etc. per centimeter are *very* difficult to plot and read and should be avoided.
In choosing scales it sometimes helps to turn the paper so that the "x-axis" is either the long or short dimension of the paper.

3. Label the Axes

The vertical and horizontal axes of the graph paper should carry labels indicating the quantities plotted, with units. In our previous example the label on the y-axis would be: S (cm). Some instructors also ask students to put a *legend* on the graph: Plot of S versus *t*.

4. Circle Your Data Points

Each data point should have a neat circle drawn around it. If more than one experimental trial is used then circles, triangles, squares, etc. may be used to distinguish these and a legend added: trial 1; trial 2; etc.

5. Drawing a Straight Line Through the Data Points

When the data fall on a straight line (or are expected theoretically to do so), a ruler may be used to draw a straight line through the points. Observe the following rules: the line is drawn to match the data trend, and for data with some "scatter" balance some points above and below the line. Points which fall far outside the general data trend should be double-checked for correct plotting, then, if found correctly plotted, ignored in drawing the line. Extrapolations to larger or smaller values, thus outside of the range of the data set, should be indicated by making the line "dashed" not solid.