

# INTRODUCTION TO THE PHYSICS LABORATORY

All of the laws of physics are expressions of experimentally observed phenomena in nature. In the laboratory you will have an opportunity to observe and discover those phenomena directly. Laboratory work is a very important part of a course in General Physics. It reinforces the student's understanding of fundamental concepts and principles while, at the same time, helping the student to develop skill in carrying out scientific measurements. For these reasons, the successful completion of the laboratory component will be required of every student.

## GENERAL LABORATORY DIRECTIONS

### 1. Responsibility

This laboratory has been equipped at considerable expense, so it is essential that you exercise care in the use of the equipment. At the beginning of each laboratory period you should check the list of required equipment for the experiment (see Laboratory Manual) to confirm that you have all the requisite parts and that they are in good working condition. You should report missing or damaged equipment to your instructor immediately. At the end of each period, please set your workstation in order and again check that all of the equipment is there. By following this simple procedure, you will help us to ensure that equipment is maintained in good working order. Additionally, you will aid the instructor in keeping the laboratory running smoothly.

### 2. Preparation

Before you come to the laboratory you should read:

- (a) The instructions for your assigned experiment,
- (b) The relevant sections of your textbook, and
- (c) The questions at the end of the experiment, in order that you may look for their answers while performing the experiment.

The schedule of the experiments and the instruction manual are available at the department website:

[http://depthome.brooklyn.cuny.edu/physics/phylabs\\_new.html](http://depthome.brooklyn.cuny.edu/physics/phylabs_new.html)

You should download and bring a printed copy of each experimental write-up to the Lab. Data sheets are also included in these instructions.

### 3. Performing Experiments

Lab experiments are complementary to the theories discussed in the class. There will be occasions when an experiment precedes the theory taught in class. It is your responsibility to read the appropriate material in the text. In most instances, the presentation of the theory in class will either be in parallel or it will precede the experiment.

The experiments are to be treated as a discovery and confirmation of the underlying physical principles. They are not to be regarded as a recipe of steps to complete the experiment.

There are many experiments that use the computer and data acquisition system. The computer program also has a data analysis facility. Do not print all the graphs generated. Print only those you need for your report or a representative graph.

#### 4. Submission of Report

The report on each experiment is due, and is to be handed in individually, either at the end of the laboratory session or at the next laboratory meeting following the one in which the exercise was performed. A late submission is subject to a penalty decided by the Instructor.

#### 5. Laboratory Grades

The basis for the grade for an experiment will be:

- (a) *The student's performance in the laboratory* including preparation, attentiveness, initiative, level of participation in group work, skill in doing the measurements, etc.
- (b) *An assessment of the lab report* based on quality of the measurements, correctness of the computations and analysis of results, clarity of discussion, correctness of answers to questions, and neatness.

You must pass the lab component of the course in order to pass the course. Specifically:

(1) students must have an *overall* passing grade in the lab component of the course – i.e., a minimum of 60% of the maximum overall lab grade.

(2) Students who do not complete any given Lab should make it up from another section; otherwise, a grade of “zero” will be assigned for the missed Lab. For details, see “Make-up policy” below.

The final grade for the course will be assigned based on the overall performance of the student in the course. The overall laboratory grade weight will be 25-30 % of the final course grade. Students who earned a passing grade [(D-) or higher] in Phys1100/2100 and who want to retake the course to improve their grade may either retake the lab component or they may use their previous lab score which will then be used to assign the overall course grade.

It follows that students who previously received a failing grade (F, W, WU, etc) in the course must repeat the lab component of the course.

#### 6. Make-up policy

As outlined above, the student is responsible for making up a missed Lab. A Lab that is missed must be made-up from another section of the Lab during the week the Lab is set up. A grade of zero will be assigned for a missed Lab.

The Lab schedule and rooms are posted in each laboratory and on the website

[http://depthome.brooklyn.cuny.edu/physics/phylabs\\_new.html](http://depthome.brooklyn.cuny.edu/physics/phylabs_new.html).

#### OBSERVATIONS AND DATA

All data sheets should be headed with the date, the experimenter's name, the names of the his/her lab partners, and the laboratory section number. All observations and data should be entered in a suitable tabular form previously arranged by the student for this particular experiment. Data sheets must

be initialed by the instructor before you leave the laboratory if they have not been handed in. Each student must have a copy of the original data. Data should be recorded on a clean sheet of paper or on the data sheet provided, never on scraps of paper. You should become accustomed to taking neat data from the start. You should label all observations in such a way that the instructor can see what they mean without any explanation from you, otherwise later you may not know what they mean. Never erase data or observations once recorded. If you think they are wrong, cross them out with a single line, and set the right figures beside or below the wrong ones.

By “observations” we mean the numerical quantities you actually read from the instruments. For example, if the length of a line is to be measured, the actual readings of the ends of the line are observations. The length itself, obtained by taking the difference between the readings of the ends is, of course, a deduction from the observations. We shall call such primary deductions “data”; from the data the final results are calculated and conclusions drawn. Instruments can, and in general must, be read to the limit of their precision by "estimating" the last figure of the reading. For example, when a thermometer is graduated in degrees, the tenths of a degree can, and in general should, be estimated, and so will be subject to error, arising from the uncertainty of the estimate.

As soon as you have completed the observations you should present your data sheets to the instructor for approval. The instructor’s approval does not necessarily mean that the results are sufficiently accurate to be finally acceptable. When the instructor has approved your data, and not until then, you should proceed with whatever computations and graphs are required. Each student must do his or her own calculations and graphs.

Your presence in the laboratory will be required for the full laboratory period. When you have finished with the experiment, you may begin writing your report, seeking help from the instructor if needed. Alternatively, you may seek help with homework problems or anything else associated with the course.

The majority of experiments employ the metric system of units (MKS or CGS). Some employ the British system of units. You should be familiar with all 3 systems. All fractions should be recorded as decimals.

## HOW TO WRITE A REPORT

The report should contain, in the order described:

1. **Cover sheet**, with your name, the names of your partners, the instructor’s name, the title of the laboratory exercise, and the date on which it was performed.
2. Briefly explain the purpose of the experiment.
3. **The original data sheets must be submitted** even if copies revised to look neat are included.
4. **Graphs.** Every graph should have an appropriate descriptive title. All graphs should be prepared neatly and carefully, with the axes labeled clearly and the scales chosen for maximum clarity. Make your graphs large enough so that data points can easily be read from the graphs. If the graph calls for a straight line or a smooth curve fit, make sure that you follow proper procedures for doing this. Your instructor will give you appropriate guidance in this. You should never simply connect the dots on a graph.

If your graphs are generated by a data acquisition and analysis program in a computer such as Vernier Logger Pro, you can include a print-out of the graphs. You may also use the data from the data acquisition system and plot your own graph using a computer program such as Excel. You do not need to include the raw data from the data acquisition system in the report.

5. The results should be tabulated and clearly labeled. This should be a ruled table summarizing the final computed results (not the data), together with the accepted values for these computed results whenever they are known, the standard deviations of your results, and also the percent error of the quantities in question.
6. The calculations used to obtain the tabulated results. These computations are based on the original data taken in the laboratory and include all quantities asked for in the instructions. If the calculations are very repetitive, it is sufficient to show a representative calculation.
7. A discussion of the results obtained, the uncertainties in your measurements, a comparison with accepted values if appropriate, and the possible sources of error in your measurements. Your discussion of the experiment should be written only after you have completed the calculations, drawn up a tabular summary of the results, and plotted all graphs called for. Your discussion need not go into the theory of the experiment insofar as it is covered in the text, but may well take up any point of interest not discussed in the text. The discussion should never repeat procedure. It should certainly contain a comparison of the results actually obtained in the experiment with results to be expected as well as a meaningful discussion of limitations in the experimental procedure and possible sources of error. A further discussion is given below.
8. A conclusion in which you discuss the significance of your results and summarize what has been learned from the experiment.
9. Answers to all of the questions posed for this laboratory exercise.

### **Example of experimental results and partial discussion of the results:**

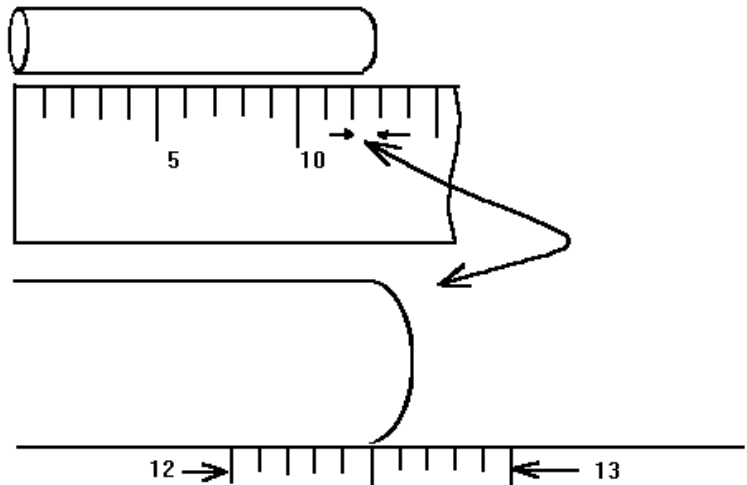
The same distance is measured four times with an inch scale and four times with a centimeter scale. The average results and their standard deviations (see next section) are  $(8.42 \pm 0.02)$  inches and  $(21.63 \pm 0.02)$  centimeters. From these results, the calculated ratio of cm/inch is  $(2.57 \pm 0.01)$ , while the correct ratio is 2.54 cm/inch.

The measured result differs from the correct result by more than 2 standard deviations indicating that something was wrong in the measurements. Under such circumstances, you should first check all the calculations and then discuss it with your instructor, who may suggest that you repeat some of the measurements. If the discrepancy persists, some meaningful discussion as to why it might have occurred is required, and you should give serious thought to the matter. You might even discuss potential sources for measurement error that definitely could not be responsible for the discrepancy. For example, if both scales are engraved on the same piece of material, then the discrepancy could not be due to expansion or contraction of the ruler because both scales would change in such a way that the ratio would be constant. You should make a serious effort to identify one or more potential sources of error that could possibly account for the discrepancy, and/or suggest ways to further investigate the matter.

Please refrain from saying that it was a case of "personal error" or "observational error," since statements like that are so vague as to be totally meaningless. You must make your discussion specific and concrete.

## INTERPRETATION OF DATA

Suppose we want to measure a physical quantity, say, the length of a piece of paper, the time for a pendulum to swing back and forth, or the weight of a brass sphere. Any measuring apparatus, no matter how sophisticated, is uncertain to some degree. For example, if a ruler is used to measure the length of a cylindrical tube, as shown in the figure to the right, we can read the ruler, with no uncertainty, to the nearest millimeter (tenth of a centimeter), which is the smallest marked division on our ruler. We find 12.5 cm. We can also, with care, estimate to the nearest hundredth of a centimeter, by imagining that the small subdivision (a tenth of a centimeter) is divided into ten equal parts. We might read it as 12.48 or 12.49 cm. In either case, we would have to say there is an uncertainty of .01 cm, or perhaps .02 cm, in the value quoted. To understand the significance of any scientific data that you collect, and to convey information to others, it is important to understand the uncertainties present in your results.



One way to get a quantitative measure of uncertainty is to make your measurements a number of times. If the measurements are all made independently, you will get different values, and by looking at how wide the spread is in your values, you can get an idea of the uncertainty. Let  $x$  be the quantity you are measuring. Say you have  $n$  measurements,  $x_1, x_2, \dots, x_n$ . We would like to define

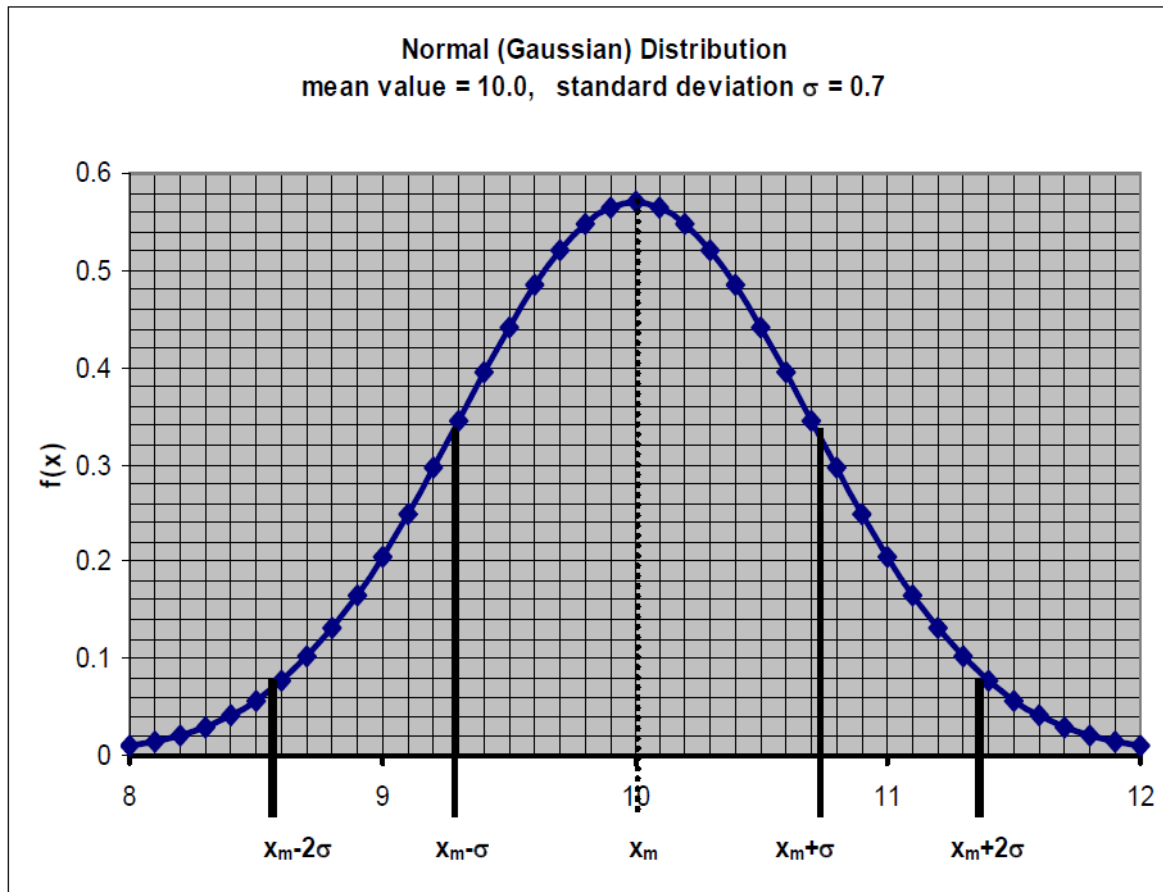
1. one quantity that gives our best estimate of the correct value for  $x$ , and
2. one or more quantities that measure the uncertainty in your results.

The most commonly used value for the best estimate is the average, or mean, of your  $n$  measurements, although other estimates are sometimes used.

To get a measure of the spread of data around the mean, we could tabulate the difference between each measurement and the mean,  $x_1 - x_m, x_2 - x_m$ , etc. We might think of averaging these quantities, but note that some will be positive and some will be negative. If we add them up, we will find the positive ones canceling the negative ones, so we always get zero for an answer. If instead we add up the squares,  $(x_1 - x_m)^2, (x_2 - x_m)^2, \dots$ , which are all positive, we get a positive quantity which is a measure of the spread of the data around the mean. We define a quantity called the "standard deviation," denoted by the Greek letter  $\sigma$ , by means of the following equation:

$$\sigma = \sqrt{\frac{\sum_{i=1}^N (x_i - x_m)^2}{N - 1}} .$$

To understand the significance of the mean and the standard deviation, we must discuss the concept of a Gaussian distribution, also referred to as a “normal distribution.” An experiment subject to random error will yield such a distribution of measurements. The figure below shows a graph of a normal distribution whose mean is  $x_m = 10$  and whose standard deviation is  $\sigma = 0.7$ , normalized in such a way that the total area underneath the curve is 1. This normalization allows for an interpretation in terms of probabilities, as will be explained later.



The science of statistics shows that, under a wide range of conditions, the vertical coordinate of this curve gives the relative probability of finding any particular value of  $x$ . For example, consider the possible values,  $x = 8.8$  and  $x = 9.6$ . The ordinates for these, from the graph, are 0.13 and 0.48, respectively. The ratio of these is  $0.48/0.13 = 3.7$ . If we make a new measurement of  $x$ , we are 3.7 times more likely to get  $x = 9.6$  than to get  $x = 8.8$ .

Another way to understand the normal distribution is to think of a range of possible values for  $x$ . When we measure  $x$ , what is the probability that we will get a value anywhere between  $x = 8.8$  and  $x = 9.6$ ? This probability will be exactly equal to the area under the curve between those values of  $x$ . A calculation (using integral calculus) gives the value 0.24, for this area. If you don't want to think in terms of probability, think of it this way: If someone makes 100 measurements of  $x$ , there would be about 24 that came out between 8.8 and 9.6.

Assuming that all values of  $x$  are possible between minus infinity and plus infinity, it had better be the case that the entire area under the curve is equal to one. That is, in fact, the way the

normal distribution is constructed, no matter what the values of  $x_m$  and  $\sigma$  are. (Look at the graph and see, roughly, if that makes sense.)

Now we can make an assertion about the standard deviation that shows its utility. For any set of data that obey the normal distribution, and no matter what values  $x_m$  and  $\sigma$  take on, the probability of a new measurement coming out between  $x_m - \sigma$  and  $x_m + \sigma$  is .68. This range is shown in the figure above (look at the figure and see if that fraction seems about right). Further, the probability of a new measurement coming out between  $x_m - 2\sigma$  and  $x_m + 2\sigma$  is about .95. Similar statements can be made about other ranges, but these two probabilities give you a feel for the spread of the data, and a way to respond to new measurements. If someone comes along and says he or she measured  $x$  to be 9.5, you would say that's quite consistent with your data; it's within one standard deviation of the mean, i.e. between 9.3 and 10.7. If someone finds a value 11.6, you would have to be dubious; it's beyond two standard deviations of your data. It could be right, but the chance is less than 5% that it is (because 95% of all measurements should be between 8.6 and 11.4).

A second measure of uncertainty, called  $\sigma_m$ , tells you how to compare two mean values. It is defined by:

$$\sigma_m = \frac{\sigma}{\sqrt{N}}.$$

If another set of measurements of the variable  $x$  is made, and it yields a mean value  $x_m$ , the probability is .68 that this value will fall between  $x_m - \sigma_m$  and  $x_m + \sigma_m$ . In this laboratory, we will often compare our results to "accepted" values, those given in handbooks and published papers. These should be thought of, not as "correct" values or "true" values, but as results that have been found with more sophisticated apparatus or in more time-consuming experiments than ours, and so probably have smaller standard deviations than ours. Thus, a good result is within  $\sigma_m$  of the accepted value; a fair result is within  $2\sigma_m$ .

Bear in mind that the discussion above has to do with differences in measurement results that are entirely due to random variations. There also may be what are called systematic errors, something in the measurement process that we have not taken account of that makes the results systematically too large or too small. For example, in timing some rapid event and hitting a stopwatch, my reaction time may be slow so that I always hit the clock a little too late; or a length measurement may be consistently wrong because the temperature in the room is high and this makes the ruler expand. When two measurements of the same quantity differ by more than two or three standard deviations, we expect that some systematic error is causing the discrepancy.

The accuracy of a result can be determined only when the "correct" value is known. The discrepancy between the result,  $M$ , that we have obtained in the laboratory, and the "correct" value,  $M_t$ , is usually expressed as a "percent error", more properly referred to as percent discrepancy. It is given by the following expression:

$$\text{"% error"} = \frac{(M - M_t)}{M_t} \times 100.$$

A positive percent error of 3%, therefore, means that the result obtained was greater than the "correct" value by 3%.

## Making Graphs in Excel


Microsoft Excel is a powerful program that can be used for calculations and plotting graphs in the laboratory experiment. The Excel window consists of a spreadsheet which looks like of a paper ledger sheet. This page will lead you through the steps for creating graphs in Excel.

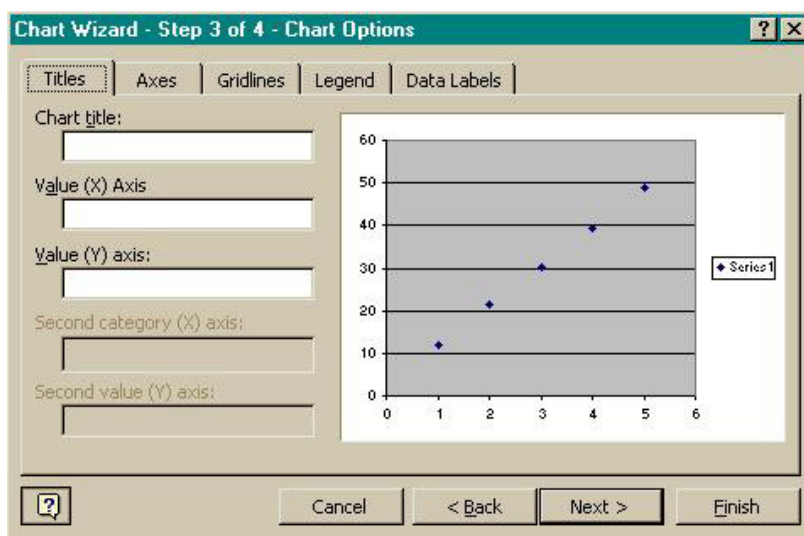
Open Excel from the Start button (Start/Programs/Microsoft Office/Excel). You can import the data or paste into the cells or enter manually. For getting started, enter the sample data given in the table (including the title of the columns) into cells A1 through A6 from first column and B1 through B6 from column 2. This sample data in the table is from a lab on DC circuits. The student was trying to determine how the resistance (R) of a wire depends on its length (L).

Length (cm)	Resistance (Ohms)
1.0	12.1
2.0	21.3
3.0	30.2
4.0	39.2
5.0	48.8

Save the file with your desired file name.

## Making/Changing a Graph

- Select all the cells that contain the data that you want to graph. Click 'Insert' and 'Chart' and select "Scatter", or open chart wizard clicking  => Chart Wizard Icon
- Click on the Chart Wizard icon. You will see a series of dialog boxes.
  - o Screen 1: Choose "XY (Scatter)" and click "Next."
  - o Screen 2: This screen allows you to choose which data to plot. Since you did this before starting the Wizard, just click "Next."
  - o Screen 3: This screen has multiple menus. Play with the settings to see what they do. Make sure your final graph has a title, axes that are labeled (with units), and no legend. When you are done, click "Next"
  - o Screen 4: This screen selects where you will store the graph. Choose "As object in" to store the graph in the same worksheet as the data and click "Finish"



- Excel plots the graph with the data in the first column for the x- axis and the others for the y-axis. Once the graph is made, you can modify most features of the graph by double-clicking on the



feature you want to change. You can also right-click on a feature to get a menu. Try changing the color of the plot area, the numbers on the axes and the appearance of the data points.

### **Adding Error Bars**

Right-click on a data point and choose "Format data series..." Click on the "Y error bars" tab. Choose "Both" under "Display" and "Fixed Value" under "Error Amount". Then enter the uncertainty for the y-values in the box marked "Fixed Value."

### **Adding a Trendline**

Sometimes you want to find (and interpret) the equation that relates the two variables you graphed. To make a trendline and determine its equation, right-click on a data point and choose "Add trendline." Choose the shape that best describes your graph. Click on the "Options" tab. Check the box for "Display equation on chart". Use the simplest equation that you think will cut through all the error bars on your graph. You may need to try a couple of trendlines before you get the most appropriate one. To clear a trendline, right-click on the trendline and select "Clear".

Warning: It is very easy to use the trendline tools to produce nonsense. The purpose of this tool is to find the simplest mathematical model that explains the relationship between the two variables you are graphing. Look at the equation and shape of the trendline critically: Do they make sense? Is this the simplest possible explanation for the relationship between the two variables?

### **Copy Data and Graphs into a Word Document**

You can also copy graphs and data from Excel to Word. Just select the graph (or cells) and use the Ctrl-C and Ctrl-V shortcuts to copy and paste.

### **Graph generated by equation**

The value in a cell in Excel can be generated using a formula. Thus a new column can be generated as a function of the data in a given column. In Excel, a formula is a mathematical equation that must begin with an equal sign (=) and type the formula as in a computer language. In place of the 'variable' you should choose the corresponding cell. There are lots of functions available in Excel including normal mathematical operation such as trigonometric, statistics etc.

In order to practice generating data from formula, save your previous data as 'Freefall'. Change the name of first column (A1) into "Time (sec)", second column (B1) into "Velocity (m/sec) and add third column (C1) with name "Distance (m)". Delete your data in column B and extend the data in column A up to value 10.

Now click on cell B2 - this will highlight that cell and bring the cursor to formula bar on top. Now type the expression given inside the parenthesis ( $=9.8*A2$ ) and press "Enter". This will add the value in cell B2 which is the result of multiplying the value in cell A2 and 9.8 (value of the acceleration due to gravity).

In order to generate data in column B from the data in column A using the same formula, you can copy the formula easily. Click in the cell B2. Bring the big positive sign to the lower right corner of the cell. Cursor sign will change into thin positive sign. Now click at that corner and drag your mouse down along the column B to cover all the data in column A. You will see that data is generated in column B.

You can repeat these steps in cell C2 by typing the formula  $(=0.5*9.8*A2^2)$  and press 'Enter'. This will add the value in cell C2 from the value of 't' given in cell A2 and using the formula,  $d = \frac{1}{2}gt^2$ . Drag down the corner of the cell C2 to fill all the cells as you did before for column B.

In order to plot graphs using the new data, highlight all the columns, A, B and C and 'Insert' chart and select 'scatter'. It will plot two graphs together. You can play with the graphs adding separate trendline in each plot as you did before.

Excel has a help wizard if you like to learn more!