EXPERIMENT 1
Introduction to Computer Tools and Uncertainties

Objectives

- To become familiar with the computer programs and utilities that will be used throughout the semester. You will learn to use *Microsoft Excel* and *Kaleidagraph* to perform some simple tasks.
- To become familiar with experimental uncertainties.

A few starters:

- Always bring a floppy disk or flash memory drive with you to class and save your work often.
- The *Excel* spreadsheet is made up of rectangles called "cells".
- *Kaleidagraph* is a graphing program that you will use to analyze the data we compute in the *Excel* spreadsheet.
- Once you have the data you can make a graph that will quickly and easily show what trends or relations the data exhibits. *Kaleidagraph* is versatile and allows you complete control over how the data will be presented. It is up to you to decide (or to be instructed) as to what kind of graph will be best.

Theory

Microsoft Excel is a spreadsheet program that allows you to manipulate text as well as data. Most importantly for the labs you will be doing, *Excel* can perform calculations quickly that would otherwise be very time consuming. Learning a few basic commands and skills in *Excel* now will save you a considerable amount of calculation time the rest of the semester.

Uncertainties

The scientist endeavors to make measurements subject to as little uncertainty (often colloquially called "error") as possible. Here error does not mean a mistake, but rather a physical inability to make perfect measurements. All measurements are to some extent imperfect, and therefore the results obtained are always subject to some uncertainty. The scientist must indicate the magnitude of these uncertainties.

We express the uncertainty of a quantity x by writing $x \pm \delta x$, where δx is the uncertainty of x. Uncertainties are always:

- positive numbers
- have the same units as the quantity in the equation

Random Errors:
When you make a series of measurements of the same quantity using the same measuring instruments, you often find that you do not obtain exactly the same answer each time. Your measurements are said to be affected by random errors. Random errors arise from small, uncontrollable differences in the way each measurement was made. Random errors determine the uncertainty in the value of a directly measured or calculated quantity.

Systematic Errors:
If the measured value differs systematically from the correct value, then the measuring equipment is said to contain systematic errors. Such errors can result from either improper calibration of the equipment or from a failure to account properly for some unexpected perturbation such as friction. These errors are generally harder to estimate than random errors.

Some general rules about uncertainties:

- An uncertainty is always a positive number $\delta x > 0$.
- If the uncertainty of **x is 5%,** then $\delta x = .05x$.
- If the uncertainty of x is δx, then the fractional uncertainty of x is $\delta x/x$.
- If you measure x with a device that has a precision of u, then δx is at least as large as u.
- The uncertainty of $x + y$ or $x - y$ is $\delta x + \delta y$.
- If d is data and e is expectation:

  The difference is $\Delta = d - e$

  % difference is $(\Delta / e) \times 100\%$

  They are ***compatible*** IF $|d - e| < \delta d + \delta e$
- Fractional uncertainty of $z = xy$ **or** x / y is:

  $$\delta z / z = \delta x / x + \delta y / y$$

Appendix A contains a more detailed reference guide to uncertainties.

Graphs

Graphs allow mathematical relationships to be visualized and consequently more clearly understood. Graphs also help in determining the mathematical relationships between variables.

(a) Data Sheet: Before making your graph, record your data in a systematic form, showing the units and uncertainties for each measurement. In this course, you will use an *Excel* spreadsheet to document your data. This way there will be no confusion in your mind about what point you are graphing.

(b) Graphing Software: You will use *KaleidaGraph* to graph and help you analyze your data.

(c) Choosing Axes: If you are asked to graph a vs. b, the variable before the vs. (a) goes on the vertical axis, and the variable after the vs. (b), goes on the horizontal axis. Label both your axes (showing units) and title the entire graph (at the top), so readers can identify what you are plotting.

(d) Choosing Scales: The scales should be chosen so that you can easily see any meaningful variation in the data, but random errors are not magnified out of proportion to their significance. Your axes need not always begin at zero, but consider carefully whether they should.

(e) Error Bars: Wherever possible, indicate the uncertainty of each point by using error bars. An error bar is a line passing through the data point and extending from the smallest value which that point could have, up to the largest value it could have. An error bar parallel to the vertical-axis shows the uncertainty in the variable on that axis, and an error bar parallel to the horizontal-axis shows the uncertainty in the variable on that axis. In most cases you will have uncertainties in only one of your variables. Your instructor will tell you when error bars can be omitted in a variable.

(f) Finding the Best Straight Line through a Set of Data Points: *KaleidaGraph* can be used to fit a straight line to your data, complete with the equation of this best fit line. In addition, *KaleidaGraph* will provide an estimate in the uncertainty in the slope and y-intercept of your best fit line.

Procedure

Part 1

In this part of the experiment you will use *Excel* and *Kaleidagraph* to graph the x and y positions of a projectile versus time.

Open the lab folder entitled *Introduction to Computers* which is in the "251 Lab" folder on the computer's desktop. Remember, you can open the folder by double clicking on the icon with your mouse. Then double click on the document ending in ".xls". The "xls" indicates the document is an *Excel* spreadsheet. Click on the tab in the lower left hand corner of the spreadsheet labeled "PART 1". You should see two data tables on the spreadsheet. The first data table is used to define the acceleration due to gravity (g); the initial x and y coordinates of the object's position (x_0 and y_0); and the initial x and y velocities (v_{x0} and v_{y0}). The second data table will be used to display the x and y locations of the object at various times.

Fill in the first column of the second data table with times t = 0.0 sec through t = 3.0 sec in increments of 0.1 sec. Do not waste time filling in each of these values by hand; instead let *Excel* do the work for you. Here's how: In the first cell of the time column (cell **B11**), enter 0. Then in the second cell of the column (**B12)**, you can give *Excel* the formula you want it to follow. In each cell in the column, we would like *Excel* to add 0.1 seconds to the cell immediately above it. So, in cell **B12** enter "=B11+0.1". The "=" lets *Excel* know the cell contains a mathematical or logical operation. After entering the formula, cell **B12** should contain 0.1. Next, highlight the entire column of the data table, starting with the cell that has the formula in it (**B12**), open the "edit" menu at the top of the screen, scroll down to "fill" and select "down". The entire column should now be filled with numbers from 0 to 3.0 in increments of 0.1.

If you are viewing a spreadsheet and you are not sure what formula *Excel* is using for some calculation, you can click on the cell and the equation will be displayed in the formula bar near the top of the screen. Try it by clicking on cell **B23** which should contain "1.2". In the formula bar "=B22+0.1" should now be displayed.

The location of the projectile depends on the initial conditions and the acceleration due to gravity. The object's location at time t is given by:

$$x = x_0 + v_{x0}t \quad \textbf{(1)}$$

and

$$y = y_0 + v_{y0}t - \frac{1}{2}gt^2 \quad \textbf{(2)}$$

We would like to use the same method here to calculate the values for the location of the object (x and y values), as we did for the time values in the second data table. However, you need to either redefine the cells containing g, x_0, y_0, v_{x0} and v_{y0} before using them in an equation with the fill-down method; or explicitly reference these cells in an equation. The method presented and used in this lab will be to redefine the cells. To start with, let's redefine the name of the cell which will contain the acceleration due to gravity. Click on cell **B4**, select "insert" from the menu at the top of the screen, scroll down to "name" and choose "define". A "define name" window should open up. Enter "g" into the top line in the define name window and select "OK". Now, when referring to this cell in an *Excel* formula just enter "g" and when the fill-down option is used, excel will not change the referenced cell. Now, redefine the cell names cells C4, D4, E4 and F4 to "x0", "y0", "vx0" and "vy0" respectively.

We need to give numerical values to the acceleration due to gravity, as well as the initial coordinates of the position and components of the velocity. The acceleration due to gravity is 9.8 m/s^2, x_0 = 20 m, y_0 = 15 m, v_{x0} = 12 m/s and v_{y0} = 10 m/s. Simply enter the numerical values (not the units) into the corresponding cell.

The next step is to enter the correct *Excel* formula to calculate the positions x and y. In order to do this, you need to enter equations **(1)** and **(2)** in a language which *Excel* can understand. The Excel formula for the position x, which should be entered in cell C11 is "=x0+vx0*B11". Then use the fill-down method to calculate the rest of the x positions. The *Excel* formula for the position y which should be entered into cell D11 is "=y0+vy0*B11-0.5*g*B11^2". Use the fill down method to calculate the other y positions. A reference to some useful *Excel* equations can be found in Appendix B.

Once your data table is complete, you are ready to transfer your data into *Kaleidagraph* using the cut-and-paste method. The steps in this process are:

1. Highlight the area you want to move. Highlight ONLY data. DO NOT include any cells containing text, such as column headers. The program will not make a graph for you if you do.
2. Choose "copy" from the "edit" menu at the top of the screen, or press "Ctrl-C" to copy the highlighted text to the computer's clipboard.
3. Open *Kaleidagraph* usually by double clicking its icon on the desktop and click on the upper left-most cell the spreadsheet that appears.
4. Choose "Paste" from the edit menu, or "Ctrl-V" to paste in your data.

You can change the column names in Kaleidagraph by double clicking on them after you've transferred the data. In this case, you want to call the first column "Time (sec)", the second column X (meters) and the third column Y (meters).

You are now ready to make a graph. At the top of the screen, pull down the "Gallery" menu, scroll down to "Linear" and select "Scatter". This option is used to create a scatter-plot of the x and y coordinates of the projectile. A plot window should open. Click on the bubble under the X column for Time (sec), the Y-column for X (m) and the Y-column for Y (m); then click the "New Plot" button. This will create a scatter plot with time plotted on the horizontal axis and both the X and Y coordinates plotted on the vertical axis.

Graphs should always contain proper labels. This means each axis should be labeled, complete with units and the graph should have a title. To change the label of the vertical axis, double click on it. An "Edit String" window should appear. Change the text in the window to "X (m) and Y(m)". The same method is used to change the horizontal axis label and the graph's title. The appropriate way to title a graph is "what's on the vertical axis" versus "what's on the horizontal axis".

Part 2

In this part of the experiment, you will use *Excel* and *Kaleidagraph* to graph and calculate the slope and intercept of a set of data. In addition, *Kaleidagraph* will provide an estimate of the uncertainty in the slope and intercept.

Click on the "PART 2" tab near the bottom of your *Excel* spreadsheet. You should find a data set of times and positions of a ball rolling across a horizontal surface. You will also notice two empty data columns – you'll get to those shortly. Transfer the data in the first two columns into *Kaleidagraph* and make a position vs. time graph.

When graphing data which include experimental uncertainties, you should include error bars. The experimental uncertainty in the position of the object is given in your *Excel* spreadsheet. To add error bars, select "Plot" from the menu at the top of your screen and scroll down to "Error Bars". An "Error Bar Variables" window should appear. Use your mouse to check the box under "Yerr". An "Error Bar Settings" window should now appear. Make sure the "Link Error Bars" box is checked. Just above and just below the "Link Error Bars" box, you should see two identical pull-down selection boxes. These allow you to define the size of your error bars and because you have the error bars linked, you only need to change one of these. Clicking on one of these boxes will give you the choice of setting your error bars as a % of the value, a fixed value, a standard deviation, a standard error, or referencing them to a data column. For this exercise, choose a fixed value and then enter the uncertainty given on your *Excel* spreadsheet in the "fixed value" box. Click OK and then click plot. You should now have error bars on all of your data points on your graph. **Note: The numerical value of the uncertainty used here is for this example only and should not be used in subsequent labs requiring an uncertainty in a length or distance.** For additional information on estimating uncertainties in measurements, see Appendix A.

You can change the scale on either of your axes by selecting the "Plot" menu at the top of the screen and choosing "Axis Options". The default setting in *Kaleidagraph* is to have the axes automatically set. However, this option allows you the flexibility of overriding this setting and choosing the limits of your axes which will adequately display your data.

The next thing you will do is to have *Kaleidagraph* find and plot a best fit line to your graph. To do this, select "Curve Fit" from the menu near the top of the screen, scroll down to "General" and choose "fit1". A "Curve Fit Selections" window will open, check the box and click “OK”. *Kaleidagraph* will plot a best fit line on your graph. Also, a small data table will appear on your graph. The equation of the line is represented as “y=m1+m2*M0” in this data table where, “y” is the variable plotted on the vertical axis, “M0” is the variable plotted on the horizontal axis, “m1” is the coordinate where the line crosses the vertical axis (sometimes referred to as the y-intercept) and “m2” is the slope of the line. The data table will display numerical values for the slope and the intercept, as well as their respective uncertainties (δ slope and δ intercept). The bottom two lines “R” and “Chisq” are a measure of how well your data are represented by your best fit line and will not be used in this course. You should include this graph in your lab report.

Using your slope, intercept (int) and their respective uncertainties (δslope and δint), plot the lines with the greatest AND least possible slope which could reasonably represent your data. To do this, you will need to return to your *Excel* spreadsheet. The equation corresponding to the greatest possible slope is:

$$X_{greatestslope} = (slope + \delta slope) * t + (\mathrm{int} - \delta\,\mathrm{int})$$

The equation corresponding to the least possible slope is:

$$X_{leastslope} = (slope - \delta slope) * t + (\mathrm{int} + \delta\,\mathrm{int})$$

Use these equations to generate data points in your *Excel* spreadsheet for the lines of greatest and least reasonable slope. Transfer them into your *Kaleidagraph* data table and make a new plot of your data. Your plot should include your best fit line, your line having the greatest reasonable slope and your line having the least reasonable slope. Include error bars on your best fit line only – do not include error bars on your line having the greatest reasonable slope or least reasonable slope. Instead of using the general fit option, use the “Linear” curve fit option in *Kaleidagraph* for the three lines on this graph.

You now have your data and graphs. You should print out all of your data tables and all of your graphs. These must be turned in to your instructor at the end of the class session for grading. In addition, you should include the answers to any required questions and hand written sample calculations (one calculation for each operation done by Excel – i.e. you should include one example of $X_{greatestslope}$, one example of $X_{leastslope}$, etc.).

Questions:

1. What is the slope of the best fit line (whenever asked about a measured quantity, you should ALWAYS include both units and an uncertainty)?

2. What is the “y-intercept” of the best fit line?

3. What is the equation of the line having the greatest reasonable slope for this set of data?

4. What is the equation of the line having the least reasonable slope for this set of data?