Experiment 1

Introduction to Computer Tools and Uncertainties

1.1 Objectives

- To become familiar with the computer programs and utilities that will be used throughout the semester.
- To become familiar with experimental uncertainties.

1.2 Introduction

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.

Once you have the data and computations from Excel, you can make a graph that will quickly and easily show what trends or relations the data exhibits. Kaleidagraph is a versatile graphing program and allows you complete control over how the data will be presented. It is up to you to decide as to what kind of graph will be best, though you will often be given guidance, especially for the first few experiments.

1.3 Miscellaneous comments

- Always bring a flash drive with you to class and save your work often. When the computer restarts, it erases all changes to the hard drive.
- 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.

1.4 Theory

Uncertainties

When we make a measurement, we need to know how precise that measurement is. The amount of precision of the measurement is called the *uncertainty* — we need to be able to report how uncertain we are about a measurement that we have taken. For example, if I measured how long my finger was with a ruler, I might say that my finger was measured to be $9.5 \pm 0.5\,\text{cm}$ — that is, I'm confident that it is actually between $(9.5 - 0.5)\,\text{cm}$ and $(9.5 + 0.5)\,\text{cm}$.[1] This is a lot more meaningful of a statement than if I measured $9.5 \pm 5.0\,\text{cm}$. I wouldn't know much about my finger length at all, and finding gloves that fit would be a nightmare!

An oft-used synonym for "uncertainty" is "error". 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. Note that even though "δx" has two characters, we treat it as one variable, not "δ" multiplied by "x". Uncertainties are always positive numbers, and they always have the same units as the quantity in the equation (2 meters + 2 seconds doesn't make much sense!).

[1] There is a more rigorous definition of uncertainty and confidence, but we will not use it in this course.

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, and the differences make the measurement fall either above or below the true value, with equal probability. Random errors determine the uncertainty in the value of a directly measured or calculated quantity.

Systematic Errors

Unlike random errors, *systematic errors* tend to make each of your measurements be off in the same direction. For example, if you weighed a series of rocks on a scale, and put them on a plate each time, then you'd be measuring the weight of the plate as well each time, making the scale read higher than the actual weight of the rocks every time.

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, though they can be predicted more easily, as in the case of the plate.

Some general rules about uncertainties

Appendix B contains a more detailed reference guide to uncertainties, but here is a summary:

- An uncertainty is always a positive number, $\delta x > 0$.
- If the uncertainty of x is δx, then the *fractional uncertainty* of x is $\delta x / x$.
- If the fractional uncertainty of x is 5%, then $\delta x = 0.05x$.
- If you measure x with a device that has a precision of u, then δx is at smallest as large as u (you might make your reported uncertainty larger to account for some other difficulty in measurement).

- If you add or subtract two quantities with uncertainties, the uncertainties add to give the uncertainty of the result (since they could both be wrong in the same direction lower or higher than the true value). So if $z = x + y$ or if $z = x - y$, then $\delta z = \delta x + \delta y$.
- if d is your mesaured value ("data") and e is the expected value,
  - The difference is $D = d - e$.
  - % difference is $D/e \times 100\%$.
  - They are *compatible* if $|D| < \delta d + \delta e$.
- If you multiply or divide two quantities with uncertainties, the fractional uncertainties add to give the fractional uncertainty of the result (contrast with adding or subtracting above). So if $z = xy$ or $z = x/y$, then $\delta z/z = \delta x/x + \delta y/y$.

Graphs

It's hard for people to read a table of numbers and see a pattern or trend. Graphs allow mathematical relationships to be visualized and consequently more clearly understood. Graphs also help in determining the mathematical relationships between variables.

1.5 In today's lab

You will learn to use Microsoft Excel and Kaleidagraph to perform some simple tasks.

1.6 Equipment

- **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.
- **Graphing software.** You will use Kaleidagraph to graph and analyze your data.

- **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.
- **Choosing scales.** The range of 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 (Is zero a physically relevant point for the experiment?).
- **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 reasonably 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.
- **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.

1.7 Procedure

Part 1: Graphing data points

In this part of the experiment, you will use Excel and Kaleidagraph to graph the x and y positions of a projectile as they change with time.

Entering data and formulas into Excel

1. Open the lab folder titled `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.

2. Double-click on the Excel file.

3. In the lower left hand corner of the spreadsheet window, click on the tab 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 horizontal and vertical coordinates of the object's position (x_0 and y_0), and the corresponding initial velocities ($v_{x,0}$ and $v_{y,0}$). The second data table will be used to display the x and y locations of the object at various times.

4. Fill in the first column of the second data table with times $t = 0.0\,\mathrm{s}$ through $t = 3.0\,\mathrm{s}$ in increments of $0.1\,\mathrm{s}$. Do not waste time filling in each of these values by hand — instead, let Excel do the work for you. Here's how:

   a) In the first cell of the time column (cell `B11`), enter 0.

   b) 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`.

   c) Click and drag the mouse to 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. Alternatively, left click the bottom right corner of a cell and fill down by dragging the mouse down to lower cells.

5. 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 position in the horizontal direction at time t is given by

$$x = x_0 + v_{x,0}t \tag{1.1}$$

and in the vertical by

$$y = y_0 + v_{y,0}t - \frac{1}{2}gt^2, \tag{1.2}$$

where g is the acceleration due to gravity, $9.8\,\mathrm{m/s^2}$. 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 names of the cells containing g, x_0, y_0, $v_{x,0}$, and $v_{y,0}$ 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.[2]

6. To start with, let's redefine the name of the cell which will contain the acceleration due to gravity. Right click on cell `B4`, and select 'define name' from the window that appears. A `New name` window should open up.

7. Enter `g` into the top line in the new name window and select `OK`. Now, when referring to this cell in an Excel formula, you can just enter `g`, and when the fill-down option is used, Excel will not change the referenced cell like it did with the cells for time.

8. Redefine the cell names for `C4`, `D4`, `E4`, and `F4` to `x0`, `y0`, `vx0`, and `vy0` respectively.

9. We need to give numerical values to the acceleration due to gravity, as well as the initial position and velocity. The acceleration due to gravity is $9.8\,\mathrm{m/s^2}$. Let's put our object $20\,\mathrm{m}$ away from us and $15\,\mathrm{m}$ above the ground, with an initial horizontal velocity of $12\,\mathrm{m/s}$ away and initial vertical velocity of $10\,\mathrm{m/s}$ upwards. Enter each numerical value (not including the unit) into its corresponding cell.

[2] An alternative way to tell Excel that you want to use a particular cell and not increment down the column is to use the $ symbol before the row number. For example, when typing equation 1.1 instead of using the defined cell name x_0 you could use C$4.

10. The next step is to enter the correct Excel formula to calculate the positions x and y as a function of time. In order to do this, you need to enter Eqs. 1.1 and 1.2 in Excel's programming language. The Excel formula for the position x, which should be entered in cell `C11`, is `=x0+vx0*B11`.

11. Use the fill-down method to calculate the rest of the x positions.

12. 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 C.

13. Print out the Excel spreadsheet with your data. Also print out the formula view which is gotten by pushing the `Ctrl`+˜ keys.[3] This will display the formulas for the entire spreadsheet. Pressing these two keys again reverts back to the calculated numbers. Make sure none of the formulas in the formula view are cut-off, you may need to resize some columns. When printing it is a good idea to fit the spreadsheet to a single page as long as it is still legible, changing the orientation to landscape often helps.

Transferring data to Kaleidagraph

Once your data table is complete, you are ready to transfer your data into Kaleidagraph using the cut-and-paste method. **If you cannot fix something that broke in Kaleidagraph, sometimes you will need to close and restart the program.**

Here are the steps to transfer your data:

1. Highlight the area you want to move. Highlight only the data values. Do not include any cells containing text, such as column headers. The program will not make a graph for you if you do.

2. From the drop-down menu, choose `Edit` ▶ `Copy`, or press `Ctrl+C` to copy the highlighted text to the computer's clipboard.

3. Open Kaleidagraph by double-clicking its icon on the desktop.

[3] The tilde (˜) key is to the left of the number 1 on the US keyboard.

4. Click on the upper-left-most cell of the spreadsheet that appears.
5. Choose `Edit` ▶ `Paste` from the drop-down menu, or press `Ctrl+V` to paste in your data.

Graphing in Kaleidagraph

You are now ready to make a graph.

1. You can change the column names in Kaleidagraph by double-clicking them after you've transferred the data. In this case, you should name the first column "Time (s)", the second column "X (m)" and the third column "Y (m)".
2. To choose the graph type, choose `Gallery` ▶ `Linear` ▶ `Scatter`. This option is used to create a scatter-plot of the x and y coordinates of the projectile. A plot window should open.

   We want to plot both the x position and y position versus time. This means that we want both x and y to be on the `Y`-axis, and time to be on the `X`-axis.[4]
3. Click on the bubble under the `X` column for `Time (s)`, the `Y`-column for `X (m)` and the `Y`-column for `Y (m)`.
4. 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. Each axis should be labeled with the variable name and the units in parentheses, and the graph itself should have a title.
5. 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 physical quantity is on the vertical axis" versus "what physical quantity on the horizontal axis". Include this graph with your lab report.

[4]Apologies for the overused variable y, as it is used for both the vertical direction in the graph and the vertical direction in the physical situation. Be careful about which you are referring to.

Part 2: Analyzing the graph

The slope and y-intercept often have physical meaning, and we can use the graphing software to calculate them. 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 y-intercept.

Adding error bars

1. Click on the `PART 2` tab near the bottom of your Excel spreadsheet. You should find a set of times and positions for a ball rolling across a horizontal surface whose motion is described by Equation 1.1. (You will also notice two empty data columns — you'll get to those shortly.)

2. Transfer the data in the first two columns into Kaleidagraph and make a position vs. time graph.

3. When graphing data which include experimental uncertainties, you should include error bars to help the reader understand how significant the trend shown is. The experimental uncertainty in the position of the object is given in your Excel spreadsheet. To add error bars, select `Plot` ▶ `Error Bars`. An `Error Bar Variables` window should appear.

4. 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. Since you have the error bars linked, you only need to change one of these, and the other will follow. 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.

5. For this exercise, choose `Fixed Value` from the drop down menu and then enter the uncertainty given on your Excel spreadsheet in the `Fixed Error` box.

6. Click `OK` and then click `Plot`. You should now have error bars on all of your data points on your graph. For additional information on estimating uncertainties in measurements, see Appendix B.

> **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. You will find your own uncertainties in those experiments.**

Plotting a best-fit line

The next thing you will do is to have Kaleidagraph find and plot a best-fit line to your graph.

1. Select `Curve Fit` ▶ `General` ▶ `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. (Note that the table can be moved elsewhere on the graph by clicking and dragging if it is covering up your data points.)

   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 (also 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 y-intercept, as well as their respective uncertainties, δ(slope) and δ(int). 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. Include this graph with your lab report.

   As mentioned before the slope and y-intercept often correspond to physical quantities. To understand what they mean for this graph, compare Kaleidagraphs's equation of the line (Eq. 1.3) with the equation that describes the motion of the ball (Eq. 1.4).

$$y = m1 + m2 * M0 \tag{1.3}$$

$$x = x_0 + v_{x,0} * t \tag{1.4}$$

The graph plots the position of the ball (x in Eq. 1.4) on the vertical axis (y in Eq. 1.3) versus time (t in Eq. 1.4) on the horizontal axis ($M0$ in Eq. 1.3). Matching up the remaining variables in Eq. 1.3 with Eq. 1.4 reveals that the slope ($m2$) corresponds to the initial velocity of the ball ($\mathrm{v}_{x,0}$) and that the y-intercept ($m1$) corresponds to the initial position of the ball (x_0).

2. We'd like to get a visual representation of what is meant by the slope and intercept uncertainties given by the Kaleidagraph straight line fit. With this in mind, we will use the slope, y-intercept (int) and their respective uncertainties, δ(slope) and δ(int), to plot the lines with the largest and smallest slope which could reasonably represent your data (by reasonable we mean one uncertainty unit away from the best fit).

   To do this, you will need to return to your Excel spreadsheet. The equation corresponding to the largest reasonable slope is

$$x_{\text{largest slope}} = (\text{slope} + \delta\text{slope}) \times t + (\text{int} - \delta\text{int})\,. \tag{1.5}$$

   The equation corresponding to the smallest reasonable slope is

$$x_{\text{smallest slope}} = (\text{slope} - \delta\text{slope}) \times t + (\text{int} + \delta\text{int})\,. \tag{1.6}$$

   Use these equations to generate data points in your Excel spreadsheet for the lines of largest and smallest reasonable slope.

3. Transfer your largest and smallest reasonable slope data to your Kaleidagraph data table. Make a new plot of your data. Your new plot should include all three data sets. Specifically, your original given data set, the data set for the largest reasonable slope and the data set for the smallest reasonable slope.

4. Include error bars on the given data set only — do not include error bars on your data points for the largest reasonable slope or smallest reasonable slope.

5. Calculate best-fit lines for all three lines using the Curve Fit `Linear` option, rather than `fit1` that you used earlier. Instead of displaying a box with parameters, it just displays the equations for each line. Include this graph with your lab report.

You now have your data and three 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.

1.8 Checklist

Remember to turn in:

1. Part 1 data table and formula view
2. Graph for Part 1 including observations[5]
3. Part 2 data table and formula view
4. First graph for Part 2 including observations
5. Second graph for Part 2 including observations
6. Answers to Questions

[5]For help on what to include in the observations see Appendix A.

1.9 Questions

When answering the questions, a measured quantity must ALWAYS include: 1) the numerical value, 2) its units and 3) its uncertainty. Unless otherwise stated, missing any of these quantities means the measurement will be considered incomplete and will receive reduced credit.

1. What is the slope of the best-fit line of the dataset from the first graph of Part 2?

2. What physical quantity does the slope correspond to?

3. What is the y-intercept of the best-fit line from the first graph of Part 2?

4. What physical quantity does the y-intercept correspond to?

5. What is the equation of the line having the largest reasonable slope for this set of data (no uncertainties are necessary in the equation)?

6. What is the equation of the line having the smallest reasonable slope for this set of data (no uncertainties are necessary in the equation)?

7. Do the lines of largest reasonable slope and smallest reasonable slope fit the data well? Explain why or why not by comparing these lines to the original best-fit line including its error bars.