Name: ________________________________

Desk: _________________

Date: _________________

Introduction to 1101 Labs

This lab introduces the basic elements of 1101 labs: taking measurements, recording data, calculating results with uncertainties, and finally, stating and discussing the conclusions. This lab also lets you perform a simple experiment, and write a complete lab report. "Formal" lab reports consist of following sections: Purpose, Apparatus, Data, Calculations, Uncertainty Analysis, Conclusions and Discussions.

We have supplied a template for the experiment in the "A Real Lab Report" section. In future labs that follow this structure, you will have to prepare your own.

Watch the lecture video attached to the Brightspace lab folder in "Course Content" for a review of measurements, uncertainties and precision analysis calculations.

Data

Data is the heart of the lab. It should be clear and easy to understand. Data must be written in non-erasable ink to preserve integrity. "Write in pen, draw in pencil" is a good rule of thumb for any scientific document.

When recording data, you must

- Clearly explain what the data are: is it the length of a pencil? Mass of a cart?
- Record all digits that you can read or estimate from the measuring device.
- Give units, using the unit of the measuring device.
- Give uncertainty. See below on how to assign proper uncertainties.

First, we must build up an important concept: data are not exact numbers. Rather, each piece of data has a small range, or a little window around the number, within which the "true" value lies. To reflect this, we record the data to be the readings plus/minus their uncertainties. Uncertainty is limited by the instrument precision. But it is more important to realize that uncertainty depends heavily on the situation.

Instrument precision

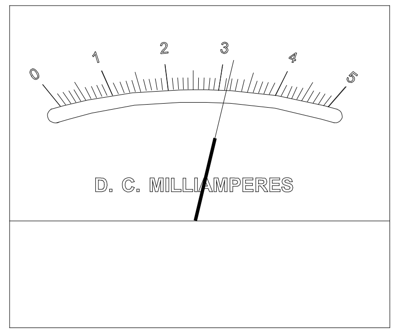
An instrument's precision is the smallest quantity it can distinguish. The instrument manual should give this value. Without a manual, we usually assume the precision is a portion of its smallest division on the scale. In this lab course, we usually use *half of the smallest division* to be the instrument precision.

Range of possible values
Quite often the actual readings are not as precise as the instrument's precision. Maybe the pointer is fluctuating; maybe the edge is jagged; maybe repeating the measurement gives a different reading. In these cases, the uncertainty is roughly half of the range of the possible values, where the range may be estimated from a single reading or calculated from the "scatter" between multiple readings by:

$$\text{scatter} = (\text{maximum reading} - \text{minimum reading})/2$$

Next, we will practice how to take a reading and to assign an uncertainty.

Practice 1: Uncertainty as given by the instrument's precision



Read the current *I*, from the ammeter on the right. The units of the ammeter are milli-amperes (mA). Assume the ammeter reads "zero" with no current.

Here the pointer is sharp and stable. You should keep reading until you have to estimate between the finest division lines. The uncertainty would be half of the smallest division. Record the current and its uncertainty below.

The current through the ammeter is *I* = (_______ ± _______) mA.

Practice 2: In the following data table, find 4 things around your desk, like your mouse, keyboard, eraser, pencil, coffee cup, etc and record the measurements and an approximate uncertainty. Also get the width and length of your desk. Choose 4 things that are of fairly regular but different shapes.

Object and dimension measured	measurement (cm)	Uncert (cm)
Length of desk		
Width of desk		

Table 1: Dimensions of random things on my desk

Note that the uncertainty in these measurements will likely NOT be “half the smallest division” of your ruler. Think about such issues as:

- Are the edges of your object completely flat and lining up with the end of the ruler?
- How many times did you have to use your ruler? The uncerts add up!
- Is there any parallax in how you looked at your object?
- How EASY was the measurement to perform?

The more difficult a measurement, the less confident you likely are with that measurement. The uncert in that measurement would then be bigger than for an easier measurement. In your first worksheet, was it easier to measure the diameter of the apple, or the length of a machined cylinder?

Calculations

It is common that the final result is calculated from the data, rather than being the raw data itself. For example, to measure the area of a desktop, you would measure its length and width. The result (desk’s area) is calculated from the length and the width in the “Calculations” section of your report.

The “Calculations” section should be as follows:

- Convert units appropriately.
- Give (or derive if needed) the symbolic equation that calculates the result from the data.
- Substitute in the values of data and calculate the numerical result, keeping units and not rounding.

Practice 3: Calculate the area of your desk A. Convert your data to meters first. Then derive/write a formula that calculates the area **of a rectangle *A* from its length *L* and width *W*** (symbols first). Then substitute in the average dimensions to find the area in m^2. Do not include uncertainties in this section, and keep 5 or more non-zero digits if you need to truncate a number given by your calculator.

Uncertainty Analysis

This section in your lab report is to find the uncertainty of your calculated result. It has nothing to do with how you decide uncertainty in the raw data, which should be in the "Data" section. However, the uncertainty in the result comes from the uncertainties in data. That is why this section is also called "uncertainty propagation".

To find the uncertainty of the result, you need to calculate both the absolute uncertainty and the relative uncertainty (percentage uncertainty) in your final result. For most of our labs, the calculation is from a product or quotient, which means that it is more convenient to calculate the relative uncertainty first.

Practice 4: Calculate the relative uncertainty of your desk's area *A*, and then turn it into the percentage uncertainty by multiplying 100%. Does it have any units? Don't round your answers yet.

The relative uncertainty of the area of the desk: $\frac{\delta A}{A} =$ %uncert =

Practice 5: Calculate the absolute uncertainty of your desk's area *A*, in m^2.

The uncertainty of the area: $\delta A = \left(\frac{\delta A}{A}\right) A =$

Conclusions

Once you find the final result and its uncertainty, it is time to report them in the "Conclusion" section. The rules for writing conclusions are:

1. The conclusion must be in full sentences, answering the purpose of the lab. Do not only use symbols.

2. The result must have the value and the (absolute) uncertainty. The uncertainty will have 1 (or rarely 2) non-zero digits. Never keep 3 or more non-zero digits for any uncertainty. It is best to include the percentage uncertainty at the end of the result, also with 1 or 2 non-zero digits.

3. The result must have the same decimal precision as the uncertainty. The results 0.3 ± 0.04 and 52.395 ± 0.3 do not have the correct number of digits, while 0.30 ± 0.04 and 52.40 ± 0.35 do.

4. Both the value and the (absolute) uncertainty must have proper units, and their units must be the same. If the numbers are very large or small, use scientific notation (S.N.). Using S.N. is just like using a different unit; you must use the same power of 10 for both the value and the uncertainty. For example, $(1.496 \pm 0.025) \times 10^{11}$ m is good, while $(1.496 \times 10^{11} \pm 2.5 \times 10^{9})$ m is not good.

Practice 6: Report your results of the area of the desk, like this:

Sample: The area of the extra large-size pizza was found to be (0.22 ± 0.04) m^2 ($\pm$ 18%).

Your conclusion:

The area of my desk was found to be ________________________________.

Discussion

A lab report is incomplete without the "Discussion" section. Usually you discuss two aspects:

(1) How confident are you with your result? And why? Compare your result with an accepted value. Agreement within the uncertainty is a good sign that your result is valid.

(2) Another important issue you want to discuss are "other physical factors". These are the factors that may affect the accuracy of your result, but have been **ignored** in your uncertainty analysis. Especially when your result disagrees with the reference value, you must try to give physical reasons why there is a disagreement. "Human error" and "data uncertainties" are not physical factors!

Sometimes, your experiment does not work — you get an unreasonable value that cannot be explained by other physical factors. There are mistakes somewhere. You should check all your work including re-taking the data. If you cannot fix the mistake, you should discuss it — how it happened, what you did wrong, how to fix it if you had time — in the "Discussion" section. A nice discussion could rescue a good portion the mark that would be otherwise lost.

A Real Lab Report

Now, you will apply all of these concepts and practice writing a complete lab report on measuring your own reaction time.

Your reaction time is the time that it takes for you to react to an unexpected event. For example, an Olympic sprinter could start running approximately 0.15 seconds after the starting gun fires. Visual stimuli take longer for your brain to process.

You will be doing an experiment with some help from your partner. Watch this really fun video to get an idea of what will be involved:

https://www.youtube.com/watch?v=3XM-4Qavh5k

With your partner holding the ruler, put your thumb at a spot that is reproducible, like at the 10cm mark. Because of the thickness of your thumb and the distance between the ruler and your fingers, the uncertainty in this starting position will likely be around 0.5cm. Same for where you catch the ruler.

When your partner drops the ruler (unexpectedly), try to catch it as quickly as possible. The location of your thumb on the ruler where you caught it is the "reading" value. The data table in the report template will help keep your measurements CLEAR and UNAMBIGUOUS.

In your Conclusions, (as described above), you will state your reaction time, in proper format with appropriate sig figs, etc. The Discussions section should be where you compare your reaction time to, say, the folks in the video, an Olympic sprinter or other sources you find online. Make some comments on how fast you are! The uncert in your result is due to what? (It's from your inconsistency.) Discuss how you think you could become faster or more consistent. A better ruler will not help. Don't even TRY to go there.

The following pages have a template for writing this report. All future lab reports must follow the same layout, except you will not have to write the "Method" section.

Name: ________________________________

Partner: ____________________________

Date: _________________

My Reaction Time

Purpose: Find my reaction time by catching a falling ruler.

Method: (This will not be required in future lab reports, but is an essential part of real experimental papers.) My lab partner will hold a ruler from one end, letting it hang vertically. I will place my thumb and forefinger at some **specific spot near one end** of the ruler and try to catch it when my partner **unexpectedly** lets go of it. The distance *d* the meter stick falls will be used to calculate my reaction time *t:*

$$t = \sqrt{\frac{2d}{g}}$$

To ensure accuracy, we will do the measurement 5 times. We will each use our own data.

Apparatus: a meter stick, another person to drop the ruler

Data:

Table 1: The drop distance when I catch the ruler (cm)

Initial thumb position y_0		
final thumb position y	Reading 1	
	Reading 2	
	Reading 3	
	Reading 4	
	Reading 5	
Average final position y_{avg}		
Drop distance $d = y_{avg} - y_0$		
Unc. in drop distance δd		

Note: uncertainty δd is calculated from scatter of $\delta d = (y_{max} - y_{min}) / 2$

Discuss the different ways of looking at uncert in this experiment and explain why the scatter uncert is most likely the most significant source of uncert here:

Calculations:

Calculate your reaction time t using $g = 9.81 \pm 0.01$ m/s^2. Remember to do any appropriate unit conversions first. Keep/show your units and do not round at this point.

Uncertainty Analysis:

Calculate the relative uncertainty ($\delta t/t$) and the absolute uncertainty (δt) of the reaction time.

Conclusions:

My reaction time was found to be ______________________ (± %).

Discussion: