Name: ________________________________

Partner(s): _____________________________

1125 Section: __________

Desk # _______________

Date: _________________

Introduction to 1125 Labs

For this lab, each student must take his/her/their own data and complete their own handout.

This lab introduces the basic elements of the 1125 lab: taking measurements, recording data, calculating results and its uncertainties and, finally, stating and discussing the conclusions.

This lab also lets you perform a simple experiment and write a complete lab report. Our 1125 lab reports consist of the following sections: Purpose, Apparatus, Data, Calculations, Uncertainty Analysis, Conclusions and Discussion.

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.

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 a number, within which the "true" value lies. To reflect this, we record the data to be the readings plus/minus their uncertainties. Uncertainty is influenced by the instrument precision, but it is very 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's manual should give this value. Without a manual, we usually assume that the precision is a portion of the smallest division on the scale. In this lab course, we usually use *half of the smallest division* to be the instrument precision.

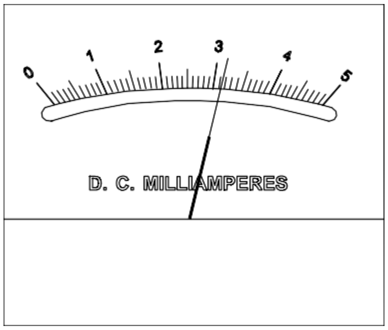
Range of possible values
Quite often the actual readings are not as precise as the instrument's precision. Maybe the pointer is fluctuating; maybe the edge is jagged; maybe repeating the measurement gives a different reading. In these cases, the uncertainty is roughly half of the range of the possible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

scatter = (maximum reading - 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.

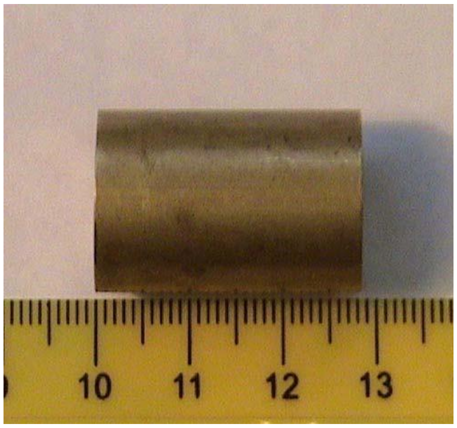


Here the pointer is sharp and stable. You should keep reading until you have to estimate between the finest division lines. The uncertainty would be half of the smallest division. Record the current and its uncertainty below.

The current through the ammeter is I = (_____ $\pm$ _______) mA.

Practice 2: Uncertainty as given by the range of a single measurement (situation-dependent)

Read, from the pictures below, the size of an apple and the length of a well-machined cylinder. The unit of the ruler is cm. Do <u>not</u> draw lines on the pictures.



The size of the apple is $D=$ (_______ $\pm$ ______) cm.

The length of the cylinder is $L=$ (_______ $\pm$ _______) cm.

Note: for the two lengths above, although the ruler is the same, the uncertainties should be different to reflect the different ranges. The decimal places of the value and the uncertainty should match. [For example, the decimals match in the quantity (1.4 ± 0.2) kg , but they do not in (1.35 ± 0.2) kg .]

Practice 3: Uncertainty as given by the scatter of multiple measurements

$$\text{uncertainty (scatter)} = \frac{\text{range}}{2} = \frac{\text{maximum reading-minimum reading}}{2}$$

Measure the diameter of the personal size pizza below and record the data. Choose 4 different directions that reflect its shape. When making the measurements, treat it as a real pizza: the ruler should not touch it, and no lines should be drawn on it! Naturally, there will be uncertainty due to parallax.

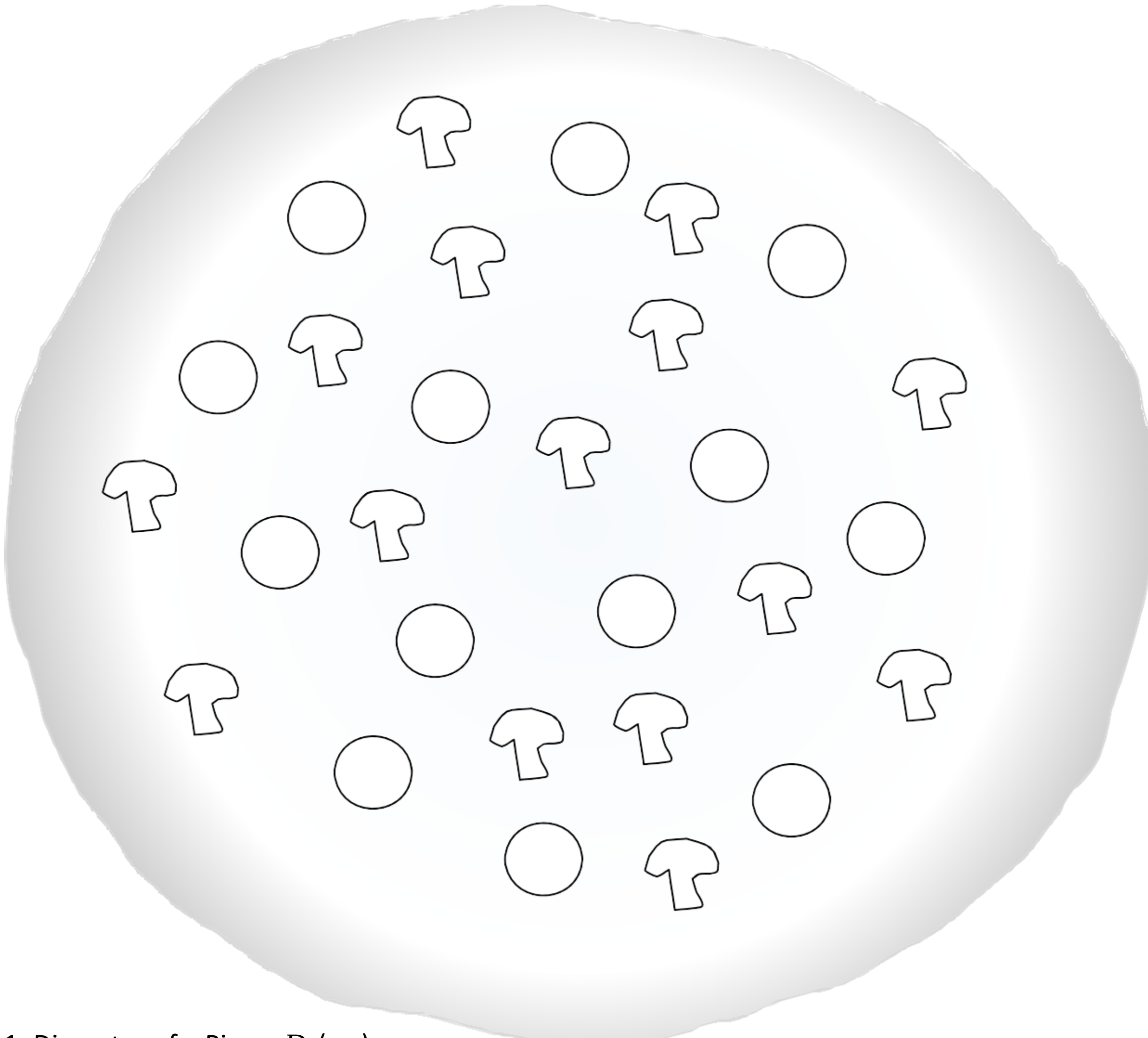


Table 1: Diameter of a Pizza, D (cm)

Reading 1	
Reading 2	
Reading 3	
Reading 4	
Average reading	

Ruler precision =

Uncertainty for a single reading (parallax, etc.) =

Uncertainty from scatter =

Final uncertainty (the largest of the above): $\delta D =$

Note: when truncating numbers from your calculator, keep 5 or more non-zero digits for the average diameter and 3 or more for its uncertainty.

Here we used a table to organize the data. Data tables are easier for people to understand, and there is less repetitious writing. For example, you can put the description and units in the table title.

In this example, we listed all three aspects that affect uncertainty: (1) instrument precision; (2) uncertainty from a single reading; and (3) uncertainty from scatter between multiple readings. The final (assigned) uncertainty is the largest of the three. Here the scatter is larger than the ruler's precision (0.05 cm) and the uncertainty for a single reading (about 0.3 cm), so the scatter becomes the final uncertainty, δD. In a later experiment when we measure the diameter of a wooden disk, scatter may be quite small or even zero. The general principle is to always assign the largest of the three uncertainties as the final uncertainty.

Given that uncertainties can be very situation-dependent, you should write a short note below your data table explaining how you came up with your uncertainty value(s).

Calculations

It is common for the desired quantity/result to be 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 (the desk's area) is calculated from the length and the width in the "Calculations" section of your report.

In the "Calculations" section you should do as follows:

- Convert units appropriately.
- State (or derive if needed) the symbolic equation that calculates the result from the data.
- Substitute in the values of the data (including units!) and calculate the numerical result.

Practice 4: Calculate the area of your pizza, A.

Convert your data to meters and derive a formula for the area of a circle, A, in terms of its diameter D. Next, substitute in the average diameter reading to find the area in m^2. Do not include uncertainties. [We will use them in the next section.] 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 source of the uncertainty in the result is the uncertainties in the 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 (also, the percentage uncertainty, when multiplied by 100%). For most of our labs, the result is a product or quotient so calculating the relative uncertainty first is more convenient.

Practice 5: Calculate the relative uncertainty of your pizza's area, $\delta A / A$: derive an expression for it, and calculate its value and percentage value. Does it have any unit? Don't round your answers yet.

$$\frac{\delta A}{A} =$$

Practice 6: Calculate the absolute uncertainty of your pizza's area, δA, in m^2.

$$\delta A = \left(\frac{\delta A}{A}\right) A =$$

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 must have 1 or 2 non-zero digits. Never keep 3 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 ± 0.32 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 7: Report your results for the area of the pizza, as in the sample conclusion below:

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

Your conclusion:

The area of the personal-sized pizza was found to be ___________________________________.

Practice 8: From the list of choices below, provide the letters that identify the mistakes in the following conclusions. Each question has two mistakes.

List of Mistakes:
(a) The conclusion uses a symbol that is not properly defined. (b) The uncertainty has too many digits. (c) The value and the uncertainty do not match in decimal places, or it is hard to tell whether they match. (d) Unit is missing. (e) Did not properly use scientific notation.

8-1. The mass of the Earth is (6.0×10^{24} ± 3.1×10^{22}) kg. Mistakes: ________________

8-2. The spring constant of spring #3 is (33.46 ± 3.75). Mistakes: _______________

8-3. ρ is (0.2236 ± 0.0117) Ωm. Mistakes: _______________

8-4. The diameter of a red blood cell is (0.00004 ± 0.00002) (± 50%). Mistakes: ____________

8-5. I is (0.35 ± 0.012) A. Mistakes: _______________

Practice 9: Work out the uncertainty propagation equations for the quantities below. Show your growing mastery at this skill!

Equation	Uncertainty equation
$p = \frac{F}{A}$	
$T = 2\pi\sqrt{\frac{m}{k}}$	
$a_{\text{avg}} = \frac{v_{\text{f}} - v_{\text{i}}}{t}$	
$L = \frac{1}{2}MR^2\omega$	

Discussion

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

(1) The confidence in your result: Why are you confident or not? The answer to this is usually based on a comparison of your result with an accepted value. Agreement within the uncertainty is a good sign that your result is valid.

(2) “Other physical factors”: These are the factors that may affect the accuracy of your result but have been ignored in your uncertainty analysis. For example, if a ruler is accurate at 20^{o}C, measurements made under a different temperature will be slightly off. Under all circumstances but especially when your result disagrees with the reference value, you must think of and discuss the physical reasons leading to your results and/or, possibly, to 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 you would fix it if you had the time, etc. — in the “Discussion” section. A strong discussion could rescue a good portion of the mark that would be otherwise lost.

A Real Lab Report

Now, you will apply the concepts introduced above by practicing writing a complete lab report on measuring your own reaction time.

Your reaction time is the time that it takes to react to an unexpected event. For example, an Olympic champion could start running approximately 0.15 seconds after the starting gun fires.

The following pages have a template for writing the report. Except for the “Method” section, which won’t be part of them, all future lab reports must follow the same layout given in the template.

Name: ______________________________

Partner(s): ___________________________

1125 Section: __________

Desk # _______________

Date: _________________

My Reaction Time

Purpose: Find my reaction time by catching a falling meter stick.

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 meter stick from one end, letting the meter stick hang vertically. I will place my thumb and forefinger at some specific mark **near the middle** of the meter stick and try to catch the meter stick when my partner **unexpectedly** lets go of it. The distance d that the meter stick falls will be used to calculate my reaction time, t:

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

To ensure accuracy, we will repeat the measurement 5 times. (Each partner has their **own data**.)

Apparatus: a meter stick

Data:

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

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

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

Calculations

Calculate your reaction time, t, using g = (9.81 ± 0.01) m/s^2. Remember to do any appropriate unit conversions first.

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: