Name: ________________________________

Partner(s): _____________________________

1125 Section: __________

Desk # _______________

Date: _________________

**Introduction to 1125 Labs**

*For this lab, each student must take his/her 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 following sections: Purpose, Apparatus, Data, Calculations, Uncertainty Analysis, Conclusions and Discussions.

**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 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*

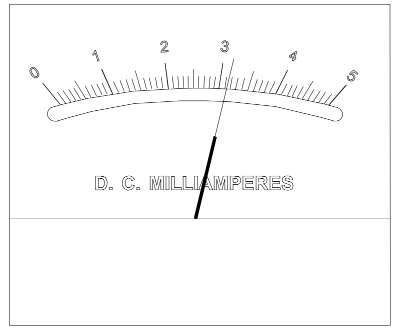
Quite often the actual readings are not as precise as the instrument's precision. Maybe the pointer is fluctuating; maybe the edge is jagged; maybe repeating the measurement gives a different reading. In these cases, the uncertainty is roughly half of the range of the possible values, where the range 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.

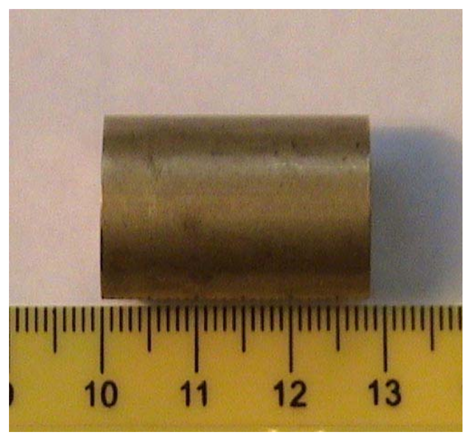



Here the pointer is sharp and stable. You should keep reading until you have to estimate between the finest division lines. The uncertainty would be half of the smallest division. Record the current and its uncertainty below.

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

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

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 not draw lines on the pictures.


The size of the apple is $D$ = (_______ ± _______) cm.

The length of the cylinder is $L$ = (_______ ± _______) 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.

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

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

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 real pizza: the ruler should not touch the pizza, and do not draw lines on the pizza! Naturally, there will be uncertainty due to parallax.

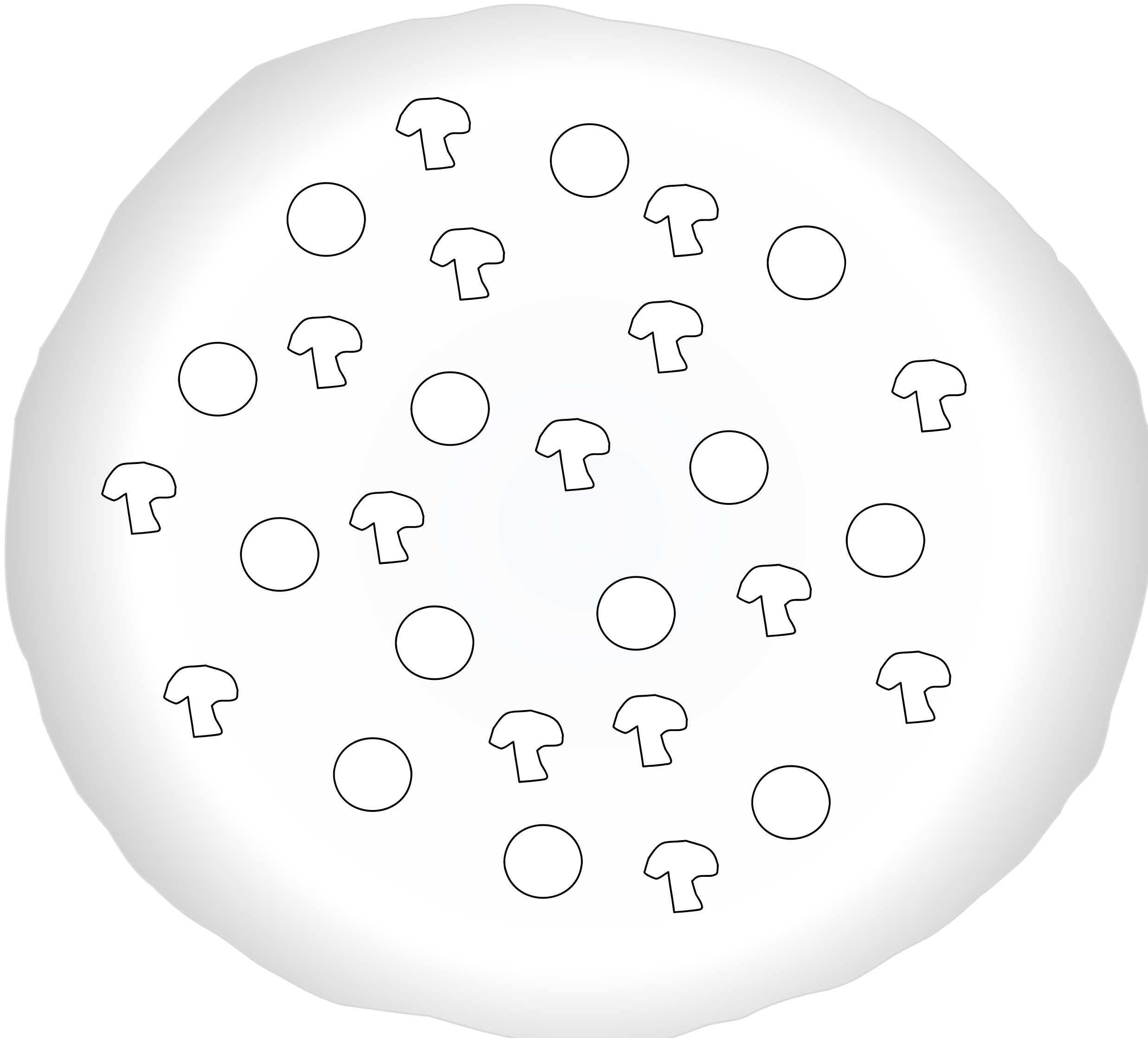


Table 1: Diameter of a Pizza *D* (cm)

| | |
|---|---|
| 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 above) =

*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 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 for a single reading; (3) uncertainty from scatter between multiple readings. The final 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, $\delta D$. In a later experiment when we measure the diameter of a wooden disk, scatter may be quite small or even zero, and you should use whichever is the largest of the three 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 that the final result is calculated from the data, rather than being the raw data itself. For example, to measure the area of 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.

**Practice 4:** Calculate the area of your pizza $A$. Convert your data to meters first. Then derive a formula that calculates the area of a circle $A$ from its diameter $D$. Then substitute in the average diameter reading 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 source of the uncertainty in the result is 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). For most of our labs, the result is a product or quotient, which means that it is more convenient to calculate the relative uncertainty first.

**Practice 5:** Calculate the relative uncertainty of your pizza's area $A$, and then turn it into the percentage uncertainty by multiplying 100%. Does it have any unit? Don't round your answers yet.

| |
|---|
| The relative uncertainty of the area: <br><br> $\frac{\delta A}{A} =$ |

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

| |
|---|
| The uncertainty of the area: <br><br> $\delta A = \left(\frac{\delta A}{A}\right) A =$ |

## 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 $0.3 \pm 0.04$ and $52.395 \pm 0.3$ do not have the correct number of digits, while $0.30 \pm 0.04$ and $52.40 \pm 0.35$ 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 7:** Report your results of 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:** 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 ($6.0\times10^{24} \pm 3.1\times10^{22}$) kg. Mistakes: ______________
8-2. The spring constant of spring #3 is (33.46 ± 3.75). Mistakes: ______________
8-3. $\rho$ 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 following to show your mastery of uncertainty propagation skills!

| Equation | Uncertainty equation |
|---|---|
| $F = ma$ | $\frac{\delta F}{F} = \frac{\delta m}{m} + \frac{\delta a}{a}$ |
| $T = 2\pi\sqrt{\frac{m}{k}}$ | |
| $a_{avg} = \frac{v_f - v_i}{t}$ | |
| $L = \frac{1}{2}MR^2\omega$ | |

## Discussion

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

(1) 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. For example, a ruler is accurate at 20°C, so the readings will be slightly off when you use under a different temperature. 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 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 this report. All future lab reports must follow the same layout, except you will not have to write the "Method" section.

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* 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 his/her **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 $d = y_{ave} - y_0$ | | |
| Unc. in drop distance $\delta d$ | | |

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

**Calculations**

Calculate your reaction time $t$ using $g = 9.81 \pm 0.01$ m/s$^2$. Remember to do any appropriate unit conversions first.

**Uncertainty Analysis:**

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

**Conclusions:**

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

**Discussion:**