# Uncertainty of Measurement and Report Writing

This lab introduces the concept of uncertainty of measurement, and provides guidance toward proper report writing for physics experiments. One foundational aspect of measurement uncertainty is correctly quantifying and propagating experimental uncertainties. To demonstrate this, a simple experiment, *Material Identification by Density* is performed using three different measurement methods. Moreover, this lab manual will cover concepts for writing a proper lab report.

> Text that is outlined in a box are comments that are related to the report writing process. This helps delineate content that is related to the report writing process and the experiment itself. Remember that a lab report should be a self contained document of the whole experimental process. Invest time in learning how to write a proper report as it is a critical part of the scientific process.

## Physics Topics

If necessary, review the following topics and relevant textbook sections from Serway / Jewett "Physics for Scientists and Engineers", 9th Ed.

- Units and Measurement (Serway 1.1)
- Significant Figures (Serway 1.6)
- Uncertainty and its Propagation (See the writeup "Introduction to Measurement Uncertainty and Error Analysis", posted on the Ryerson physics lab website.).

**Note:** Propagation of uncertainty is discussed in Serway Appendix B.8. However, the discussion is too oversimplified for our purposes. A more complete coverage of the topic can be found in "Laboratory Guide - Physics" on how to propagate uncertainty.

## Introduction

> The introduction should capture the experiment's objective. It should succinctly describe the goal of the experiment, and how it is achieved. It should be at most 1-2 paragraphs.

The material of a block of unknown material is identified by determining the density and comparing it to a table of known values. The volume of the block is determined using three separate single measurement methods. For the purpose of this lab, the uncertainty of each method will be taken to be the uncertainty of the measurement instrument. Based on each method, the unknown material will be attempted to be identified. The uncertainties will be used as a metric to determine if the results are consistent or inconsistent.

## Theory

The theory section should cover the core physics concepts being investigated. The section should present the equation to be studied and when within the scope of the course, contain the derivations of the physics. If an external reference was used for the derivation, it must be correctly cited. Any cited references should be correctly written in APA citation format. Any graphs that illustrate or predict the expected results should be included in this section.

### Uncertainty in Single Measurement

When performing experiments, it is best practice to perform the measurement several times to be able to confidently report results. However, this may not always be practical, and a single measurement could be sufficient. When performing a single measurement, the uncertainty can be quantified based on the measurement instrument meaning the limiting factor is the precision and accuracy of the instrument itself.

In an ideal scenario, the instrument would have an uncertainty of half of the smallest division or increment. However, this is not always true as many other factors could contribute to the uncertainty of the actual measurement. Generally the goal is not to minimize the uncertainty but to best represent the uncertainty in the experiment performed. For the sake of this exercise, the uncertainty will be based strictly on the measurement instrument.

### Density of Materials

Uniform materials have well defined densities and may thus be identified by its density. The density of the metal ($\rho$) may be calculated from its mass $m$ and volume $V$ using the formula

$$\rho = \frac{m}{V}. \tag{1}$$

Provided that the mass and volume can be measured, the density can then be determined. Using this density and a table of known density values, it is possible to determine the unknown material.

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## Pre-Lab Questions

Pre-lab questions are designed to help with the lab and pre-lab quiz. Completing them is optional; **however,** the questions prepare you for the experiment to be performed. It is highly recommended that the pre-lab questions are completed or attempted. Remember that the in-lab time is limited preparation is key to maximize that time.

Please complete the following questions prior to coming to lab. They will help you prepare for both the lab and the pre-lab quiz (Found on D2L).

**1.)** A garden plot is a rectangle which measures $5.00\text{m} \pm 0.05\text{m}$ long and $2.00\text{m} \pm 0.04\text{m}$ wide. Calculate the area of the garden and propagate the uncertainty to give your result **with uncertainty**.

**2.)** Devise (or research) a volume displacement experiment that uses a beaker, graduated cylinder, and tape while minimizing uncertainty.

## Apparatus

The lab report should outline the experimental set-up, any specific configurations or unique quantifiable attributes of the equipment. A dedicated apparatus section in the lab report is optional; **however,** these characteristics must be integrated into another section of the report (such as the procedure).

The apparatus section will contain a list of equipment needed for the lab. Before beginning any experiment, to the best of one's ability, research or learn about the equipment to be used. In particular for this experiment, it is crucial to learn how to use Vernier Calipers.

- One (1) unknown material
- Triple beam balance
- Graduated cylinder
- Metre stick
- Vernier Calipers
- Beaker
- Masking tape

## Procedure

The procedure section of the report should contain all the relevant information to recreate the experiment performed. This means a detailed account of settings, values and the apparatus configuration used to perform the experiment. It should systematically outline the steps taken for the experiment and be written in a manner that anybody should be able to repeat the experiment performed.
In some cases, the lab manual contains step-by-step instructions. If so, a simple reference to the manual is sufficient; **however,** specific details related to the experimental performed, or any deviations from the intended procedure must still be included.

Follow the instructions below to complete the experiment. The procedure section of the report should be more detailed than the instructions below. Record each reading with the appropriate uncertainty for single measurement, including a brief explanation in words for how the uncertainty was estimated for each measurement.

**1.)** With the equipment provided, determine the mass of the block.

**2.)** Determine the dimensions of the unknown material using the following equipment:

- The metre stick. **Hint: Devise (and include in the report) a procedure that is reliable.**
- The Vernier Calipers. **Hint: Some calipers might be offset from zero with the jaws fully closed - can this be quantified?**
- The beaker, graduated cylinder and tape. **Hint: Revisit Pre-Lab Question 2**

## Analysis

The analysis section provides guidance on what should be included in the Results and Calculations section of the report. Results from the experiment should be presented in an organized manner. This generally means tables and/or graphs of results. Determine a method to present the results in a coherent, organized manner. It is good practice to show a sample calculation for any analysis that is unique to the experiment. If the analysis method is a rudimentary, such as taking the Mean (Average), it is acceptable to state the equation used but not necessarily show the entire calculation.

**1.)** From each single measurement, calculate the volume, and the density of the block as well as propagating uncertainty. Show these calculations in your lab report.

**2.)** Based on the calculated densities, attempt to identify the unknown material using known densities presented in the table in Appendix A. For the purpose of this lab, do not use any other identifying qualities aside from the density to determine the material.

**3.)** Consider each measurement method, could the material be determined unambiguously? **Hint: Pay attention to the uncertainty.**

**4.)** For each measurement method, calculate the percent error between the calculated density and the one selected from the table. Use these results to make a concluding statement for each measurement method regarding the identity of the unknown material.

## Wrap Up Questions

This section is designed to make sure that the physics implications of the experiment and knowledge of the physical concepts covered are understood. The answers to these questions should be integrated into the report in a seamless manner and were designed to maintain the overall flow of the report. Each question is tagged with a section where one might expect to integrate the answer to the question.
In the Results and Conclusions section of the lab report, discuss the main observations and outcomes of the experiment, and summarize any significant conclusions. Discuss the validity of the result or possible reasons why the results were invalid.

**1.)** [Results] Consider the validity of determining an average density from the three measurement methods. Calculate the the average density (as well as propagating uncertainty) and justify why it is (or is not) beneficial to report the average for this situation.

**2.)** [Discussion] The uncertainty of the measurements were defined by the measurement instruments. Comment on other possible sources of uncertainty and provide an estimate of their magnitude. When should these sources of uncertainty be used instead of the measurement instrument uncertainty? Would considering these factors change the conclusion of the report?

**3.)** [Discussion] There is a fundamental difference between percent error and uncertainty. Explain in the report what that is and hence the need to calculate percent error.

**4.)** [Conclusion] What conclusion can one make based on the results agreeing or disagreeing with a theoretical or accepted value?

## Writing a Report

Any remaining time of the lab should be spent beginning to write the report for the experiment. For this lab, time is provided to begin organizing a proper report. Later sessions will not provide much (or any) time and must completed outside the session. Use the remaining time to create a draft of the report. Be sure to ask questions regarding the report while in the lab session as your TA may not respond to emails in a timely manner. A complete report is to be submitted before the specified due date. Use the comments outlined in boxes, as well as these additional comments to assist with writing a comprehensive lab report:

### Title Page

Include the following: report title, your name, your partner's name, the course, section number, instructor and TA name.

### Introduction

The introduction should capture the experiment's objective. It should succinctly describe goal of the experiment, and how it is achieved. It should be at most 1-2 paragraphs.

### Theory

Ensure that the theory section captures the core physics - things such as the history of the experiment, although interesting, is generally off-topic for such reports. Depending on the complexity of the subject, this section should be a few paragraphs but also contain derivations and equations (when applicable).

### Procedure

When completing the procedure section, it helps to read through the section as if it were a person that has not completed the experiment. This will help to identify any information that might be lacking in the procedure. Do not forget to include details of the experiment. The critical parts of the apparatus section should be included here if there was no dedicated apparatus section. The procedure section is important but do not waste (your) time reinventing the wheel.

### Results and Calculation

Results and calculations should have supporting text explaining what is being done. If a reader cannot follow what is happening, then the report is useless. It is key to guide any reader through the analysis process to reach the goal of the experiment. Graphs and tables are a great way to succinctly summarize results provided they are well organized and labelled. Also note that any large sets of raw data should not be put in this section (where might such information go?)

### Discussion and Conclusion

Conclusions should be succinct and easy to understand the result of the experiment. Make use of proper organization and labelling so you can reference results with ease. Be sure to include important aspects such as things that might have affected the experiment here.

### References

Reference any resources used. **Remember that direct copying is considered plagiarism.** Any cited references should be correctly written in APA citation format.

### Appendices

If large quantities of data are obtained, or lengthy details are needed, but break the overall flow of the report, they should be referenced and placed in the appendix.

## Appendix A - Density of Common Materials

| **Material** | **Density ($g/cm^3$)** |
|---|---|
| Aluminum | 2.70 |
| Titanium | 4.50 |
| Zinc | 7.13 |
| Tin | 7.28 |
| Iron | 7.87 |
| Brass | 8.4 - 8.7 |
| Copper | 8.96 |
| Silver | 10.49 |
| Lead | 11.36 |
| Acrylic | 1.19 |
| Polycarbonate | 1.2 |
| Polyethylene | 0.952 - 0.965 |