Name: **Section:** **Date:**

Physics 221
Lab Physics for Science and Engineering I
Experiment 2: Measurement and Uncertainty

THEORY

Purpose

Students will learn the proper technique for using several measuring instruments. These instruments will be used to determine the substance that an object is composed of by calculating the density of that object. Proper use of significant figures will be emphasized and a method for error propagation will be taught.

Introduction

The science of measurement (metrology) is a field of study that requires careful thought concerning the statements one makes about nature so that the most useful observations possible are recorded and communicated. A scientific observer must be diligent in mastering many different skills to ensure this outcome. These skills include the proper use of measurement instruments, understanding the limits of those instruments (scientific uncertainty), never claiming to have more knowledge than one has actually gathered (significant figures), and reporting findings with language that ensures the collected knowledge will be well understood (units). The objective of this experiment is to introduce these concepts and provide practical experience with them.

Units

Consider a person who reports that they have walked "100 steps". In hearing this statement, a listener can glean a general sense of the distance that the walker has traveled, with "steps" being a unit of distance, and "100" being the number of units. We will define a unit as a standard by which an observer can impart meaning to their measurements. While this unit (steps) is not inherently incorrect, it is also not a *good* unit because everyone's steps do not cover some well-defined, uniform distance; everyone has various length legs and gaits. Observers need a collection of agreed-upon, standardized units so that experimental knowledge gathered by one person may be confirmed (or brought into question) by another person's similar experiment.

The standardized units that we will use in this lab course are the units of the "Systéme International" (S.I. Units) whose definitions are established and maintained by The International Bureau of Weights and Measures, and were adopted in 1875 when 17 countries, including the United States, signed "The International Treaty of the Meter" in Paris, France. The three base units that will be used in this course are the meter (m), second (s), and the kilogram (kg).

Significant Figures

Significant Figures and their importance were discussed at length during last weeks lab. Recall the following rules:

1. All nonzero digits are significant

2. A zero is significant if it is:

    - between two significant digits

    - after all nonzero digits and after the decimal point

3. A zero is not significant if it is:

    - Before all nonzero digits

    - At the end of a value but before the decimal point's position

Rule for Addition and Subtraction:

- The result is given to the same decimal place as the least precise of the last significant digits in each.

Rule for all other operations:

- The result is given to the same number of significant figures as the least number of significant figures in any value.

Scientific Uncertainty

All measurements have associated uncertainties. To understand the significance of a measurement, these uncertainties must be understood and quantified. There are may sources of uncertainty for a given measurement, some of which are more significant than others. Although uncertainties in measurements can come from more than one source, during this experiment we will only quantify the uncertainty that comes from the measuring instrument's smallest-increment. (The smallest-increment of a measuring device can also be called its readability, resolution, or least-count.)

Generally, the uncertainty of a measuring instrument that displays a digital readout is ± its smallest-increment, while the uncertainty of a measuring instrument with an analog display is ± half of its smallest-increment. These uncertainty values should be recorded with each measurement that you take. All uncertainties in the course should be reported to *one significant figure.*

Propagating uncertainties through calculations can be done in many ways, some of which we will learn in this course. However, to get a maximum estimate of the uncertainty range associated with a calculated number we will use the "Half Max-Min" Method:

$$\delta_f = \frac{f_{max} - f_{min}}{2}$$

Example:

Suppose we want to calculate the area of a rectangle after measuring the side lengths to be:

$$x = 10.0\ m\ \pm\ .5\ m$$

$$y = 30.0\ m \pm\ .5\ m$$

The area A of the rectangle will be:

$$A = xy\ m^2 \pm \delta_A\ m^2$$

$$A = 300\ m^2 \pm\ \delta_A\ m^2$$

So, to calculate the uncertainty of the area, we will use:

$$\delta_A = \frac{A_{max} - A_{min}}{2}$$

Where A_{max} is the maximum possible area given the uncertainties in x and y, and A_{min} is the minimum possible area given the uncertainties in x and y.

A_{max} will be:

$$A_{max} = x_{max} y_{max}$$

$$A_{max}\ = (10.5\ m)(30.5\ m)$$

$$A_{max} = 320.25\ m^2$$

By the sig-fig rules:

$$A_{max} = 320\ m^2$$

Similarly, A_{min} will be:

$$A_{min} = 280\ m^2$$

So, we can calculate the uncertainty in the Area, δ_A:

$$\delta_A = \frac{320\ m^2 - 280\ m^2}{2}$$

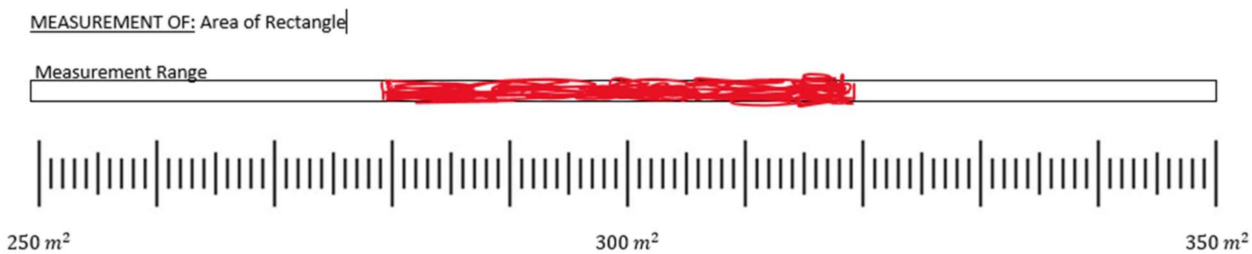
$$\delta_A = 20\ m^2$$

Note that our uncertainty only has one significant figure, so there is no need to round!

We can now report our calculated area:

$$\boxed{A = 300\ m^2 \pm 20\ m^2}$$

As part of this experiment, you will be asked to shade in a range of values corresponding to the range of uncertainty of your measurements. If we were to perform this exercise for our calculated area, it would look like:



Density

The density (r) of a substance is defined as its mass (m) per unit volume (V).

$$\rho = \frac{m}{V}$$

The density of any pure substance will remain the same regardless of a particular sample's size or mass. Although the S.I. unit for density is ${kg}/{m^3}$, we will use the unit ${g}/{cm^3}$. The following table contains densities for substances that you may encounter in this lab.

Material	***Density (g/cm^3)***
Solids	
Metal:	
Aluminum	2.70
Stainless Steel	7.8
Brass	8.44 - 8.75
Bronze	8.74 - 8.89
Copper	8.96
Lead	11.3
Mercury	13.5336
Rock:	
Granite	2.64 - 2.76
Slate	2.6 - 3.3
Diamond	3.51
Garnet	3.15 - 4.3
Corundum	3.9 - 4.0
Wood:	
Pine (Yellow)	0.37 - 0.60
Oak	0.60 - 0.90
Ebony	1.11 - 1.33
Misc.:	
Ice	0.917
Bone	1.7 - 2.0
Chalk	1.9 - 2.8
Glass (Lead)	3 - 4
Fluids	
Atmosphere (STP)	0.001225
Water (20°C)	0.99821
Water (0°C)	0.99984
Mercury (20°C)	13.546

Table 1.1: Density of Selected Materials

PROCEDURE

Part 1: The Vernier Caliper

Your TA will pass out a worksheet explaining how to measure length with a Vernier Caliper. Pay attention to your TA's demonstration of how to operate this instrument; when used properly, you will be able to measure lengths with a precision as high as five-hundredths of a millimeter! Complete the worksheet by measuring and recording the dimensions of the metal block on your lab table.

Part 2: Smallest-Increment and Uncertainty of Measuring Devices

Determine the readability and uncertainty of the following five devices on your lab bench:

- Ruler
- Protractor
- Triple Beam Balance
- Electronic (Digital) Balance
- Vernier Caliper

Record these values in the table in "Table 1" of your Worksheet.

Part 3: Comparing Density Measurements of Varying Precision

-- Lower Precision Method –

1) Zero the triple beam balance.
2) Using the triple beam balance, measure the mass of the metal cylinder provided. Record this measurement and its uncertainty in Table 2.
3) Measure the height and diameter of the metal cylinder using the ruler. Record this measurement and its uncertainty in Table 2.
4) Calculate the radius of the cylinder. Record this value and its uncertainty in Table 2.
5) Calculate the volume of the cylinder. This is equal to the area of its circular base times its height. Record this value and its uncertainty in Table 2. Determine the Uncertainty using the "Half Max-Min" method.
6) Calculate the density, ρ, of the metal cylinder. Record this value and its uncertainty in Table 2. Determine the Uncertainty using the "Half Max-Min" method.
7) Identify the metal that the cylinder is made of using the density chart provided above. What is the percent error between your calculated value and the accepted value?

-- Higher Precision Method –

8) Zero the digital balance.

9) Using the digital balance, measure the mass of the metal cylinder provided. Record this measurement and its uncertainty in Table 3.

10) Measure the height and diameter of the metal cylinder using the Vernier Caliper. Record this measurement and its uncertainty in Table 3.

11) Calculate the volume of the cylinder. This is equal to the area of its circular base times its height. Record this value and its uncertainty in Table 3. Determine the Uncertainty using the "Half Max-Min" method.

12) Calculate the density, ρ, of the metal cylinder. Record this value and its uncertainty in Table 4. Determine the Uncertainty using the "Half Max-Min" method.

13) Identify the metal that the cylinder is made of using the density chart provided above. What is the percent error between your calculated value and the accepted value?

-- Visualizing Uncertainty –

14) On the back of the worksheet you will find a density scale and areas to record the ranges of values that you've calculated. Using the uncertainties that you calculated, shade in the area of the low-precision bar and the area of the higher precision bar that span the range of your measurements. Draw an "X" directly on the scale where the theoretical value is located.