LAB 2: Measuring Devices, Uncertainty, and Density*

Equipment List:
one aluminum block
meter stick(s)
metric ruler
triple-beam balance
digital balance
vernier calipers

Purpose: To familiarize you with various measuring devices and measurement uncertainty. You will gain experience performing error propagation to understand how uncertainty in individual measurements leads to a range of possible values for a quantity calculated from these measurement. You will also get hands-on experience calculating a density.

Introduction: In this experiment you will measure the density of an aluminum block and find the uncertainty in your value. The density, ρ ("rho"), of a uniform object is the ratio of the object's mass to its volume, $\rho = \frac{m}{V}$.

Use the following general error propagation equation to analyze the errors involved in making calculations involving measurements with their own uncertainty. If q is a function of the values $x,\ y,\ z$ combined by division or multiplication and each with a corresponding uncertainty $\Delta x,\ \Delta y,\ \Delta z$, then Δq, the uncertainty in q, can be found using the expression

$$\frac{\Delta q}{q} = \sqrt{\left(\frac{\Delta x}{x}\right)^2 + \left(\frac{\Delta y}{y}\right)^2 + \left(\frac{\Delta z}{z}\right)^2}. \tag{1}$$

Strictly speaking, this equation should be written in terms of the standard deviations of the measurements. An individual measurement, say of length, would be repeated a very large number of times and the best estimate for the true value of the length would be the average of all the measurements. The standard deviation could then be interpreted as the uncertainty of the value and the standard deviation of q would be related to the standard deviations of $x,\ y$, and z as in equation (1). To save time in this lab, we will instead take each measurement only once, and assume that the imperfect precision of the measuring device is the biggest source of variation and uncertainty. We can use this formula because we assume the errors caused by imprecise measurements are random.

As an example of how to use equation (1), suppose the area A of a rectangle is calculated from measurements of its length x and width y. The area of a rectangle is given by

$$A = xy$$

*Based on labs by Prof. Luna and Prof. Newton.

so that the error propagation equation for the uncertainty in A becomes

$$\Delta A = \sqrt{y^2 (\Delta x)^2 + x^2 (\Delta y)^2}\,.$$

The uncertainty in the area can now be calculated from the measured values x and y and their uncertainties Δx and Δy.

Note: for this lab any measurements and calculations should be stated in the standard form of: measurement value = $x_{\text{meas}} \pm \Delta x$.

Procedure:

Part 1: Using the measuring instruments

1. Learn to use the measuring devices needed in this lab.
2. Figure out and record the uncertainty of each device.

Part 2: Area of the table top

1. Measure the length and width of you lab bench surface with meter stick(s) and record the values and their uncertainties.
2. Calculate the area of the lab bench top surface and its uncertainty.

Part 3: Density of an aluminum block

1. Measure the dimensions of the aluminum block with the metric ruler and vernier calipers.
2. Measure the mass with the block with the digital balance and triple-beam balance.
3. Calculate the density ρ_{tbr} and uncertainty of the block by using the measurements obtained from the triple-beam balance and metric ruler.
4. Calculate the density ρ_{dvc} and uncertainty of the block by using the measurements obtained from the digital balance and vernier caliper.
5. Calculate the percentage error between each of your calculated values of density and the expected value of 2.699 g/cm^3.