PHSC 2105 **Measurement, Accuracy, Precision** **Name:**______________________

Object: Learn how to use measuring instruments and interpret the results to get good measurements.

Introduction: Ideas in science can be compelling and beautiful, but without experimental testing they have little power or practical application. Ideas and predictions are tested by designing experiments, making measurements, and comparing to the prediction. A *measurement* is an observation in which you count (standard) units. For example, volumes are measured by counting volume units; volumes can also be *computed* by measuring lengths and multiplying them together.

It is the scientist's job to reduce the uncertainty as much as possible/practical, and then honestly report the uncertainties that remain.

You will get some practice making measurements by calculating the density of aluminun, water, and masonite. The density ρ of an object is defined to be its mass m divided by its volume V:

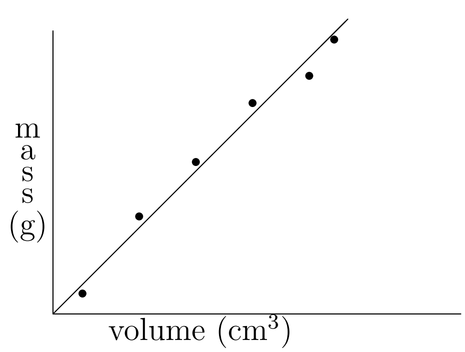
$$\rho = \frac{m}{V} \tag{1}$$

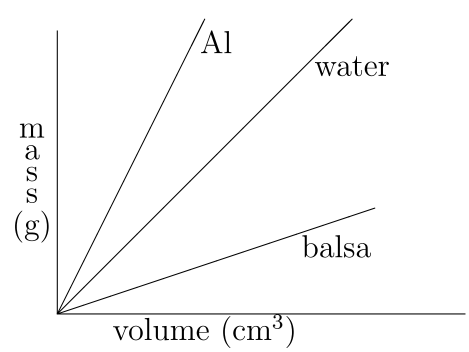
An object's mass can be measured directly using an equal-arm balance. The volume, however, is often calculated from a combination of various length measurements using a ruler or meter stick, vernier calipers, and a micrometer caliper. For a rectangular block, the volume V is calculated from the product of the measured length, width, and height: $V = L \times W \times H$. For a disk or a rod of radius r the volume is equal to the cross sectional area multiplied by the thickness or length L:

$$V = \pi r^2 \times L \tag{2}$$

Volumes of liquids can be measured directly in a graduated cylinder.

If you measure the mass and volume of a number of different-sized samples of the same substance you could plot them on a graph of mass (vertical axis) versus volume (horizontal axis). Each data point would represent one of the samples. You could then draw a best-fit straight line with a ruler through (0,0) and your data points. The slope of that straight line would represent the density of the substance. For example, some data for water might be like that below. The slope of this straight line could be computed by picking two (widely-separated) points *on* the line (not data points, since they have uncertainty in them) and use $m = \frac{y_2 - y_1}{x_2 - x_1}$ to compute the slope of the line. The slope in the example on the left should be close to 1.0 g/cm^3, the density of water. Similar lines for other substances would have different slopes; the more dense the substance, the steeper the line.





Another quantity on which to practice making measurements is the speed of sound. By measuring various distances and the times it takes sound to travel those distances you can find its speed by cal-culating the slope of the best-fit line of a graph of distance (vert. axis) vs. time (horiz. axis).

Precision is indicated by how well a group of measurements of the same quantity agree. The more precise the measurements, the more significant figures there will be and the closer they will agree. *Accuracy* is an indication of how well a measurement agrees with a "true" or accepted value (usually a consensus of many measurements by expert scientists).

Apparatus: We use various instruments to measure mass, length, and time. Play with them until you understand how they work. Your instructor will be happy to steer you in the right direction.

- Length [SI unit is meter]
  - Ruler: A typical ruler or meter stick can be read to a precision of about 1/10 cm.
  - Vernier caliper: The width or thickness of a small object can be measured by closing the jaws of a caliper around it. The result is read by noting the position of the zero line of the vernier scale. One additional digit can be obtained by observing which line of the vernier scale coincides with a line on the main scale. While a ruler has a precision of about 1/10 cm, vernier calipers have a precision of about 1/100 cm.
  - Micrometer caliper: This instrument is a "C" shaped frame with a screw adjustment. The object to be measured is placed between the anvil and the screw, which is advanced until the object is gently but firmly gripped. Using the micrometer caliper, more accurate measurements can be made on smaller objects than with the vernier caliper, even to a precision of 1/1000 cm.
- Mass [SI unit is kilogram]
  - Equal-arm balance: The object to be measured (weighed or "massed") is placed on the left-hand pan and known masses are placed on the right-hand pan until a balance is achieved. A slider is provided for fine adjustments. This balance illustrates the fundamental idea of comparing the unknown to a standard.
  - Triple-beam balance: The triple-beam balances are easier to use and more precise than the equal-arm blances; the ones we have have a precision of about 1/100 g.
  - Spring balance: Spring balances actually measure weight (old fashioned bathroom scales are an example), but they can be calibrated in mass units (assuming the user is near the surface of the earth). You won't use spring balances today.
  - Digital balance: Digital balances work well, but it is difficult to see the pinciples of operation. The accuracy and precision vary depending on the model and price paid.
- Time [SI unit is second]
  - Stopwatch: Typical inexpensive stopwatches have a precision of about 1/100 s.
- Volume [SI unit is meter^3]
  - Graduated Cylinder: Volumes of regular solids are usually computed by multiplying length measurements, but the volume of liquids can be measured directly with a graduated cylinder. Volumes of solids can also be measured by immersing them in liquids in graduated cylinders and noting the rise in the level of the liquid.

Procedure, Results, and Analysis: Use grams and centimeters in the first three procedures, even though the official SI units are kilograms and meters. Comparing to an accepted value means (in this context) using the percent difference formula in the Introduction (Module 0). Look up accepted densities in the CRC handbook, or on the web. Make separate graphs for each procedure.

1. Masonite disks: Measure the circumference, diameter, thickness, and mass of six masonite disks; use string, rulers, vernier calipers, and the equal-arm balance. Put your results in a table. Add table columns for the radius and volume. Make a graph of mass versus volume. Draw the best-fit straight line and compute its slope. Compare your value of the density of masonite to the accepted value. Make a second graph, this time of circumference versus radius. Draw the best-fit straight line and compute its slope. Compare the slope to the circle constant $\tau = 2\pi \approx 6.283185$.

2. Aluminum rods: Measure the diameter, length, and mass of four aluminum rods; use rulers, vernier calipers, and the triple-beam balance. Put your results in a table. Add table columns for the radius and volume. Make a graph of mass versus volume. Draw the best-fit straight line and compute its slope. Compare your value of the density of aluminum to the accepted value.

3. Water: Measure the mass and volume of five samples of water; use graduated cylinders and the digital balance. Put your results in a table. Make a graph of mass versus volume. Draw the best-fit straight line and compute its slope. Compare your value of the density of water to the accepted value.

4. Speed of Sound: Design your own experiment to measure the speed of sound. Write and carry out the procedure. Use units of meters and seconds. Use well-labeled tables and graphs to record and display your data. Compare your value for the speed of sound (slope of the line) with accepted value (in m/s) given by $v \approx 20.0\sqrt{T}$, where T is the air temperature in kelvin (Celsius plus 273).

   The precision of your measurement can be increased by measuring the same quantities a number of times and using averaged results. You should also try to improve the accuracy of your value by repeating the experiment for various distances and techniques.

Conclusions: What did you learn about making careful measurments, combining them into a calculation, and how to deal with uncertainty? What did you learn about accuracy and precision?