Density: Accuracy and Precision

Introduction:

Density is a measure of a substance's mass-to-volume ratio. For liquids and solids, density is usually expressed in units of g/mL or g/cm^3; these are equivalent since 1 mL is exactly equal to 1 cm^3. Density is an **intensive property** meaning that a substance's density will be the same regardless of the size of a sample. For example, steel has a density of 7.85 g/cm^3 whether you have a tiny steel ball bearing or a large steel beam. The mass and volume of each piece will be different, but the **mass-to-volume ratio** is the same!

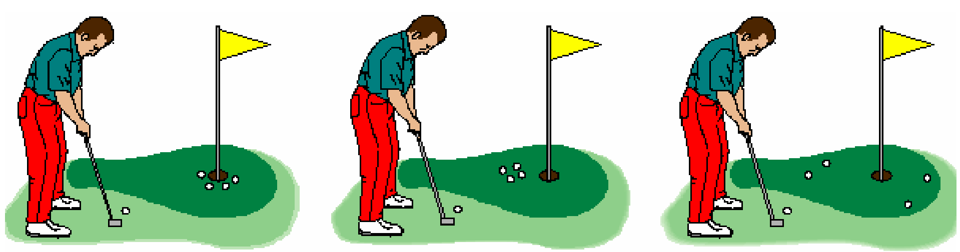
In general, different substances have different densities even if they occupy the same volume or have the same mass. For example, in the opening sequence of *Raiders of the Lost Ark*, Indiana Jones tries to replace a gold statue with a bag of sand of about the same volume. Even though the volumes may be the same, gold is much more dense than sand. As Indiana Jones found out, ignoring density and only considering volume can have dire consequences.

Similarly, two substances may have the same mass but different densities. A classic riddle asks, "Which weighs more: a pound of feathers or a pound of gold?" The answer seems easy. Since a pound is a pound, they should weigh the same. In this case, both samples weigh the same, but feathers are definitely much less dense than gold.

Accuracy versus Precision:

Accuracy is a measure of how close your measured value is to the correct value. For example, if a substance has a density of 1.23 g/mL and you measure its density to be 1.24 g/mL, then you were accurate. The difference between the experimentally measured value and the accepted value is very small.

Precision is a measure of how close repeated measurements are to each other. For example, if you measure the same substance in four trials and get densities of 1.430 g/mL, 1.431 g/mL, 1.431 g/mL, and 1.429 g/mL, your measurements are very precise since the difference between the highest and lowest measurement (the range) is small. However, these measurements are not accurate since they differ greatly from the accepted value of 1.23 g/mL. Ideally, your measurements should be both accurate and precise. The figure below provides a pictorial representation of accuracy and precision in terms of golf.



Good accuracy, good precision. Poor accuracy, good precision. Poor accuracy, poor precision.

Significant Figures:

In this lab, you will compare the accuracy and precision of densities of solids measured by two different techniques: volume displacement and volume calculation using calipers.

Mass and linear measurements are basic units in the metric system. In chemistry, mass is measured in grams and length in centimeters. Volume, on the other hand, can be considered a derived unit. The volume of a solid object can be determined by linear measurements and calculated using volume formulas. The volume of a solid can also be determined by displacement. A solid that is more dense than water will sink and displace a volume of liquid equal to the volume of the solid object. Such a volume measurement is made in mL. (Remember, 1 mL = 1 cm^3.)

Every measurement has a degree of uncertainty associated with it. The uncertainty derives from the measuring device and from the skill of the person doing the measuring. (This section adapted from http://chemistry.about.com/library/weekly/aa082701a.htm)

Say you need to measure 7 mL of water. You could use a beaker, marked in 5 mL increments. With the beaker, you could easily obtain a volume between 5 and 10 mL, probably close to 7 mL, give or take 1 mL. If you used a buret marked to 0.1 mL, you could get a volume between 6.99 and 7.01 mL pretty reliably. You would report your measurement using the appropriate number of significant figures. These include all of the digits you know for certain plus the last digit, which contains some uncertainty and must be estimated.

Determining the number of significant figures in a measurement:

- Non-zero digits are always significant (e.g., 549 cm).
- Zeroes between non-zero digits are significant (e.g., 1025 mL).
- Zeroes at the beginning of a number **are not** significant (e.g., 0.00482 m). You can always determine which digits are significant by rewriting this number in scientific notation.
- Zeroes at the end of a number and after the decimal point **are** significant (43.21000 g).
- Zeroes at the end of a number and before the decimal point may or may not be significant (5280 ft). You will have to look at the measurement to determine this.

Uncertainty in Calculations:

Measured quantities are often used in calculations in lab. The precision of a calculation is limited by the precision of the measurements on which it is based.

- **Addition and Subtraction:**
  When measured quantities are used in addition or subtraction, the answer can't have more **digits to the right of the decimal point** than any of the original measured quantities.

  Example: 32.01 m + 5.325 m + 12.1 m = 49.435 m

  Your calculator will read 49.435, but the sum should be reported as 49.4 meters because 12.1 m has only 1 digit after the decimal.

- **Multiplication and Division:**
  When experimental quantities are multiplied or divided, the answer can't have more **significant figures** than any of the original numbers.

  Example: 25.624 g / 25 mL = 1.02616 g/mL

Your calculator will read 1.02616, but the final answer should be reported as 1.0 g/mL because 25 mL only has 2 significant digits.

Using Lab Equipment:

Measuring mass using an analytical balance:

When using an analytical balance to measure mass, there are two ways to record the mass of your sample. In both cases, you should record **all** digits displayed on the balance readout. Each digit is considered significant.

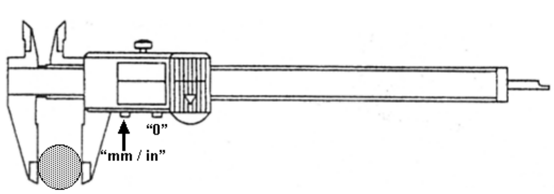
1) Measure the mass of an empty container and then the mass of the container plus the sample. Subtracting these two masses will give you mass of just the sample.
2) Analytical balances have a tare button that "zeroes" the mass of the container. If you place the container on the scale and tare the balance (press the O/T bar), you can then remove the container, add the sample, replace the container on the scale (**without** pressing the O/T bar again), and the display will show the mass of just the sample.

<u>Notes on using analytical balances:</u>

- Before weighing, make sure the doors are closed and that the scale reads 0.0000 g. If it doesn't read all zeroes, **gently press** the O/T bar in front.
- To weigh an item, open the door and carefully place the item on the center of the pan. Close the door and wait for the digital readout to stabilize (the small circle to the left of the readout will go off). Generally, the readout will continue changing over time, but the mass shown when the circle disappears will be accurate.
- **Never measure out samples *inside* the balance. Always remove the container before adding or removing sample. Placing chemicals directly on the balance can damage the balance.**
- Keep the doors closed except when loading or unloading samples.
- **Do not lean on the counter** – it will change the weight displayed.
- Record all digits that are displayed on the balance – they are all significant.
- Close the door and press the O/T button in between **each** sample to be measured.

Measuring volume with calipers:

- With the calipers tightly closed, be sure the display reads 0.00 (press the "zero" button if it doesn't). Also be sure you are measuring lengths in **millimeters** (mm) and not inches (in).
- In order to measure length, slowly roll the wheel (on the bottom right of the digital reader) until the solid object can fit between the jaws. **Do not** just slide the jaws open. To ensure a snug fit, you should be able to suspend the object <u>momentarily</u> between the lower portion of the jaws – as shown below.
- Return the jaws to the closed position in between **each reading** to make sure the display returns to zero before measuring the next length.



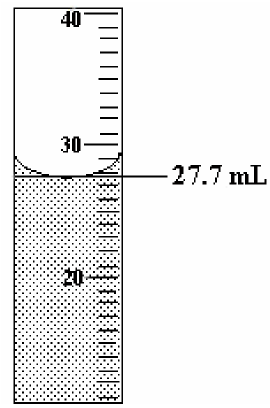
Measuring volume with glassware:

To correctly measure volume, you must determine how many significant digits can be read on the glassware. When water is placed in a glass cylinder, a concave surface forms; this curve is called the ***meniscus***. Glassware is manufactured so that the line at the bottom of the meniscus gives the most accurate reading. In order to read glassware accurately, it must be level (sitting on the counter, **NOT** hand-held) and your eye must be perpendicular to the water level.

Reading a 100-mL graduated cylinder:

Graduated cylinders are designed to measure the amount of liquid contained. They are available in many sizes. You will use the 100 mL size. **100 mL graduated cylinders can only be read to 1 decimal place (e.g. 27.7 mL or 50.5 mL)**.

- Note that 100 mL graduated cylinders have markings for each mL, so they are read to one decimal place (to the nearest 0.1 mL), as in the example to the right.
- In the picture, you can see the water volume is definitely between 27 and 28 mL but closer to 28 so you estimate the distance between them to get a measurement to one decimal place



Procedure

1. Obtain a set of 4 brass slugs and 1 aluminum slug.

2. Use an analytical balance to weigh the 4 brass slugs.

3. Use calipers to measure the length and diameter of the four brass slugs and the aluminum slug. Be sure that the calipers are reading in **millimeters** (rather than inches). Convert the caliper readings from mm to cm.

4. Using a 100 mL graduated cylinder, place sufficient water in it to cover the sample but do not add any of the slugs yet. Place a rubber stopper on the bottom of the cylinder to serve as a cushion and prevent breakage. Measure and record the volume of the water and the stopper to the maximum precision possible as shown above.

5. Carefully insert each of the **brass slugs** (do not measure the aluminum slugs)in the graduated cylinder by tipping the cylinder and sliding the sample down the side.
6. Repeat steps 2 – 5 for all slugs. Dry off the slugs, and return them to the container.

Figure 1.

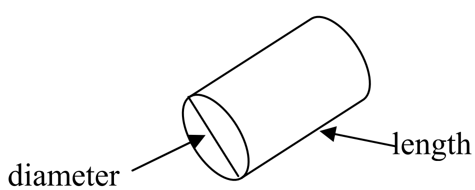
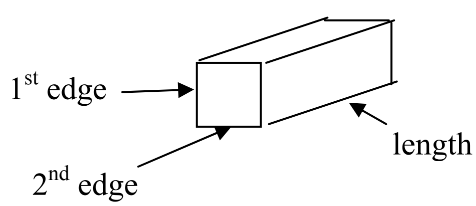


Figure 2.



Calculations

1. From the linear measurements, use the appropriate formula to calculate the volume of each slug in cm^3. These calculated volumes are expressed in cm^3 (cubic centimeters).

   The volume of a cylindrical object (Figure 1 above) is calculated by:
   $\mathbf{V = \pi \cdot radius\ (cm)^2 \cdot length\ (cm)}$ where $\pi = 3.1416$ and r is the radius of the cylinder (half the diameter)

   The volume of a rectangular or square object (Figure 2) is calculated by:
   $\mathbf{V = length\ (cm) \cdot width\ (cm) \cdot height(cm)}$

2. The volume of water displaced is represented in mL and can be calculated by:
   (volume of water + stopper + slug) minus **(volume of water + stopper)**

3. Density is defined as mass/volume, and is usually expressed as g/mL (or g/cm^3 in the metric system). Calculate the density for each metal slug in two ways:
   #1 by using the caliper measurements(units of g/cm^3), and
   #2 by using the water displacement (units of g/mL).

$$\text{density} = \frac{\text{mass (in g)}}{\text{volume (in cm}^3\text{ or mL)}}$$

   Report all values to the correct number of significant figures. Also calculate the average density value for each type of slug.

4. The accepted value of density is 8.470 g/cm^3 for brass. Determine the ***accuracy*** of your average measured values by calculating the % error for each of your average density values.

$$\textbf{\% error} = \left| \frac{\text{experimental value - accepted value}}{\text{accepted value}} \right| \times 100$$

   Percent error values are always reported as positive numbers. Note that without the absolute value bars, this can result in a negative value for the error.