Experiment 1 – Density

Overview

This experiment will give you an opportunity to learn how to/practice using several pieces of glassware and other important laboratory equipment. You should pay special attention to the proper reading and recording of data, as different pieces of equipment allow for measurement to varying levels of precision. As such, another main learning goal of this experiment is to practice the proper use of significant digits in calculations.

Density

Density (ρ) is an **intensive** property (a property that is independent of the amount of substance present) that related mass to volume for a given sample of matter. Like many intensive properties, it is a given by the ratio of two measurable **extensive** properties (properties that depend on the amount of substance present) of a substance – in the case, **mass** and **volume**. In this experiment, we will measure the density of number of substances using various methods of determining the mass of the sample as well as various methods of determining the volume of a sample.

Example: What is the volume of a piece of gold ($\rho = 19.3\ g/cm^3$) that has a mass of 12.4 g?

Solution: We can use the density to convert between the mass and the volume.

$$12.4\ g \cdot \frac{cm^3}{19.3\ g} = 0.64\underline{2}49\ cm^3 = 0.642\ cm^3$$

Note: Since both the density and the mass are measured to 3 significant digits, the answer should be rounded to three significant digits as well.

In many applications, the volume of a sample can be measured directly. For example, the volume of a liquid can be measured using a piece of glassware such as a **graduated cylinder** or a **volumetric pipet**. The difference between these pieces of glassware is that they provide different levels of **precision** (different numbers of significant digits) leading to smaller uncertainties in values calculated from these measurements.

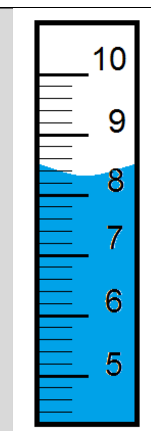
The choice of measurement tools is not trivial. Oftentimes, the precision of a given measurement is vital in determining the precision of a final calculated value. Other times (such as when a reagent is to be added in excess) the precision has no effect whatsoever on the final calculated value. Understanding when high-precision (generally more expensive) equipment is needed and when lower precision (cheaper) equipment can be used goes a long way toward impressing a colleague (or employer) with your understanding of what you are doing. Failure to make these distinctions will quickly get you labeled as one who does not understand what she or he is doing in the laboratory. This experiment will help you to grow in your appreciation of how various tools are used in the lab and how they affect the precision of calculated values based on measurements using those pieces of equipment.

Graduated Cylinder

A graduated cylinder is an inexpensive piece of equipment that is used to determine the volume of a sample of liquid. It is a cylindrical container with markings (graduations) indicating the volume. The example shown to the right is a 10 mL graduated cylinder, and has major markings every mL, and minor markings every 0.2 mL. Graduated cylinders come in many different sizes. The size to be used depends on the total volume to be measured. For example, when needing to measure ~850 mL of solution, a 10 mL graduated cylinder would be a poor choice. A better choice might be a 1000 mL graduated cylinder!

Graduated glassware is properly read by estimating the position of the bottom of the **meniscus** (in the case of aqueous media) to within ± 0.2 of a minor marking. **This is accomplished by estimating the last decimal place**. In the case of this particular graduated cylinder, that means measuring to within 0.04 mL. Failure to indicate the correct number of decimal places will result in a poor score on this laboratory because it indicated incorrect usage of the piece of glassware.

Example: Indicate the volume of liquid contained in the graduated cylinder shown in the diagram.



Solution: The meniscus lies between the 8 mL and 9 mL major markings. It also lies between the 0.2 mL and 0.4 mL minor markings. Thus, the correct volume will be between 8.2 L and 8.4 mL. If it is estimated to be about half-way between the minor markings, the correct volume will be reported as 8.30 mL ± 0.04 mL.

Note: reporting the volume as 8.3 mL will result in a deduction of points due to reporting too few significant digits! This misrepresents the uncertainty in the measurement to be ±0.1 mL rather than the correct uncertainty of ±0.04 mL.

Volumetric Pipet

Graduated cylinders are very useful, but oftentimes do not provide the precision needed for a measurement. Each piece of volumetric glassware is individually calibrated to deliver a very specific volume of solution. (The individual calibration process leads to the high cost of these devices, so don't break them!) When precise and reproducible volumes of liquid samples are required, a volumetric pipet is perfect for the job.

A volumetric pipet is designed to deliver the same volume of liquid each time it is used. In order to do this, it must be carefully calibrated by the manufacturer. Each pipet will have a mark someone on the glass above the bulb. The actual precision of a volumetric pipet should be printed on the side of the pipet, or made available by the manufacturer. For most applications in the lab (for example using 1, 2, 5, 10, 25 mL volumetric pipet) it is a good bet that the precision will be to ±0.02 mL. So the reported volume using a 10 mL volumetric pipet would be 10.00 ±0.02 mL, giving four significant digits in the value.

The pipet should be rinsed three times with the sample that is to be delivered to a reaction vessel (such as a flask or a beaker.) This ensures that any residual sample in the pipet is at the same concentration as the sample itself. Once rinsed, the pipet can be used to deliver a sample.

Using a rubber bulb (**never pipet by mouth**!) liquid is drawn into the pipet to a level above the mark. The bulb is then removed and the user places a finger over the opening to prevent the liquid from draining. By carefully manipulating an opening with a finger, the user can drain just enough liquid until the meniscus rests with its bottom just on the mark. The sample can then be delivered to the desired container by removing the finger and allowing the liquid to drain freely.

If properly used, (using only gravity to drain the pipet), there will be a small amount of liquid remaining in the tip of the pipet. Do not use the bulb to "blow" this liquid out! The pipet is calibrated to account for this small amount of liquid that remains.

Measuring volume with a beaker

Most beakers have markings on the side that indicate approximate volumes. These markings are only approximate and cannot be trusted for precise measurements of volume! If one needs only an approximate volume (such as in the case of a reagent to be added in clear excess) a beaker can be used to estimate the volume. However, in cases where better precision is needed, one should choose to use a graduated cylinder (moderate precision) or a volumetric pipet (highest precision) for the job.

Having discussed the glassware needed to determine liquid volume, it is time to discuss the kinds of lab equipment used to determine mass.

Top-loading Balance

A **top loading balance** can be used to conveniently determine a mass to within ±0.01 g. It can be used when there is no need for greater precision than that (such as when a reagent is to be added in excess). The top-loading balance is a good choice for quick measurements, or for measurements of masses that will not be used in final calculations (since the use of the top-loader may limit the number of significant digits in one's final calculated values.

Many modern electronic top-lading balances have **self-taring** feature. To understand what this is, let's consider how one might measure the mass of a sample using a non-self-taring method.

Assuming one is to measure the mass of NaCl(s) to be used in an experiment, one might use a piece of **weighing paper** or a **weigh boat**. The mass of the weigh boar or weighing paper (or beker or whatever contains the weighed sample) is called the **tare mass**. Consider the following example:

Example: Kritika records the following data in her laboratory notebook in order to determine the mass of NaCl(s) she is using in her experiment:

Description	Mass
Weigh boat	1.04 g
Weigh boat + sample	12.83 g

What mass of NaCl(s) did she use?

Solution: The mass of sample is calculated as a simple difference:

Weigh boat + sample	12.83 g
Weigh boat	-1.04 g
Sample	11.79 g

Note: One must be careful with significant digits when subtracting the tare mass of a weigh boat or weighing paper (or beaker, or whatever is the tare container) because it is possible to lose significant digits when taking differences!

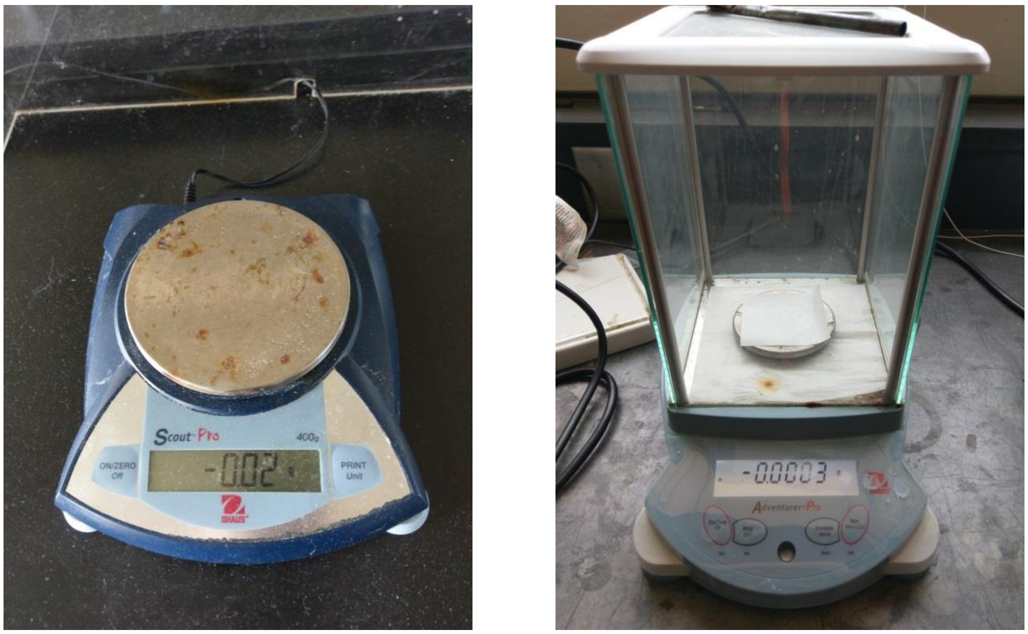
Self-taring balances allow the user to set the "zero" by pressing a button or bar on the balance after the weigh boat or weighing paper is placed on the pan. This can be very convenient for many applications, although some applications require manual taring.

Analytical Balance

An **analytical balance** is capable of measuring a mass to very high precision (±0.0001 g). This tolerance is so small that the mass of a fingerprint on a piece of glassware is measurable! This requires a number of precautions when using the analytical balance. A couple of pointers to keep in mind:

1. Always close the windows around the pan when using an analytical balance. Air currents can disrupt the pan and alter the measured mass of an object!
2. Never attempt to measure the mass of an object that is not at room temperature. Temperature differentials inside the glass box can disrupt the pan, altering the perceived mass of the sample!

3. When measuring the mass of a liquid sample, the liquid container must be closed. Evaporation will lead to a continually decreasing mass, wheich is measurable on the analytical balance!
4. Handle glassware in such a way as to avoid fingerprints. The mass of a fingerprint is significant compared to the tolerance of the balance.
5. Like all high-precision laboratory equipment, analytical balances are expensive. Treat them with care!



A top-loading balance (left) and an analytical balance (right).

With these tools in place, one can measure the density of a liquid fairly easily. The measurement of the density of a solid sample is a little bit more challenging. While it is easy to determine the mass of the sample, the determination of volume might require a bit more creativity. We will use three different methods in this experiment.

Determining the Density of a Solid Sample

When a solid sample has a simple shape (such as a rectangular solid) for which the calculation of volume is simple, one needs simply to calculate the volume from direct measurements, perhaps using a ruler.

Example: José measures the length, width, and height of a rectangular block of metal using a ruler. He find the values to be 6.0 mm x 9.0 mm x 43.2 mm respectively. Using a top-loading balance, he determines the mass to be 45.02 g. What is the density of the block?

Solution: Density is given by mass/volume. The volume in this case is given by the product of the end measurements.

$$\rho = \frac{mass}{volume} = \frac{45.02\ g}{(6.0\ mm)(9.0\ mm)(43.2\ mm)} \cdot \frac{10^3\ mm^3}{cm^3} = 1\underline{9}.2987\ \frac{g}{cm^3}$$

The correct answer will have 2 significant digits, due to the measurement of the length and the width. If the result is needed to more significant digits, José would need to use a more precise measuring tool to get the length and the width.

Thought question: Would the use of the analytical balance to get the mass of the metal improve the precision (increase the number of significant digits) in José's calculated density?

Displacement Method

Archimedes very famously used the method of displacement to measure the volume of an object that did not have a regular shape (in this case, the King's crown.) (*1*) The method is very simple:

1. Measure a volume of liquid. Call this the *initial* volume.
2. Drop the object into the liquid.
3. Measure the new volume level. Call this the *final* volume.

The volume of the object is given by the difference between the initial and final volume measurements.

Example: Kofi measures the density of a cylindrical piece of metal using the method of displacement. He measures an initial volume of 3.42 mL of water in a 10 mL graduated cylinder. He then carefully places the metal into the cylinder and notes that the water level has now increased to 7.15 mL. Using an analytical balance, Kofi measures the mass of the metal to be 46.2517 g. What is the density of the metal?

Solution: First, let's find the volume. This is given by the difference between the final and initial volumes measured in the graduated cylinder.

$$V_{metal} = V_f - V_i = (7.15\ mL - 3.42\ mL) \cdot \frac{cm^3}{mL} = 3.73\ cm^3$$

The density is then given by the ratio of the mass divided by the volume.

$$\rho = \frac{mass}{Volume} = \frac{46.2517\ g}{3.73\ cm^3} = 12.\underline{3}9992\ \frac{g}{cm^3}$$

The final value will have three significant digits, and be reported as 12.4 g/cm^3.

Thought Question: Would Kofi's final result be any different if he had used the top-loading balance instead of the analytical balance?

Pycnometer Method

A **pycnometer** is a constant volume device that can be used to determine the volume of a solid sample. The method involves measuring the internal volume of the device, using the mass of a liquid of known density needed to fill the pycnometer. Then, the pycnometer is loaded with the solid sample, and the remaining volume is filled with the liquid. Subtracting the mass of the pycnometer and solid sample yields the mass of liquid not displaced by the solid. The volume of the solid is then calculated using the difference of the volume of the pycnometer, and the volume of liquid not displaced by the solid.

Example: From the following data, determine the density of the solid sample. The liquid being used is ethyl alcohol, which as a density of 0.78945 g/mL at 20 ^{o}C.

	Mass (g)
Pycnometer	32.4572
Pycnometer + alcohol	54.0378
Pycnometer + solid sample	54.8212
Pycnometer + solid sample + alcohol	75.3843

Solution: First, let's determine the internal volume of the pycnometer. To get this, we need to know the mass of alcohol needed to fill the device.

$$mass\ alcohol = (54.0378\ g - 32.4572\ g) = 21.5806\ g$$

The volume of alcohol (and thus the internal volume of the pycnometer) can now be determined from the density:

$$volume = \frac{21.5816\ g}{0.78945\ g/mL} = 27.33\underline{7}51\ mL$$

The mass of sample used can be determined by a very simple difference:

$$mass\ sample = (54.8212\ g - 32.4572\ g) = 22.3640\ g$$

Now for the tricky part. The volume of the solid is determined by the total volume of the pycnometer minus the volume of alcohol surrounding the solid sample. In order to get that, We need to use the mass of alcohol surrounding the sample. Fortunately, that can be determined by simple difference!

$$mass\ alcohol\ sur.sample = (75.3843\ g - 54.8212\ g) = 20.5631\ g$$

The volume of this amount of alcohol can be calculated from the density:

$$vol.alcohol\ sur.sample = \frac{20.5631\ g}{0.78945\ g/mL} = 26.04\underline{7}37\ mL$$

The volume of the sample then is calculated as the difference of the volume of the pycnometer and that of the alcohol surrounding the sample:

$$vol.sample = (27.33\underline{7}51\ mL - 26.04\underline{7}37\ mL) \cdot \frac{1\ cm^3}{1\ mL} = 1.29\underline{0}14\ cm^3$$

And finally, the density is given by the mass to volume ratio:

$$\rho_{sample} = \frac{22.3640\ g}{1.29\underline{0}14\ cm^3} = 17.3\underline{3}46\frac{g}{cm^3} = \mathbf{17.33\frac{g}{cm^3}}$$

Note: Due to taking differences where significant figure as lost, it was necessary to know the density of the liquid to five significant figures in order to get the density of the sample to four significant digits!

Experimental description

This experiment will consist of two main parts. Part I will involve the determination of the density of a liquid sample. Part II will involve the determination of the density of a solid sample.

I. <u>Density of a Liquid</u>

a. Using a **graduated cylinder**, determine the density of the liquid to which you are assigned by your laboratory instructor, using the
   - **i. Top loading balance**
   - **ii. Analytical balance**

b. Using a **volumetric pipet** to determine the volume of sample, determine the density of your liquid using the
   - i. Top-loading balance
   - ii. Analytical balance

II. <u>Density of a Solid</u>

a. Using a ruler to determine the dimensions of your assigned solid sample, determine its volume. Then, using an appropriate balance, determine the mass of the object. From these data, calculate the density.

b. Now determine the density of a solid using the displacement of liquid methods discussed in the text. You will do this using two different methods:
   - i. Graduated Cylinder method
   - ii. **Pycnometer** method

Vocabulary and Concepts

References

1. Chowdhury, R. ‘Eureka!’ – The Story of Archimedes and the Golden Crown. http://www.longlongtimeago.com/once-upon-a-time/great-discoveries/eureka-the-story-of-archimedes-and-the-golden-crown/ (accessed July 31, 2018).

Pre-Laboratory Assignment - Density

Name ______________________________ Section ___________________________

1. Nancy needs to determine the density of a liquid (in g/mL) to three decimal places (±0.001 g/mL) for her research project. Which of the following combinations of lab equipment and measurements will provider her sufficient precision for her determination?
   a. Graduated cylinder: 8.34 mL, Top-loading balance: 10.39 g
   b. Graduated cylinder: 8.34 mL, Analytical balance: 10.3908 g
   c. Volumetric pipet: 10.00 mL, Top-loading balance: 12.46 g
   d. Volumetric pipet: 10.00 mL, Analytical balance: 12.4590 g

2. LaKeisha is measuring the density of a solid piece of metal using the graduated cylinder method. She initially measures a volume of water in the cylinder to be 3.28 mL. After placing the metal into the graduated cylinder, the new volume was 8.72 mL. The mass of the metal was 46.26 g on a top loading balance.
   a. What is the density of the piece of metal? _______________________

   b. Would LaKeisha have got more significant figures in her calculated value had she used the analytical balance?

   ____

3. Binh is determining the density of a solid using the pycnometer method. He chooses to use water (0.9982 g/mL at 20 ^{o}C) as the liquid in the pycnometer. He determines the following data using an analytical balance:

	Mass (g)
Pycnometer	47.4291
Pycnometer + alcohol	73.4193
Pycnometer + solid sample	130.7001
Pycnometer + solid sample + alcohol	144.7063

What is the value for the density of the solid that Binh determines? Show your work below.

Report Sheet – Density

Name ________________________________ Date ______________________________

Lab Partner(s) ____

Part I – Density of a liquid

a. Graduated cylinder method

	top loading balance	analytical balance
Mass of graduated cylinder	________________	________________
Mass of graduated cylinder + sample	________________	________________
Volume sample	________________	________________
Sample density	________________	________________

b. Volumetric pipet method

	top loading balance	analytical balance
Mass of container (tare)	________________	________________
Mass of container + sample	________________	________________
Volume sample	________________	________________
Sample density	________________	________________

Part II – Density of a solid

a. Ruler method

	top loading	analytical	
Mass	__________________	__________________	
Dimensions of object	____________	____________	____________
Volume	__________________		
Density	__________________	__________________	

b. <u>Displacement method</u> top loading analytical

	top loading	analytical
Mass	______________	______________
Volume without sample	______________	
Volume with sample	______________	
Density	______________	______________

c. Pycnometer Method (use the analytical balance)

	Mass (g)
Pycnometer	
Pycnometer + liquid	
Pycnometer + solid sample	
Pycnometer + solid sample + liquid	

In the space below, calculate the density of the solid sample. Show all of your work!