Name: Section: 201L- Date:

Expt 1: Density Measurements and Uncertainties

Objectives

- To learn the basics of good lab practice
- To learn how to estimate uncertainties
- To learn how to propagate uncertainties
- To learn how to compare measurement methods

Equipment

- One set of five (5) unknown cylinders of the same composition
- One beaker
- One or two 50 mL graduated cylinders
- One vernier or digital caliper
- One micrometer
- One digital scale or beam balance
- One "mass hanging" assembly

Safety

- **Never drop metal cylinders into glass containers!**
- Please read the section below on proper use of a graduated cylinder.

Introduction

One very important and useful property of materials is the **density, ρ,** of that material. Density is defined to be the amount of mass contained within a certain volume:

$$\rho \equiv \frac{m}{V} \qquad (1)$$

This property can be used to determine the total mass of an object if we know its volume, or it can be used to determine if an object will float in a liquid (if the liquid has a higher density than the object). The density of an object is also a useful property to help identify it.

In this lab, your job will be to determine the density of a set of rods of a given composition. Measuring the mass will be the easy part. ***You will use three methods to determine the volume:*** Direct measurement with scales, measurement of the amount of water it displaces, and measurement of its equivalent weight of water. You will tabulate your results and compare the first method with the second and third methods.

It will be to your benefit to be slow and careful while performing this lab.

Theory

The calculation of density in equation (1) will require a determination of the mass and volume of each rod. The final density will be an average of the computations for each method of measuring the volume of the cylinder. We will need the uncertainty in the computed density. This comes from equation (R2) in your lab manual:

$$\left(\frac{\delta\rho}{\rho}\right)^2 = \left(\frac{\delta m}{m}\right)^2 + \left(\frac{\delta V}{V}\right)^2 \qquad (2)$$

Direct Measurement

A measurement of the height and radius of the cylinder allows you to compute the volume using the formula:

$$V = \pi r^2 h \tag{3}$$

The propagated uncertainties come from the formulas (R2) and (R3) in the laboratory hand out. If our uncertainty in measuring the radius and height are δr and δh, we first we compute the uncertainty in r^2 using (R3):

$$\frac{\delta(r^2)}{r^2} = 2\frac{\delta r}{r} \tag{4}$$

and then we compute the uncertainty in volume using (R2):

$$\left(\frac{\delta V}{V}\right)^2 = \left(\frac{\delta(r^2)}{r^2}\right)^2 + \left(\frac{\delta h}{h}\right)^2 \tag{5}$$

or, substituting:

$$\left(\frac{\delta V}{V}\right)^2 = \left(2\frac{\delta r}{r}\right)^2 + \left(\frac{\delta h}{h}\right)^2 \tag{6}$$

Notice that we can take the left side directly and use it to compute the uncertainty in density once we have the uncertainty in measuring the mass. Instead of re-computing it every time you need it, it might be useful to write this value down for each rod.

Measurement of Displaced Water

This measurement gives a direct result with the uncertainty, δV, given by the uncertainty in measuring the markings on the graduated cylinder.

Measurement of Equivalent Weight of Water

This is probably the most difficult measurement to understand, but the easiest to compute with very good accuracy. If you simply drop a mass into the water and let it sit at the bottom of the beaker, the weight you will measure will simply be the weight of the water plus the weight of the mass. However, if the mass is *suspended* in the water, the tension in the string will take up some of that weight. How much?

Imagine that a block of Styrofoam were in the water. It would float. Why? Because it is *less* dense than water. Now imagine a block of gold in the water. It would sink. Why? Because it is *more* dense than water. So if we had something with *exactly* the same density as the water, it would neither float nor sink: it would remain stationary at any depth.

By using the tension in the string to support the cylinder, we are compensating for the higher density and forcing the cylinder to remain stationary---so it acts as if it were the same density as the water. When we measure the weight of the water plus the *suspended* mass, we should get the weight of the water *plus the weight of water which has the same volume as the cylinder*. Therefore, we find the volume of the cylinder by, first, finding the difference in mass with and without the cylinder:

$$m_w = m_2 - m_1 \tag{7}$$

The uncertainty in this determination comes from (R1) in the laboratory handout:

$$(\delta m_w)^2 = (\delta m_1)^2 + (\delta m_2)^2 \tag{8}$$

Then we use equation (1) to determine the volume of the cylinder:

$$V = \frac{m_w}{\rho_w} \tag{9}$$

where ρ_w is the density of the water. This has an uncertainty given by (R2):

$$\left(\frac{\delta V}{V}\right)^2=\left(\frac{\delta m_w}{m_w}\right)^2+\left(\frac{\delta \rho_w}{\rho_w}\right)^2 \quad (10)$$

Then we can use equation (2) to compute the uncertainty in measuring the density of the rod.

Experimental Procedure

Once you've picked three different-sized rods made of the same material, the first item of business is to record the common data for each of the three experiments: the masses of each of the cylinders. Enter this in Table 1 in your Raw Data sheet.

Remember that, when estimating your measurement uncertainty, a good rule of thumb is to use plus-or-minus half of the smallest increment you can measure directly. Sometimes you can use a smaller value than this if you feel you can interpret the spaces between the markings more accurately. For digital measurements, however, this is not possible.

Direct Measurement

It is important that, whenever you use a tool to measure something, that tool reads zero when nothing is present (not verifying this means you may have a "Zero Error"---see your Lab Manual). Before measuring a cylinder with the calipers and micrometer, close the jaws of each completely and ensure that you read zero before you take a measurement. If it does not read zero, you will need to either fix the zero reading or compensate for it.

Using the Digital Calipers to Measure Length

First, verify that the digital calipers read in millimeters. You should see the "mm" symbol appear in the display. If it is reading in inches, press the blue "mm/inch" button one time.

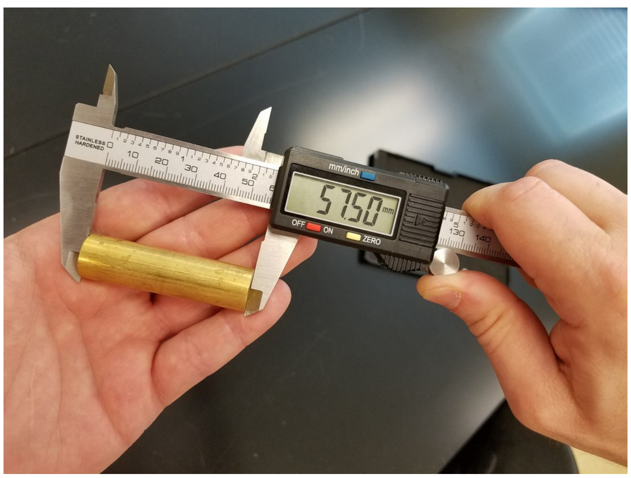

Figure 1: Correct Measurement with Digital Calipers

Second, you must ensure that the calipers read zero when you close the jaws and put just a little bit of pressure on the thumb wheel. If the reading is not zero, hold the jaws closed with just a little pressure on the thumb wheel and (with the other hand) press the "ZERO" button one time. The display should now read zero.

You can now take measurements of the length of the rod as shown in Figure 1.

Notice that your accuracy is limited to two decimal places, so your height measurement will have an uncertainty of δh = 0.005 mm. You should take three or four measurements by rotating the cylinder slightly between each measurement and report the average value.

Using the Digital Micrometer to Measure Diameter

Now measure the diameter of your cylinder with the micrometer. Once again, we first need to ensure we're measuring in millimeters. If the display does not read "mm," press and hold the "in/mm" button until it does. Second, we check to make sure that the micrometer reads zero when nothing is in place. To do this with the MARATHON CO 0030025 micrometer, close the gap on the micrometer by rotating the **big** wheel until it clicks. If the reading on the micrometer is not zero, press and **hold** the "SET" button until it does.

You can now take measurements of the diameter of the rod as shown in Figure 2. Notice that the rod is standing on the table while one hand holds the frame of the micrometer and the other hand rotates the big knob. ***Always use the big knob when changing the gap in the digital micrometer.*** This knob has a ratchet which, when properly used, always gives the same pressure to the measuring bar keeping all of your measurements consistent.

Figure 2: Proper Measurement with the Digital Micrometer

Because the accuracy is is 0.001 mm, your uncertainty in the *diameter* of the cylinder will be δd = 0.0005 mm. What is the uncertainty in your radius? Using (R2) we find that

$$\left(\frac{\delta r}{r}\right)^2 = \left(\frac{\delta d}{d}\right)^2 \tag{11}$$

$$\delta r = \delta d \left(\frac{r}{d}\right) = \delta d \left(\frac{r}{2r}\right) \tag{12}$$

But the radius is half the diameter so

$$\delta r = \frac{\delta d}{2} \tag{13}$$

as you might have expected.

Enter your data into Table 2. Watch your units!

Measurements Using Water

Because the final measurement requires knowledge of the density of water, we should measure this now while the graduated cylinders are dry. **<u>You will need to measure the mass of a known volume of water.</u>** I will leave the details up to you, but remember that you will need to determine your uncertainty in this measurement, again using (R2):

$$\left(\frac{\delta \rho_w}{\rho_w}\right)^2 = \left(\frac{\delta m}{m}\right)^2 + \left(\frac{\delta V}{V}\right)^2 \tag{14}$$

Measurement of Displaced Water

The graduated cylinders measure liquid volume in milliliters. But this unit is the same as a cubic centimeter (cm^3). You will need to fill the graduated cylinder with just enough water to fully submerge the cylinder (about 25 mL of water should do). Measure this amount of water by reading the location of the bottom of the meniscus.

Care must be taken when using a graduated cylinder. They are tall and thin and tip easily. When they tip, they spill their contents and---quite often---break. ***<u>You will lose points on your laboratory for breaking equipment.</u>***

Even though we are only using water, general practice demands that you ***<u>never</u>*** set the graduated cylinder on a table and crouch down so that your eyes are level with the cylinder. If the graduated cylinder should tip, its contents could splash into your face. In a general chemistry laboratory, you might well be using liquids much less benign than water. The proper way to read a graduated cylinder is to hold it up from the top so that it hangs straight down at eye level.

Figure 3: A graduated cylinder showing 20 mL of fluid.

You will need to measure the difference between the volume with (V_2) and without (V_1) the cylinder. **Care must be taken when placing the metal cylinder into the graduated cylinder.** The metal cylinder can easily break the graduated cylinder if you simply drop the metal into the glass. Even if you don't break the graduated cylinder, you will splash water out of the cylinder which will make your measurement unusable. For this reason, **tilt the graduated cylinder as much as possible and allow the metal cylinder to gently slide down the glass wall**. Be certain that the metal cylinder is *<u>completely dry</u>* before putting it in the water and ensure that it is fully submerged before you take data. Record the difference in water volume readings. If your graduated cylinder is marked in 1 mL increments, then your uncertainty *in each measurement* is no more than $\delta V = 0.5\ cm^3$, but could be a bit less if you are *very* careful.

Enter your data in Table 3. Watch your units!

Measurement of Equivalent Weight of Water

For your final measurement of the volume of the metal cylinders, you will need to fill a beaker with some water and place it on your scale. Note the mass of the water plus beaker for each measurement as m_1.

Next, tie a loop of wire around your *completely dry* metal cylinder and be sure that it can be dangled without dropping. Then, gently lower the cylinder into the water until it is completely submerged. **Do not let it touch the bottom of the beaker**. Use a clamp to hang the metal at this height so that the tension will not change in the wire. Measure the new mass, m_2, and use the information in the theory section to compute the volume of the cylinder.

Enter your data into Table 4.

Raw Data

Table 1. Mass Characteristics of Test Cylinders

Cylinder Number	Mass (g)	δm (g)	$\delta m/m$

Table 2. Details of Direct Measurement of Cylinders

Cylinder	h **(cm)**	$\delta h/h$	d **(cm)**	r **(cm)**	$\delta r/r$	V **(cm^3)**	$\delta V/V$	ρ **(g/cm^3)**	$\delta\rho$ **(g/cm^3)**
Average									

Uncertainty in the: height of the cylinder: $\delta h =$ radius of the cylinder: $\delta r =$

Density (and uncertainty) of tap water as measured: $\rho_w =$ $\delta\rho_w =$

Table 3. Details of Volume Measurement of Cylinders

Cylinder	V_1 **(cm^3)**	V_2 **(cm3)**	V **(cm^3)**	δV **(cm^3)**	$\delta V/V$	ρ **(g/cm^3)**	$\delta\rho$ **(g/cm^3)**
Average							

Table 4. Details of Displaced Water Measurement of Cylinders

Cylinder	m_1 **(g)**	m_2 **(g)**	m_w **(g)**	δm_w **(g)**	$\delta m_w/m_w$	V **(cm^3)**	$\delta V/V$	ρ **(g/cm^3)**	$\delta\rho$ **(g/cm^3)**
Average									

Uncertainty of measuring m_1 and m_2 : $\delta m =$

<u>Your Lab Report</u>

EXPERIMENTAL PROCEDURE Section

In one or two paragraphs, ***<u>describe the method you used to measure the density of tap water.</u>*** **You will be graded on your ability to clearly describe what <u>you</u> did.** The description should be clear enough that someone else could reproduce your results by reading this section. **Although it is tempting to write "instructions," you will be graded poorly if you do so.**

DATA Section

What was your average measured density for the substance (you must include the uncertainty!):

CONCLUSION section

In a few paragraphs, answer the following questions. Do ***<u>NOT</u>*** use bullets, use full paragraphs.

- What substance do you think you have?
    - What is the accepted density of that material (CITE YOUR SOURCE)?
    - How does your measured density compare to the accepted density [use the percent error formula]?
    - Was density alone enough to identify the material? What other qualities did you use?
- How well do the three methods measure volume (compare the δV and $\delta V/V$ for each)?
- Does each method give similar answers for the volume of each cylinder?
- How does the uncertainty in the volume measurement affect the uncertainty in the density measurement?
- What sources of error/uncertainty did you have? How could you have removed or reduced them?

Appendix

Include your signed and completed data sheet
Include a sample calculation for every computation you made.