Accuracy and Precision of Laboratory Glassware: Determining the Density of Water

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During the semester in the general chemistry lab, you will come into contact with various pieces of laboratory glassware.

- beakers
- Erlenmeyer Flasks
- volumetric flasks
- pipettes
- burets
- graduated cylinders

Some of these pieces (e.g. beakers, Erlenmeyer Flasks) are used primarily to hold liquids during experiments. Upon closer inspection, you will also notice that they, like other glassware, have graduations on the side to measure volumes. As a matter of fact, all of the glassware listed above can measure volumes. Why do we have so many pieces of glassware if they all do the same basic job of measuring volumes?

Laboratory glassware can generally be divided into two main types based on how they measure volumes:

- those that are manufactured to *contain* certain volumes
- those that are manufactured to *deliver* certain volumes

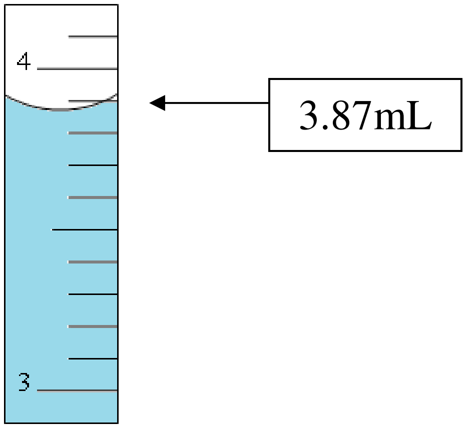
If a piece of glassware is manufactured to *contain* liquids, the volume of the liquid inside will be the amount indicated by the markings on the outside of the glassware. The more expensive pieces of glassware may have the letters “TC” printed on it. “TC” means “to contain.” Some less expensive glassware that are made to contain certain volumes may not have any markings to indicate this.

If a piece of glassware is manufactured to *deliver* a specific volume of liquid, the amount indicated on the glassware is correct only once the liquid is dispensed into another container. These pieces of glassware usually have the letters “TD” printed on it. “TD” means “to deliver.”

One of the first things that needs to be discussed before we can use any measuring device in the lab is something called significant figures. The first thing to realize is that there is no such thing as a perfect measurement. Even when using expensive lab equipment there some degree of uncertainty in measurement.

The general rule of thumb is: you can estimate one more digit past the smallest division on the measuring device. If you look at a 10mL graduated cylinder, for example, the smallest graduation is tenth of a milliliter (0.1mL). That means when you read the volume, you can estimate to the hundredths place (0.01mL).

Use the bottom of the meniscus to determine the volume in the 10mL graduated cylinder. Since the smallest division (graduation) is a tenth of a milliliter, we can estimate to a hundredth of a milliliter (0.01).



Portion of a 10mL graduated cylinder

However, some glassware such as volumetric flasks and volumetric pipettes only have a single line to indicate volume. This is because they are made to measure just one specific volume. In the case of the glassware used in general chemistry lab, both the 10mL volumetric pipette and 50mL volumetric flask will have two sig figs after the decimal point (i.e. 10.00mL and 50.00mL).

For the 150mL beaker and the kitchen measuring cup, assume that 50.mL has two sig figs (it will not be obvious based on the volume markings).

Recording and analyzing lab data:

If a metal rod has known a length of 1.23 cm and you measure its length using three different measuring devices (A, B, and C), you obtain the following data.

Data Table: Measured Lengths of Device A, B, and C

	Device A (cm)	Device B (cm)	Device C (cm)
Trial 1	1.43	1.24	1.19
Trial 2	1.43	1.23	1.23
Trial 3	1.43	1.25	1.22
Trial 4	1.42	1.22	1.26

The first thing we like to is to find an average from our multiple trials. As you may know, there are different types of averages. The types you may have heard about in your math classes are most likely *mean*, *median*, and *mode*. Many times when we say "average" or "simple average" we are actually referring specifically to the *mean*. A mean is calculated as follows: add all of the values together and divide by the number of values. For example:

$$\frac{(1.43+1.43+1.43+1.42)}{4} = 1.4\underline{2}75 \text{ or } \underline{\mathbf{1.43cm}} \text{ (Based on sig. figs.)}$$

The "2" is underlined in the unrounded answer because based on the addition rule, when the answer is rounded, it should have three total sig figs. If I want to use the *unrounded* number for another calculation in the future, the underline will remind me of the sig figs that number actually has. The

"4" that it is in the denominator of the equation is an exact number and therefore has an infinite number of sig figs.

Using the same formula we can then calculate a mean for the other measuring devices:

	Device A (cm)	Device B (cm)	Device C (cm)
Average	**1.43**	**1.24**	**1.23**

How do we describe how "good" these measuring devices are based on our measurements and means? There are two ways we can describe these measurements – by their *accuracy* and *precision*.

<u>Accuracy</u> is a measure of how close your measured value is to the true value or other standard. Although sometimes we use *qualitative* (verbal) words to describe the accuracy (such as good accuracy and bad accuracy), a *quantitative* (numerical) measure is more useful when comparing measuring devices based on laboratory data. Our quantitative measure of accuracy is called **percent error**.

$$\text{Percent Error} = \left| \frac{(\text{Experimental Value - Theoretical Value})}{\text{Theoretical Value}} \right| \text{x } 100$$

So, for each measuring device, using the averages calculated previously, we can calculate a **percent error**. If you use the values from Device A:

$$\text{Percent Error} = \left| \frac{1.4\underline{2}75 - 1.23}{1.23} \right| \text{x } 100 \ = \ 16\%$$

The lower the percent error, the more **accurate** the measuring device. In this case the mean for Device A had a 16% error from the true value of the length of the metal rod.

(Notice that when calculating percent error, we used some extra significant figures from our calculation of the mean. This is done to minimize *rounding errors*; errors that come from rounding and then using a rounded number in the next calculation. Remember it's always best to round only when you need to *report* a number, as in a table. If you need to use a calculated number in another calculation, use the unrounded number.)

	Device A (cm)	Device B (cm)	Device C (cm)
Percent Error	**16%**	**0.5%**	**0.5%**

You're probably wondering why the percent error for device A has two significant figures while the others only have one. If you look at the formula for percent error, you will notice that the first step is subtraction. Thus, we must use the addition/subtraction rule. So, for device A, when we take $1.4\underline{2}75$ (unrounded average) and subtract 1.23 we get 0.1975. Since the numbers that are being subtracted each has two sig figs after the decimal point, based on the addition/subtraction rule, the answer can only have two sig figs after the decimal point: $0.1\underline{9}75$. Then, once we divide the answer by 1.23 and multiply by 100 (an exact number), we have a number with two sig figs, divided by a number with three sig figs. Based on the multiplication/division rule, our answer can only have two sig figs. The same logic gives only one sig fig for device A and B (do the calculations step by step to see for yourself).

<u>**Precision**</u> is a measure of how close repeated measurements are to each other.

Like accuracy, we can describe precision in qualitative terms (such as high precision and low precision). One way we can quantitatively (numerically) describe precision is using a statistic called *standard deviation*. Basically, standard deviation is a measure of how much a group of measurements deviate from the mean of those measurements. So, the lower the standard deviation, the more **precise** that measuring device is.

To calculate standard deviation by hand can be a bit complicated and time-consuming. Thus, you should use a graphing calculator, Microsoft Excel, or use an online calculator (http://www.physics.csbsju.edu/stats/cstats_paste_form.html) to do the calculations. When reporting standard deviations for measurements, usually only the first non-zero number is reported.

If we look at the standard deviations of our measuring devices, we can see which are the most precise.

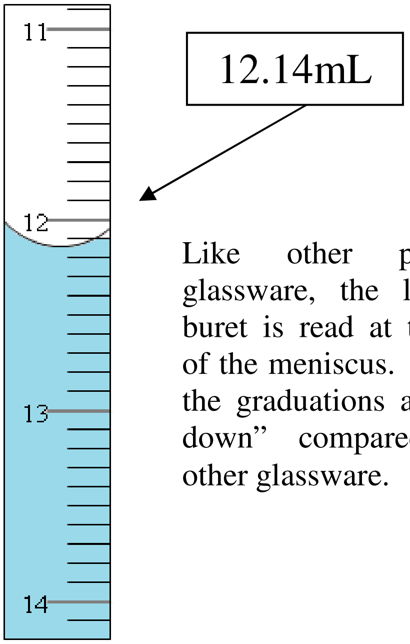
	Device A (cm)	Device B (cm)	Device C (cm)
Standard Deviation	**0.005**	**0.01**	**0.03**

Device A is most precise, while device C is the least precise after repeated measurements.

So, which measuring device is "best" to use? We want a device that is **both** accurate *and* precise. Based on our experimental data, using the percent error we calculated, we can see that Devices B and C have better accuracy than A. Also, you will notice that B and C have the same percent error. Therefore, we will need to look at the precision of these devices in order to make our final selection. Looking at the standard deviations we can see that Device B has a higher degree of precision (lower standard deviation) than C. Therefore, Device B has the best combination of accuracy and precision.

Using a buret

- **Filling the buret:** Close the stopcock. Use the beaker of water and a funnel to fill the buret about 1 mL above the "0" mark. Place a container under the buret tip and open the stopcock slowly. The buret tip should fill with solution, leaving *no* air bubbles. If the tip does not fill with solution, ask the instructor for help. Continue to let out solution until the liquid level is at "0" or below.
- **Reading the buret:** Record the volume by noting the bottom of the meniscus. (Be sure that the meniscus is at eye level). If this reading is exactly "0," record 0.00 mL. Otherwise, count the number of markings between each number, and estimate to the nearest 0.01 mL

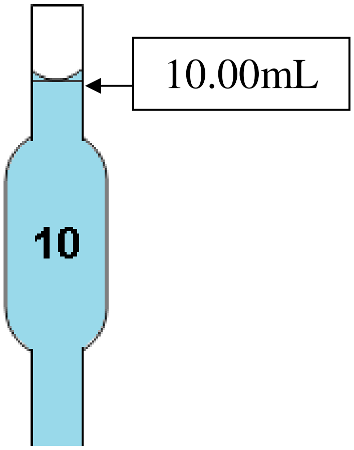


Like other pieces of glassware, the level in a buret is read at the bottom of the meniscus. However, the graduations are "upside down" compared to the other glassware.

Portion of a 50mL buret

Using a pipette

- Place the pump loosely on the top of the pipet. Place it just far enough on the pipete to get an air-tight seal. Position the tip of the bulb below the liquid level in the beaker. With your thumb, roll the wheel on the pump allowing the water to enter the tip of the pipete. Fill the pipet well above the calibration line (etched or marked above the wide center section of the pipet), **taking care not to get liquid into the pipet pump**.
- Slide the pump off the pipet while quickly sliding your index finger or thumb over the top of the pipet. Move your finger slightly and rotate the pipet to allow the liquid level to drop to the calibration line on the pipet. Then press down harder with your finger and transfer the tip of the pipet into a position over the container.



Portion of a 10mL pipete

- Remove your finger and allow most of the liquid to drain out. Then hold the tip of the pipet against the inside of the container for about 10 seconds to allow more liquid to drain.
- **Do not** try to remove the small amount of liquid remaining in the tip. Pipets are calibrated to retain this amount.

Lab Notebook

In your lab notebook, create a separate data table for each piece of glassware used. Be sure to label and title each table so you can easily identify the information contained in each one. (For example, the table for the 150 mL beaker might look like the following:

Table 1. Volumes and masses for 150 mL beaker
Mass of empty beaker: ___________________
Temperature of water: _________________

Trial	Mass of beaker with water	Mass of water	Volume of water	Density
1				
2				
3				

Procedure: Part I

1. Obtain approximately 100mL of deionized in a 250mL beaker. Place the beaker on a folded piece of paper towel on the bench. Place a thermometer in the water. Record the temperature after there is no change in temperature for at least ten minutes. This water will be used for all of the experiments. Find the *CRC Handbook of Chemistry and Physics* located in your laboratory. Using the *CRC Handbook*, look-up and record the following information:

   - The density of water at the exact temperature you measured (notice that the units in the book are kg·m^{-3}, which is the same as kg/m^3. You will need to convert to g/mL. <u>Show this work in your lab notebook</u>. Remember 1mL = 1cm^3).
   - Also, to answer post-lab questions you will need:
     - The density of water ten degrees higher than the temperature you measured.
     - The temperature at which the density of water is the highest.

2. Obtain one of the pieces of glassware listed the Table 1. Ensure that it is dry and determine its empty mass using an analytical balance. Make sure all of the doors of the balance are closed, as air currents in the lab can affect the balance. Record its mass in the Data Table. Remove the glassware from the balance.

Table 1. Laboratory glassware manufactured *to contain* specific volumes

Type of glassware	**Volume of deionized water to add**
150mL beaker	50mL
100mL graduated cylinder	50mL

50mL volumetric flask*	50mL
Kitchen measuring cup**	50mL
10 mL graduated cylinder	10mL
* can only measure a single volume ** actually made of plastic	

3. From the 250mL beaker, transfer a little less than the volume of water listed for the glassware from Table 1. Use a plastic disposable pipette to add the water drop-wise until the bottom of the meniscus is on the line that corresponds to the volume listed in Table 1. If too much water was added, remove the extra water using the plastic disposable pipette. Wipe down the outside and bottom of the beaker in case any water was spilled during the transfer.

4. Using the same balance as before, record the mass of the glassware with the added water.

5. Pour the water from the glassware back into the 250mL beaker and repeat steps 3-4 two more times with the same piece of glassware. You should have a total of three trials. You will use the empty mass from step 2 for all three trials.

6. You will then repeat the process (three trials each) with each piece of glassware listed in Table 2.

Procedure: Part II

The proper use of a pipete is a skill that takes time and practice to perfect. Therefore, you should perform at least three practice runs of filling the pipete and delivering the water back to the 250mL beaker.

1. Obtain a *dry* 50mL beaker and determine the mass of the dry, empty container. (Since the buret and pipette are made *to deliver* a specific volume, the liquid must be transferred to another container to determine the mass of the water).

2. Obtain one of the pieces of glassware listed in Table 2. Use the methods and techniques that your lab instructor mentioned at the beginning of the lab to deliver the indicated volume to the 50mL beaker.

3. Return the water to the 250mL beaker and wipe out the 50mL beaker with a paper towel until dry. Repeat steps 2 and 3 for a total of three trials for each piece of glassware.

Table 2. Laboratory glassware manufactured *to deliver* specific volumes

Type of glassware	**Volume of dionized water to dispense**
50mL buret	10mL
10mL volumetric pipette*	10mL
* can only measure a single volume	

4. Using the same balance as before, record the mass of the 50mL beaker with the added water

5. Pour the water from the 50mL beaker back into the 250mL beaker. Dry the 50mL beaker using a paper towel.

6. Repeat steps 2-4 two more times. You should have a total of three trials.

7. You will then use a similar procedure, using the 10mL volumetric pipette.

Calculations

Complete your data tables by calculating the mass of water for each trial. Using this value, calculate the density of water in units of grams per milliliter (g/mL) for each trial using the formula for density (density = mass/volume).

Lab Notebook

Next create a Summary Table that summarizes the percent error and standard deviation for each piece of glassware. List the glassware in order of the smallest percent error to the largest percent error.

Summary Table

Rank based on % error	Glassware	% Error	Standard Deviation
1			
2			
3			
7			

Accuracy and Precision of Laboratory Glassware: Determining the density of water

Name: ________________________
Section Number:________________

Turn this page in. Include the copies from your lab notebook.

Post-Lab Questions

1. For each of the following situations, determine which type of glassware would be most appropriate (beaker, pipete, buret, volumetric flask, 10mL graduated cylinder, 100mL graduated cylinder).

> Note: When working with laboratory glassware, scientists choose the glassware that is appropriate while also efficient for the experiment. For example, if an experiment calls for using *approximate* volumes, it would be a waste of time to set up a buret.

a. A lab calls for adding enough water to dissolve 5g of NaCl to make a total of 100.00mL of solution. _____________________

b. A lab calls for adding very small amounts of liquid A to solution B until a color change is detected. The amount of liquid A added must be recorded. _____________________

c. A lab calls for adding approximately 50mL of water to a solution. _____________________

d. A lab calls for adding 50.0mL of water to a solution. _____________________

e. A lab calls for delivering 10.00mL of solution Z to an Erlenmeyer flask. ________________

2. For each of the following situations during the density of water experiment, determine if the mistake would give a falsely high or falsely low density for water. For each situation, assume everything else in the experiment is done correctly. Note: It may be helpful to try some hypothetical calculations.

a. When weighing a volumetric flask full of water, a student does not notice that the outside of the flask is wet.

HIGH LOW UNCHANGED

Explanation:

b. When weighing an *empty* beaker, a student does not notice that there is some water inside.

HIGH LOW UNCHANGED

Explanation:

c. Before placing an *empty* 10mL graduated cylinder on the balance to get its mass, a student does not notice that the balance reads "-1.4444g.". When the student weighs the *full* 10mL graduated cylinder later in the experiment, she correctly sets the balance to "0.0000g."

HIGH LOW UNCHANGED

Explanation:

d. A student accidentally used the hot water faucet to deliver water to a piece of glassware. (Use the densities you recorded from the *CRC Handbook* during the lab in your explanation to received complete credit) .

HIGH LOW UNCHANGED

Explanation:

3. Two objects have the same mass but different volumes. Which will be more dense, the one with the larger volume or smaller volume? ___________________ Explain your reasoning.

4. At what temperature does water have the highest density? ____________.

5. A group of students determined the density of water using the methods in today's lab. Since the students were pressed with time, they only did one trial with using a buret. The students calculated a percent error of 8%. The manufacturer of the glassware states that the glassware should give no more than 1% error at room temperature. Give three possible sources of error that might explain this discrepancy (do <u>not</u> use the errors mentioned in question 2).

6. In lab, your group used something called "deionized" water to find the density of water. Explain what deionized water is and why your group did not use tap water instead.