Experiment 1 – Basic Techniques

Materials Needed to Complete This Experiment: Please review this video before you begin the lab. (https://www.youtube.com/watch?v=qsFGnU6F5Pc)

1. Plastic 3 mL plastic pipette, 25 mL graduated cylinder, 100 mL beaker, 250 mL beaker, a beaker bigger than 400 mL, waste beaker
2. Distilled water
3. Scale that holds up to 200.0 g with 0.01 g accuracy
4. Temperature probe

Please read the through the introduction. Viewing the video in the 7th common lab procedure to calculate the average density and standard deviation may be helpful to answer prelab question 2. Once you have read through the introduction and answered the prelab questions you are ready to start the experiment on page 4.

Common Lab Procedures/Skills in This Lab

1. **EQUILIBRATE TO ROOM TEMPERATURE (https://www.youtube.com/watch?v=fDVc5VXemOY)**
2. **RECORD THE MASS (https://www.youtube.com/watch?v=J9-CjGlkc-4)**
3. **RECORD THE TEMPERATURE (https://www.youtube.com/watch?v=7HjvuadFJJA)**
4. **CONDITION THE PIPETTE WITH DISTILLED WATER (https://www.youtube.com/watch?v=9R-9Caw2kHs)**
5. **DELIVER 2.0 mL USING THE PIPETTE (https://www.youtube.com/watch?v=XCqZkw-zhvU)**
6. **CALCULATE THE DENSITY OF WATER (https://www.youtube.com/watch?v=h4qnaTBobTM)**
7. **CALCULATE THE AVERAGE DENSITY AND THE STANDARD DEVIATION (https://www.youtube.com/watch?v=g-reM4W6QAA)**
8. **REPEAT THE MEASUREMENT MULTIPLE TIMES TO DETERMINE PRECISION**
9. **EVALUATE ACCURACY AND PRECISION**
10. **CALCULATE THE PERCENT ERROR**
11. **SIGNIFICANT FIGURES: READING A DIGITAL DISPLAY**
12. **SIGNIFICANT FIGURES: READING A GRADUATED SCALE**
13. **SIG FIGS & CALCS: ADDITION AND SUBTRACTION**
14. **SIG FIGS & CALCS: MULTIPLICATION AND DIVISION**

Introduction

In our first experiment, the most basic techniques of measurement will be introduced: using a balance, measuring a volume of liquid, and measuring temperature. We will combine these three techniques to determine the accuracy and precision of three types of labware (plastic pipette, graduated cylinder, and beaker) for measuring the density of water. Finally, we will do all of our calculations using proper significant figures.

All of the labware used in this experiment is designated “to contain”. That means when you fill the pipette, graduated cylinder, or beaker to the line, each one of these contains that amount. In order to deliver that amount, you need to get all of the water out of the piece of labware. For the pipette, we will be concerned with delivering as close as possible to all of the water and we will do our calculations based on squirting the water out of the pipette and into a preweighed beaker.

For the graduated cylinder and the beaker, we will only be interested in how much each of these contains. For these measurements, we will weigh the water while it is still in the graduated cylinder or beaker.

The balances used in this experiment will vary depending upon what you have purchased. It is important to understand how your balance works. A balance will always display all of the numbers it knows accurately plus one digit for which it estimates based on some level of uncertainty. If your scale displays 11.62 g, the scale has been calibrated to accurately know that there are between 11.60 and 11.70 grams.

The last digit, the "point two" will have some level of uncertainty: it could be, say, 11.62 g or 11.63 g or 11.61 g or even 11.64 g. This is a difficult concept, but all instruments have some uncertainty. To properly record the mass, always write down all of the digits displayed by the scale.

Accuracy is a measure of how close a measured value is to the true value. For example, if you are trying to determine the density of water at 20.0°C, the correct value is 0.998203 g/mL. If you experimentally measure out 1.05 g/mL using one type of labware and 0.974 g/mL using a second type of labware, then the second type of labware would be considered more accurate at measuring the density of water because it is closer to the correct value. One measure of the accuracy is the % error,

$$\% \text{ error} = \frac{\text{experimental value} - \text{accepted value}}{\text{accepted value}} \times 100\%$$

The experimental value will be the value you determine in lab and will often be an average of 2-3 repeat measurements. The accepted value is the value you look up or are given by your instructor. It is also called the correct value. The % error can be either positive or negative! If the percent error is negative, then your experimental value is lower than the accepted value. The sign of the percent error is often a key piece of information in evaluating the success of the experiment.

Precision is a measure of the reproducibility of multiple measurements. For example, if you measure out 20.0 mL of water using two different types of labware you might get the following results for the density of water:

Trial	Labware type #1 (g/mL)	Labware type #2 (g/mL)
1	1.02	1.05
2	1.02	0.99
3	1.03	1.03

Because the results for labware type #1 are closer together, they are more precise. Note that these two sets of data have the same average, so they would have the same accuracy but different levels of precision. One measure of the precision of a group of measurements is the standard deviation,

$$s_x = \sqrt{\frac{\Sigma(x_i - \bar{x})^2}{N-1}}$$

where s_x is the standard deviation, x_i is the *i*th measurement of a value, $\bar{x}$ is the average value of all measurements of x, N is the number of measurements of x and Σ is the "summation" sign.

Example: Given 5 different measurements of the high temperature on five very hot summer days (in °C):

44, 46, 39, 41 and 48

what is the average temperature and the standard deviation in temperature?

$\bar{x}$ = (44 + 46 + 39 + 41 + 48)/ 5 = 43.6°C

$$s_x = \sqrt{\frac{(44-43.6)^2 + (46-43.6)^2 + (39-43.6)^2 + (41-43.6)^2 + (48-43.6)^2}{5-1}} = 3.6°\text{C}$$

The proper way to report the average and standard deviation for a number is:

43.6 ± 3.6°C or 44 ± 4°C

To the proper number of significant figures. The average temperature cannot have any more significant figures than the original temperature measurements. The same goes for reporting the standard deviation. That is why the correct answer is 44 ± 4°C.

When using a balance, the significant figures are displayed for you. However, labware requires "reading" a graduated scale (= with markings) correctly. When reading a graduated scale, always record the measurement to one more decimal place than the markings on the scale. In this way, the last decimal place is an estimate (i.e., it is not known exactly). Keep this concept in the back of your mind: the way that measurements are recorded using significant figures is that all of the **KNOWN** digits are recorded, and then one more is recorded for which there is some (but not complete) uncertainty.

The purpose of conditioning a piece of labware (such as a pipette or beaker) is to ensure that the pipette or labware has the exact solution that you'll be putting into the labware without changing the concentration (either diluting or concentrating) of the solution. When you condition with distilled water, you are rinsing out any other material than the water. Conditioning always requires three rinses. If you wish to minimize the amount of solution/water used to condition, you can fill the labware with a small amount of solution/water and tip/rotate the labware to coat all surfaces with the small amount of solution with three separate small amounts of solution/water.

Common Chemistry Lab Procedures

Throughout this and the following labs, we will define specific chemistry procedures by placing them in all caps. Each procedure is explained in detail the first time, but may not be explained subsequent times. You can tell a common chemistry lab procedure because it will be in **ALL CAPS** and be **bolded**.

Density of Water (g/mL) vs. Temperature (°C)

(from Handbook of Chemistry and Physics, 53rd Edition, p. F4)

Whole degrees are listed down the left hand side of the table, while ***tenths of a degree*** are listed across the top.

	0.0	***0.1***	***0.2***	***0.3***	***0.4***	***0.5***	***0.6***	***0.7***	***0.8***	***0.9***
15	0.999099	0.999084	0.999069	0.999054	0.999038	0.999023	0.999007	0.998991	0.998975	0.998959
16	0.998943	0.998926	0.998910	0.998893	0.998877	0.998860	0.998843	0.998826	0.998809	0.998792
17	0.998774	0.998757	0.998739	0.998722	0.998704	0.998686	0.998668	0.998650	0.998632	0.998613
18	0.998595	0.998576	0.998558	0.998539	0.998520	0.998501	0.998482	0.998463	0.998444	0.998424
19	0.998405	0.998385	0.998365	0.998345	0.998325	0.998305	0.998285	0.998265	0.998244	0.998224
20	0.998203	0.998183	0.998162	0.998141	0.998120	0.998099	0.998078	0.998056	0.998035	0.998013
21	0.997992	0.997970	0.997948	0.997926	0.997904	0.997882	0.997860	0.997837	0.997815	0.997792
22	0.997770	0.997747	0.997724	0.997701	0.997678	0.997655	0.997632	0.997608	0.997585	0.997561
23	0.997538	0.997514	0.997490	0.997466	0.997442	0.997418	0.997394	0.997369	0.997345	0.997320
24	0.997296	0.997271	0.997246	0.997221	0.997196	0.997171	0.997146	0.997120	0.997095	0.997069
25	0.997044	0.997018	0.996992	0.996967	0.996941	0.996914	0.996888	0.996862	0.996836	0.996809
26	0.996783	0.996756	0.996729	0.996703	0.996676	0.996649	0.996621	0.996594	0.996567	0.996540
27	0.996512	0.996485	0.996457	0.996429	0.996401	0.996373	0.996345	0.996317	0.996289	0.996261
28	0.996232	0.996204	0.996175	0.996147	0.996118	0.996089	0.996060	0.996031	0.996002	0.995973
29	0.995944	0.995914	0.995885	0.995855	0.995826	0.995796	0.995766	0.995736	0.995706	0.995676
30	0.995646	0.995616	0.995586	0.995555	0.995525	0.995494	0.995464	0.995433	0.995402	0.995371

Figure 1. The density of water as a function of temperature.

Procedure – You will work on this lab independently (no lab partners).

A. Using a 3.0 mL Plastic Pipette to Measure Volume

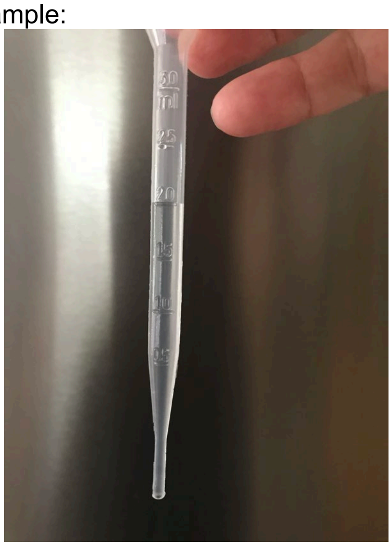
1. Fill about 400 mL of distilled water into a clean beaker and let it **EQUILIBRATE TO ROOM TEMPERATURE**. **EQUILIBRATE** means to wait until something has stopped changing. **EQUILIBRATE TO ROOM TEMPERATURE** means to allow the solution to stop changing temperature when it reaches room temperature. Once the solution reaches room temperature, it will not change temperature any more. It will have equilibrated. This will take at least 15 minutes before starting to take temperature measurements, so set this water aside. This process can be viewed in the Video **(Video 1 Equilibrate Water)** in the common lab procedures.

2. **RECORD THE MASS** of a clean 250 mL beaker. To **RECORD THE MASS**: (i) make sure that the outside of your beaker and the scale are both dry (otherwise, water can be transferred between the beaker and the scale which would change the mass of each), (ii) with the scale empty, set the scale to zero, and (iii) place the beaker onto your scale and record all of the numbers displayed by the scale. ALWAYS record all the digits on the balance's display. Record the mass in Table 1 with its units. This process can be viewed in the Video (**Video 2 Record the Mass)** listed in the common lab procedures.

3. **RECORD THE TEMPERATURE** of the 400 mL of water that was set aside in step 1. To do this, hold the end of the temperature probe in the water without putting the electronics part of the temperature probe in the water until the temperature stops changing. This process can be viewed in the video **(Video 3 Record the Temperature)** listed in the common lab procedure.

4. **CONDITION THE PIPETTE WITH DISTILLED WATER:** rinse the pipette three times with distilled water such that the distilled water coats all surfaces on the inside of the pipette with the distilled water. Typically, you can use a small amount of water and then turn the pipette on its side to coat all surfaces. This minimizes the amount of water needed to do the conditioning. This process can be viewed in the video (**Video 4 Conditioning the Pipette**) listed in the common lab procedure.

5. **DELIVER 2.0 mL** of the equilibrated water **USING THE PIPETTE** into the preweighed beaker. The preweighed beaker should not be on the scale (in case you miss the beaker and get water on the scale. Make sure there are no bubbles in the water. **RECORD THE VOLUME** in Table 1. This process can be viewed in the video **(Video 5 Deliver 2.0 mL using Pipette)** listed in the common lab procedure. Example:



6. Take a picture of your plastic pipette with 2.0 mL in it. Submit it as part of your report.

7. **RECORD THE MASS** of the flask and the water in Table 1.

8. **REPEAT THE MEASUREMENT MULTIPLE TIMES TO DETERMINE PRECISION:** Repeat step 6 (**DELIVER**) and step 7 (**RECORD THE MASS**) two more times without emptying out your beaker between trials. This means that you will have 4.0 mL total in the flask, then 6.0 mL in the beaker. All of your data goes in Table 1.

   Note: The measurement is measuring the mass of 2.0 mL of solution. You are doing the same thing 3 times: adding 2.0 mL to a beaker. That is why the volume for each trial is 2.0 mL. That is why the mass is always the mass of the *last* 2.0 mL added.

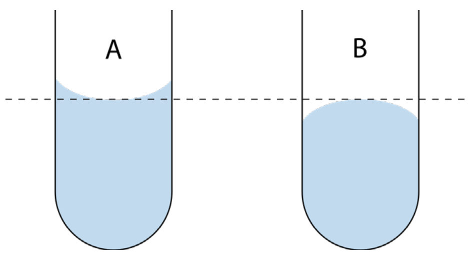
9. If you are using a pipette to deliver substances other than water, be sure to **CONDITION THE PIPETTE** (remember: three times with a small volume) with distilled water before putting it away.

B. Using a Graduated Cylinder to Measure Volume

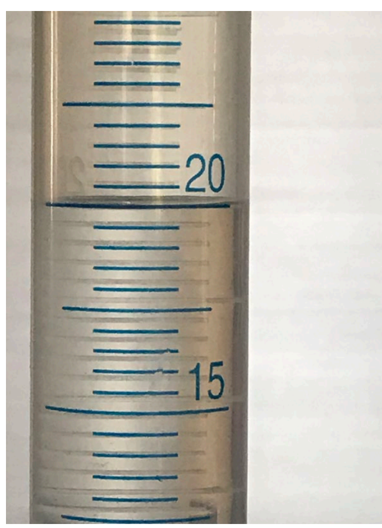
1. **RECORD THE MASS** of the clean, dry ~~25.0 mL~~ graduated cylinder.

2. **RECORD THE TEMPERATURE OF THE WATER** in Table 2**.**

3. Measure out 20.0 mL of the room temperature distilled water. Use droplets from the pipette to get the volume of water as close to the 20.0 mL line as possible. Your eyes should be at the level of the liquid surface in the graduated cylinder. The meniscus is the curved interface of the surface of the water. In A, the meniscus is said to be concave. In B, the meniscus is called convex. Always read a meniscus at the center of the liquid level.



4. Take a picture of the meniscus of the water in the graduated cylinder. Submit it as part of your report. Example:



5. **RECORD THE MASS** of the graduated cylinder with the water in it.

6. Empty out your graduated cylinder and carefully measure out another 20.0 mL of your room temperature water. There is no need to reweigh the empty graduated cylinder.

7. **RECORD THE MASS** of the graduated cylinder and water.

8. **REPEAT THE MEASUREMENT MULTIPLE TIMES TO DETERMINE PRECISION:** Repeat steps 6 and 7 at least 1 more time (for a total of three times).

C. Using a Beaker to Measure Volume

1. Choose a clean and dry 100 mL (or other) beaker that has graduations (or marks) for each 10 mL or 20 mL. **RECORD THE MASS** of the beaker in Table 3.

2. **RECORD THE TEMPERATURE** of the water.

3. Measure out 2.0×10^1 mL (20 mL in scientific notation) of the room temperature distilled water.

4. **RECORD THE MASS** of the beaker and the water.

5. Empty out your beaker and carefully measure out another 2.0×10^1 mL of your room temperature water. There is no need to reweigh the empty beaker.

6. **RECORD THE MASS** of the beaker and water.

7. **REPEAT THE MEASUREMENT MULTIPLE TIMES TO DETERMINE PRECISION:** Repeat steps 5 and 6 at least 1 more time (for a total of three times).

Calculations

A. Calculations for the Pipette and Graduated Cylinder

Note: it is important statistically that we treat each trial independently. Therefore, you want to determine the density of each trial for the pipette and graduated cylinder independently of each other trial. This means that all of the calculations for the pipette will use a volume 2.0 mL and all of the calculations for the graduated cylinder will use a volume of 20.0 mL. If you have any questions about what this means, please ask your instructor.

1. **SIG FIGS & CALCULATIONS: ADDITION AND SUBTRACTION:** Calculate the mass of water delivered by your pipette for each trial independent of each other trial. Remember, you did NOT empty the beaker for each trial. Therefore, to get the mass of water for Trial 2, subtract the "Mass of Flask and Water" for Trial 1 from the "Mass of Flask and Water" for Trial 2. This calculation is similar for the other trials. These calculations can be viewed from the list above common lab procedures **(Video 6 Addition and subtraction of sig figs).**

2. **SIG FIGS & CALCULATIONS: MULTIPLICATION AND DIVISION:** Use your mass of water and the volume of water to **CALCULATE THE DENSITY OF WATER** for each trial and put it in Tables 1 or 2. Density = mass / volume. One way to tell if you've probably done the calculation correctly is that your calculated density of water is near 1.00 g/mL. These calculations can be viewed from the list above common lab procedures **(Video 6 Addition and subtraction of sig figs).**

3. **CALCULATE THE AVERAGE DENSITY AND THE STANDARD DEVIATION**. An example calculation for standard deviation is done in the introduction to this lab. Put the average and standard deviation values in Table 4. Standard deviation has a "±" in front of it. In the event that the standard deviation is zero when calculated to the correct number of significant figures, write that in Table 4. Then, also write the percent error with the first nonzero digit in the same box. These calculations can be viewed from the common lab procedure list above **(Video 7 Calculate the Average Density and Standard Deviation).**

4. **CALCULATE THE PERCENT ERROR** with respect to the average density of water at the temperature of your water. The formula for percent error is given in the introduction to this lab. The temperature may be different for each set of calculations, which means that the density of water you use may be different for each set of calculations. The percent error can be negative. Put the value in Table 4. In the event that the percent error is zero when calculated to the correct number of significant figures, write that in Table 4. Then, also write the percent error with the first nonzero digit in the same box.

B. Calculations for the Graduated Cylinder and the Beaker

1. Use your mass of water and the volume of the water measured in your graduated cylinder to **CALCULATE THE DENSITY OF WATER** for each trial. Remember, you did empty the graduated cylinder each time, so always subtract off the dry graduated cylinder for each trial. **CALCULATE THE AVERAGE DENSITY AND THE STANDARD DEVIATION**.

2. **CALCULATE THE PERCENT ERROR** with respect to the average density of water at the temperature of your water.

3. Repeat the calculations for the beaker.

C. Trends:

1. **EVALUATE ACCURACY:** In Table 4, rank the three pieces of labware from most to least accurate. The most accurate piece of labware has the percent error that is closest to zero (could be positive or negative).

2. **EVALUATE PRECISION:** In Table 4, Rank the three pieces of labware from most to least precise.