Chemistry Lab: Introduction to Measurement
(adapted from Flinn ChemTopic Labs)

Introduction

Much of what we know about the physical world has been obtained from measurements made in the laboratory. Skill is required to design experiments so that careful measurements can be made. Skill is also needed to use lab equipment correctly so that errors can be minimized. At the same time, it is important to understand the limitations of scientific measurements.

Concepts

- Measurement
- Significant figures
- Accuracy and precision
- Experimental error

Background

Experimental observations often include measurements of mass, length, volume, temperature, and time. There are three parts to any *measurement:*

- its numerical value
- the unit of measurement that denotes the scale
- an estimate of the uncertainty of the measurement.

The numerical value of a laboratory measurement should always be recorded with the proper number of *significant figures.* The number of significant figures depends on the instrument or measuring device used and is equal to the digits definitely known from the scale divisions marked on the instrument plus one estimated or "doubtful" digit. The last, estimated, digit represents the uncertainty in the measurement and indicates the precision of the instrument.

Measurements made with rulers and graduated cylinders should always be estimated to one place beyond the smallest scale division that is marked. If the smallest scale division on a ruler is centimeters, measurements of length should be estimated to the nearest 0.1 cm. If a ruler is marked in millimeters, readings are usually estimated to the nearest 0.2 or 0.5 mm, depending on the observer. The same reasoning applies to volume measurements made using a graduated cylinder. A 10-mL graduated cylinder has major scale divisions every 1 mL and minor scale divisions every 0.1 mL. It is therefore possible to "read" the volume of a liquid in a 10-mL graduated cylinder to ,the nearest 0.02 or 0.05 mL. Three observers might estimate the volume of liquid in the 10-mL graduated cylinder shown at the right as 8.32, 8.30, or 8.33 mL. These are all valid readings. It would NOT be correct to record this volume of liquid as simply 8.3 mL. Likewise, a reading of 8.325 mL would be too precise.
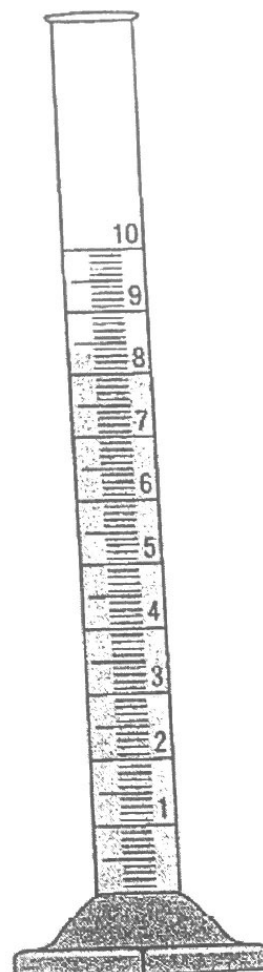
Some instruments, such as electronic balances, give a direct reading-there are no obvious or marked scale divisions. This does NOT mean that there is no uncertainty in an electronic balance measurement; it means that the estimation has been carried out internally (by electronic means) and the result is being reported digitally. There is still uncertainty in the last digit. On an electronic centigram balance, for example, the mass of a rubber stopper might be measured as 5.67 g. If three observers measured the mass of the same rubber stopper, they might obtain readings of 5.65, 5.67, and 5.68 g. The uncertainty of an electronic balance measurement is usually one unit in the smallest scale division that is reported-on a centigram balance this would be ± 0.01 g.
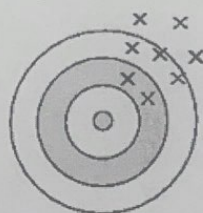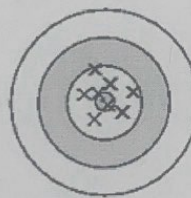

Not precise
Not accurate
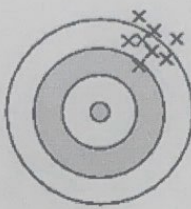
Precise
Not accurate
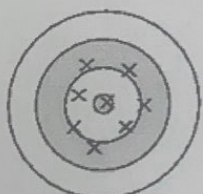
Not precise
Accurate

Precise
Accurate

These dartboard targets illustrate the difference between accuracy and precision.

Accuracy and precision are two different ways to describe the error associated with measurement. *Accuracy* describes how "correct" a measured or calculated value is, that is, how close the measured value is to an actual or accepted value. The only way to determine the accuracy of an experimental measurement is to compare it to a "true" value-if one is known! *Precision* describes the closeness with which several measurements of the same quantity agree. The precision of a measurement is limited by the uncertainty of the measuring device. Uncertainty is often represented by the symbol ± ("plus or minus"), followed by an amount. Thus, if the measured length of an object is 24.72 cm and the estimated uncertainty is 0.05 cm, the length would be reported as 24.72 ± 0.05 cm.

Variations among measured results that do not result from carelessness, mistakes, or incorrect procedure are called *experimental errors*. Experimental error is unavoidable. The magnitude and sources of experimental error should always be considered when evaluating the results of an experiment.

Experiment Overview

The purpose of this activity is to make accurate volume measurements using common glassware, to learn the meaning of significant figures in the measurements, and to compare the accuracy and precision of laboratory measurements.

Pre-Lab Questions

1. Explain how the uncertainty associated with a measurement is conveyed through the proper use of significant figures.

2. A pipet is a type of glassware that is used to deliver a specified volume of liquid. A 5 mL pipet has major scale divisions marked for every milliliter and minor scale divisions marked for every 0.1 mL. What is the uncertainty (in mL) made using this pipet? Would it be proper to report that the pipet was used to deliver 3.2 mL of liquid? Explain why or why not.
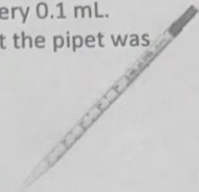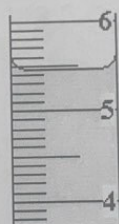
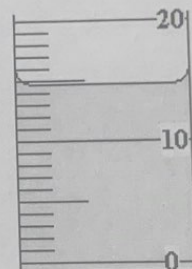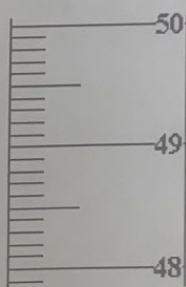3. Determine the volume of the liquids in the following cylinders:
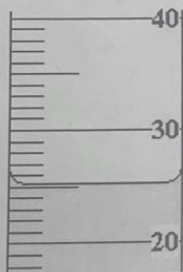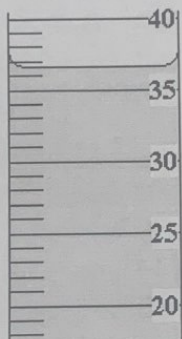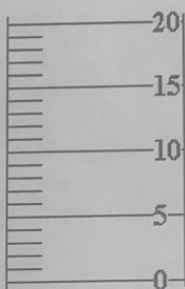
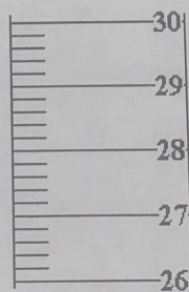a) _____ b) _____ c) _____ d) _____

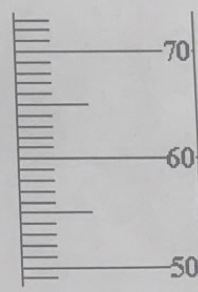Draw in the meniscus for the following readings:

a) 49.21 mL b) 18.2 mL c) 27.65 mL d) 63.8 mL

4. Label each piece of glassware using the following terms:

graduated cylinder, beaker, flask, pipet

_____   _____   _____   _____

Materials
Balance, centigram (0.01 g)
Beaker, Flask and Graduated Cylinder; all 50-mL
Graduated cylinders with colored water at different levels: 10-,50-, 100- mL
50 mL beaker and Graduated cylinders 10-, 50- and 100- mL
Pipet, Beral-type
Water

Safety Precautions
The materials in this lab activity are considered nonhazardous. Always wear chemical splash goggles when working in the laboratory with glassware, heat, or chemicals.

Throughout the lab, you will need to make careful volume measurements. Use the technique illustrated below to make accurate, consistent readings.

When water (or an aqueous solution) is contained in a narrow glass container such as a graduated cylinder, the liquid surface is not flat, as might be expected. Rather, the liquid surface is *curved* (see Figure 2-3). This curved surface is called a meniscus, and is caused by an interaction between the water molecules and the molecules of the glass container wall. When reading the volume of a liquid that makes a meniscus, hold the graduated cylinder so that the meniscus is at eye level, and read the liquid level at the *bottom* of the curved surface.
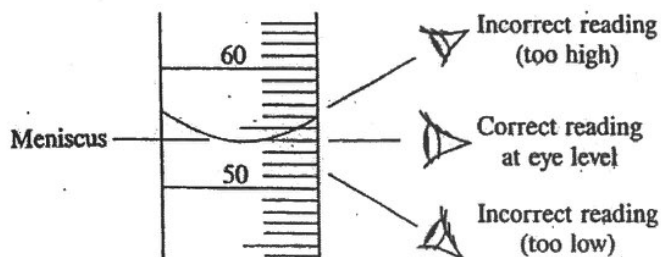
Figure 2-3. Reading a meniscus. Read the bottom of the meniscus while holding at eye level.

Procedure

Part A. Practice Making and Recording Volume Measurements with Graduated Cylinders

For this part, use the three graduated cylinders, each containing a specific quantity of liquid to which some food coloring has been added to make the volume easier to read.

1. In Data Table A, record the maximum capacity of each graduated cylinder and the volume that each major and minor scale division represents on each graduated cylinder.

2. Observe the volume of liquid in each cylinder and record the results in Data Table A. Remember to include the units and the correct number of significant figures.

3. In Data Table A, estimate the "uncertainty" involved in each volume measurement.

Part B. Comparing Volume Measurements Made with Three Different Sized Graduated Cylinders

4. Use tap water to fill a 50-mL beaker to the 20-mL mark. Use a disposable plastic pipet to adjust the water level until the bottom of the meniscus is lined up as precisely as possible with the 20-mL line.

5. Pour the water from the 50 mL beaker into a clean, 25-mL graduated cylinder. Read the volume of liquid in the 25 mL graduated cylinder and record the result in Data Table B. Remember to include the units and the correct number of significant figures based on the glassware's scale. **(Note: If the water level is not on the 20 mL mark, do NOT add or remove water. Record the level of water that you see.)**

6. Transfer the water from the 25-mL graduated cylinder to a clean, 50-mL graduated cylinder and again read its volume. Record the result with the correct number of significant figures in Data Table B.

7. Transfer the water from the 50-mL graduated cylinder to a clean, 100-mL graduated cylinder and again read its volume. Record the result with the correct number of significant figures in Data Table B. Discard the water into the sink.

8. Repeat steps 4-7 two more times for a total of three independent sets of volume measurements. Dry the beaker and graduated cylinders between trials. Record all results in Data Table B.

9. Calculate the average (mean) volume of water in the 25, 50 and 100-mL graduated cylinders for the three trials. Enter the results in Data Table B.

Part C. Comparing the Accuracy and Precision of a Beaker, Flask and Graduated Cylinder

The concept behind using <u>density</u> to see how accurate your volume readings are...	

"Known Value"	**"Experimental Value"**
Density = $\dfrac{\text{mass}}{\text{volume}}$ = _____ $\dfrac{\text{g}}{\text{mL}}$ you get the "known" value of density simply by looking it up on the given reference table (this is the target you are aiming for)	Density = $\dfrac{\text{mass}}{\text{volume}}$ = _____ $\dfrac{\text{g}}{\text{mL}}$ *for mass, you use the mass of water you measure in each piece of glassware *for volume, you use the mL of water you think are there based on the scale on the side of the glassware *since the mass and volume are amounts you measure, the resulting density will be an "experimental" value

Percent Error

The percent error formula will compare your experimental value to the known value and tell you how far away from the known (target) you are. A negative value means your experimental value is less than the known, and a positive value means your experimental value is greater than the known. A low percent error means you were able to make an accurate volume reading with that piece of glassware.

$$\% \text{ Error} = \frac{\text{experimental - known}}{\text{known}} \times 100$$

10. Using the electronic balance, measure and record (in Data Table C) the mass of a dry 50 mL beaker, 50 mL flask, and 50 mL graduated cylinder.

11. Add 25.0 mL of distilled water to **each** piece of glassware. Add the last few drops carefully so that the bottom of the meniscus is exactly at the volume you want.

12. Use the electronic balance to measure and record (in Data Table C) the mass of each piece of glassware containing 25.0 mL of water. Subtract the mass of the empty glassware to find the mass of water in each piece of glassware.

13. Use a thermometer to record (in Data Table C) the temperature of the water used in each piece of glassware. It is not necessary to measure the temperature in all three pieces, because they should be the same. Since this glassware is small, **do not let go of the thermometer** as the weight of the thermometer may cause the glassware to turn over and spill. After you have recorded the temperature, pour the water into the sink and wipe down your counters.

14. Refer to the Table of Densities provided to obtain the density of water at the proper temperature. Record the density in Data Table C. This is the "known" or "true" value of the density of water. (This is the target you are aiming for.)

15. Calculate an "experimental" value for density by taking the mass of water in each piece of glassware and dividing it by the volume of water you put in each piece of glassware as determined by reading the scale on the side of the glassware. Show all your work for these calculations and record the results in Data Table C.

16. Compare your "experimental" density (from step 15) to the "known" density (from step 14) by calculating and recording the percent error for each piece of glassware. Show all your work for these calculations and record the results in Data Table C. The formula for percent error is shown in Data Table C.

Data Table A. *Volume Measurements*

Graduated Cylinder	Maximum Capacity (mL)	Volume Given by Major Scale	Volume Given by Minor Scale	Observed Volume	Uncertainty (± how many mL)
A					
B					
C					

Data Table B. *Comparing Volume Measurements*

	Measured Volume of "20 mL" of Water		
Trial	25 mL Graduated Cylinder	50 mL Graduated Cylinder	100 mL Graduated Cylinder
1			
2			
3			
Average			

Data Table C. *Comparing the Accuracy and Precision of a Beaker, Flask and Graduated Cylinder*

	50 mL beaker	50 mL flask	50 mL graduated cylinder
a. Mass of dry glassware			
b. Mass of glassware with 25.0 mL H_2O			
c. Mass of just H_2O			
d. Temperature of H_2O			
e. Density of H_2O (from table below)	*This will be your "known" in part g*		
f. Calculated density density = mass / volume	*This will be your "experimental" in part g*		
g. % Error Between Experimental and Known Densities %Error = (exp – known) / known x 100			

Density of Water at Various Temperatures	
Temperature, °C	Density, g/mL
16	0.99897
18	0.99862
20	0.99823
22	0.99780
24	0.99732
26	0.99681
28	0.99626