CHM 130 - Accuracy and the Measurement of Volume

PURPOSE:
The purpose of this experiment is to practice using various types of volume measuring apparatus, focusing on their uses and accuracy.

DISCUSSION:
Volume measuring apparatus come in several different designs – graduated cylinders, volumetric flasks, pipets, burets, etc. Each design has a different application and a different accuracy. We are going to study these applications and the accuracy of the designs. In general, the less accurate the apparatus is, the easier and faster it is to use. So if great accuracy is not needed, why not be practical and use the fast and easy apparatus. In an experiment, the measurements made using a volume measuring apparatus should be at least as accurate as all the other measurements made in the experiment. For this reason, it is important to know the accuracy of different apparatus that are available.

There are two kinds of errors in measurements.

ACCURACY is the error associated with how close a measurement is to the true or actual value. If an instrument gives values that are very close to the true value we say that it is ACCURATE.

> ***Example:*** A graduated cylinder upon measuring the same sample three times gave 566 mL, 584 mL, and 541 mL. The average of these three values is 563.7 mL. If the true value was 563.688 mL, we would say that the average was accurate but the individual measurements were neither accurate nor precise.

PRECISION is the error associated with how close several measurements of the same quantity are to each other. If an instrument upon repeated measurements gives values that are very close to each other we say that the instrument is PRECISE.

> ***Example:*** If the measurements in the above example were 563 mL, 564 mL, and 564 mL (average = 563.7 mL) and the true value was 563.688 mL then the measurements are both precise and accurate. The last case is, of course, the ideal.

PRECISION is also used to describe the uncertainty of a single measurement based on the markings on the apparatus used. The last digit of any measured value is an estimate between the markings on the apparatus used to make the measurement. In general to determine the precision of a measuring apparatus divide the space between markings by 10. Some volumetric apparatus (volumetric flasks and volumetric pipets) have only one marking, in that case the manufacturer will print the precision on the front next to any other labels.

> ***Example:*** The markings on a 100mL graduated cylinder are every 1mL, so the volume can be measured to ±0.1mL. In the measured value 74.3mL, the value 74 is known with certainty and the .3mL is an estimate between the 74mL and 75mL markings.

Volume measuring apparatus are designed for two general purposes – to deliver or to contain a known volume.

TO DELIVER (TD) – Volume measuring apparatus that are designed to deliver a known volume into another container.

> ***Example:*** 50mL of acid is to be added to a beaker. The acid would be measured in a 50mL TD graduated cylinder then poured out into the beaker.

TO CONTAIN (TC) – Volume measuring apparatus that are designed to contain a specific volume within the apparatus.

> ***Example:*** 1L of NaCl solution needs to be made. A certain amount of NaCl would be weighed out and placed into a 1L TC volumetric flask. Water would be added to the 1L mark on the volumetric flask.

How does one determine accuracy if the true value is not known?

This is an important question since we face this problem in this experiment. THE SOLUTION TO THIS PROBLEM IS TO DETERMINE THE VOLUME BY ANOTHER METHOD WHOSE ACCURACY IS KNOWN AND WHOSE ACCURACY IS GREATER. In this case, that method is to measure the mass of the sample and convert it to volume using density.

For example, if the mass of water in a graduated cylinder is 1.485 g and the density of the water at the water sample's temperature is 0.9984 g/mL, then the volume of the water in the graduated cylinder is 1.487 mL. This calculation is shown below:

$$1.485g * \left(\frac{1mL}{0.9984g}\right) = 1.487\ mL$$

If one always uses a sample that weighs more than a gram and weighs to the thousandth of a gram, the mass will have at least four significant figures. Since the density has four significant figures, the volume measured this way will always have four significant figures—a quite accurate measurement indeed!

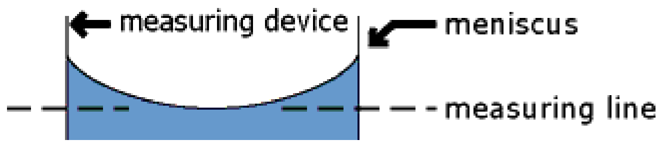
Thus, in this experiment we will use the volume determined from the mass of water to be the "true" or "actual" value. The assumed volume from the measuring device will be the "observed" value.
The formula for the percent error is:

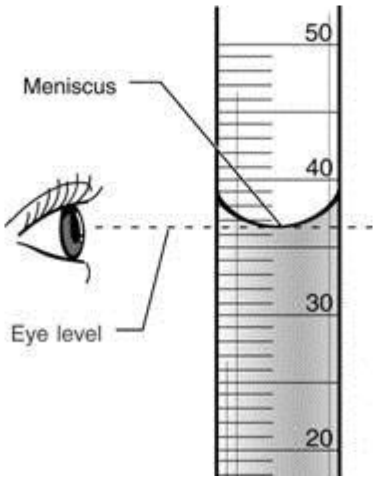
$$\%\ error = \left(\frac{observed\ value - \text{"true"}value}{\text{"true"}value}\right) * 100$$

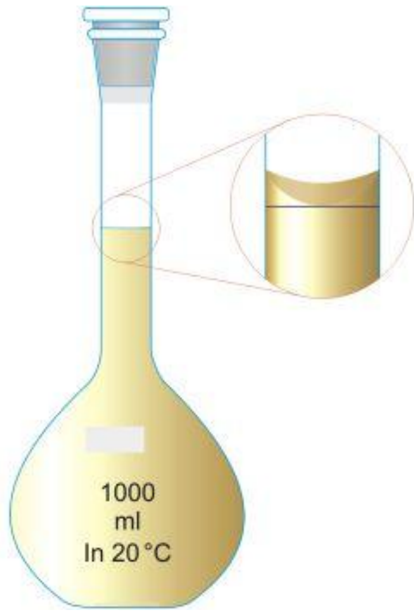
The smaller the percent error the more accurate the apparatus. In general a percent error that is less than 5% is considered to be good.

Reading volumes in graduated cylinders, volumetric flasks, pipets, and burets:

When water is measured in a narrow glass container the top of the water does not form a straight line. It forms a curved line called a **MENISCUS**. To read the volume correctly, adjust the apparatus so that the bottom of the meniscus is at eye level and record the volume at the bottom of the meniscus.







EXPERIMENTAL PROCEDURE AND CALCULATIONS

Density of Water at Room Temperature

1. Fill a large beaker with at least 150mL of distilled water. Use a thermometer to determine the temperature of the water. Record the temperature of the water on the Data Table with the correct number of significant digits.

2. Use the table below and interpolate to determine the density of water at the specific temperature measured in Step 1. Record your density on the Data Table.

The Density of Water at Different Temperatures:

Temperature in °C	Density in g/mL
20.00	0.99820
25.00	0.99704
30.00	0.99564
35.00	0.99403
40.00	0.99221

If the exact temperature measured is not on the table, then you must interpolate to determine the density.

a. Find the two temperatures that are just below (T_1) and just above (T_2) the temperature of your water sample

b. Find the density of water at these two temperatures, D_1 and D_2.

c. Determine the density of water at your observed temperature.

$$Density_{water\ sample} = D_1 + (T_{water\ sample} - T_1)(\frac{D_2 - D_1}{5})$$

d. Record your water temperature and calculated density on the Data Table.

Example:
Measured Temperature of the water = 37.70˚C
Temperatures just below and just above are: T_1 =35.00˚C and T_2 =40.00˚C
Densities at T_1 and T_2 are: D_1 = 0.99403 g/mL and D_2 = 0.99221 g/mL

$$Density_{37.7} = 0.99403 + (37.70 - 35.00)\left(\frac{0.99221 - 0.99403}{5}\right) = 0.993047 = 0.99305\ g/mL$$

Show your calculations:

Temperature	***Density***
22.00 ˚C	***0.99774***
23.00 ˚C	***0.99750***
24.00 ˚C	***0.99727***

Graduated cylinder

A. 10 mL TD graduated cylinder

a. Determine the precision of the 10mL TD graduated cylinder and record it on the table below.

b. Record the mass of an empty 50mL Erlenmeyer flask in the table below.

c. Measure 10.00mL of water into a 10mL TD graduated cylinder. Pour the water into the pre-weighed flask.

d. Record the mass of the flask + water on the table below.

e. Calculate the mass of the water by subtracting the mass of the empty flask from the mass of the flask + water. ($\text{mass}_{\text{water}} = \text{mass}_{\text{flask + water}} - \text{mass}_{\text{flask}}$)

f. Convert the mass of water to mL of water, using the density of water from Step 2 above. (mL of water = $\text{mass}_{\text{water}}$ / density of water)

g. Calculate the percent error for the 10mL TD graduated cylinder. Consider the observed value to be the mL reading on the cylinder and the "true" value to the mL value determined from the mass and density.

h. When you have completed all calculations, pour out the water to empty the flask.

Data for True Volume of 10mL TD graduated cylinder:

Precision: ±__*0.02* __mL

________________g mass of flask + water

________________g mass of empty flask

________________g mass of water / ____________ g/mL density of water

________________mL **true** volume of water *(transfer this value to the Data Table)*

Data for Observed Volume of 10mL TD graduated cylinder:

_____10.00_____mL **observed** volume of water

________________% percent error for the 10mL graduated cylinder *(transfer this value to the Data Table)*

Show your calculations:

Answers will vary – check that sig figs on % error are correct

B. 100 mL TD graduated cylinder

a. Determine the precision of the 100mL TD graduated cylinder and record it on the table below.

b. Record the mass of an empty 50mL Erlenmeyer flask in the table below.
DO NOT ASSUME that the flask has the same mass empty as before. There are likely small drops of water remaining in the flask from the previous step. That is OK. Reweigh the empty flask and record the new mass empty below.

c. Measure 10.0mL of water into a 100mL TD graduated cylinder. Pour the water into the pre-weighed flask.

d. Record the mass of the flask + water on the table below.

e. Calculate the mass of the water by subtracting the mass of the empty flask from the mass of the flask + water. ($\text{mass}_{\text{water}} = \text{mass}_{\text{flask + water}} - \text{mass}_{\text{flask}}$)

f. Convert the mass of water to mL of water, using the density of water from Step 2 above. (mL of water = $\text{mass}_{\text{water}}$ / density of water)

g. Calculate the percent error for the 100mL TD graduated cylinder. Consider the observed value to be the mL reading on the cylinder and the "true" value to the mL value determined from the mass and density.

h. When you have completed all calculations, pour out the water to empty the flask.

Data for True Volume of 100mL TD graduated cylinder:

Precision: ±__***0.1*** __mL

________________g mass of flask + water

________________g mass of empty flask

________________g mass of water / ____________ g/mL density of water

________________mL **true** volume of water *(transfer this value to the Data Table)*

Data for Observed Volume of 100mL TD graduated cylinder:

_____10.0______mL **observed** volume of water

________________% percent error for the 100mL graduated cylinder *(transfer this value to the Data Table)*

Show your calculations:

Answers will vary – check that sig figs on % error are correct

Beaker

C. 50 mL Beaker

a. Determine the precision of the 50mL beaker and record it on the table below.

b. Record the mass of an empty 50mL Erlenmeyer flask in the table below.
**DO NOT ASSUME that the flask has the same mass empty as before. There are likely small drops of water remaining in the flask from the previous step. That is OK. Reweigh the empty flask and record the new mass empty below.*

c. Measure 10mL of water in the 50mL beaker. Pour the water into the pre-weighed flask.

d. Record the mass of the flask + water on the table below.

e. Calculate the mass of the water by subtracting the mass of the empty flask from the mass of the flask + water. ($\text{mass}_{\text{water}} = \text{mass}_{\text{flask + water}} - \text{mass}_{\text{flask}}$)

f. Convert the mass of water to mL of water, using the density of water from Step 2 above. (mL of water = $\text{mass}_{\text{water}}$ / density of water)

g. Calculate the percent error for the 50mL beaker. Consider the observed value to be the mL reading on the beaker and the "true" value to the mL value determined from the mass and density.

h. When you have completed all calculations, pour out the water to empty the flask.

Data for True Volume of 50mL beaker:

Precision: ±__ ***1*** __mL

________________g mass of flask + water

________________g mass of empty flask

________________g mass of water / ____________ g/mL density of water

________________mL **true** volume of water *(transfer this value to the Data Table)*

Data for Observed Volume of 50mL beaker:

_____10._____mL **observed** volume of water

________________% percent error for the 50mL beaker *(transfer this value to the Data Table)*

Show your calculations:

Answers will vary – check that sig figs on % error are correct

Graduated Pipet

D. 10 mL TD graduated pipet

a. Determine the precision of the 10mL TD graduated pipet and record it on the table below.

b. Record the mass of an empty 50mL Erlenmeyer flask in the table below.
**DO NOT ASSUME that the flask has the same mass empty as before. There are likely small drops of water remaining in the flask from the previous step. That is OK. Reweigh the empty flask and record the new mass empty below.*

c. Measure 10.00mL of water with a 10mL TD graduated pipet. Dispense the water into the pre-weighed flask.

d. Record the mass of the flask + water on the table below.

e. Calculate the mass of the water by subtracting the mass of the empty flask from the mass of the flask + water. ($\text{mass}_{\text{water}} = \text{mass}_{\text{flask + water}} - \text{mass}_{\text{flask}}$)

f. Convert the mass of water to mL of water, using the density of water from Step 2 above. (mL of water = $\text{mass}_{\text{water}}$ / density of water)

g. Calculate the percent error for the 10mL TD graduated pipet. Consider the observed value to be the mL reading on the cylinder and the "true" value to the mL value determined from the mass and density.

h. When you have completed all calculations, pour out the water to empty the flask.

Data for True Volume of 10mL TD graduated pipet:

Precision: ±__ ***0.01*** __mL

________________g mass of flask + water

________________g mass of empty flask

________________g mass of water / ____________ g/mL density of water

________________mL **true** volume of water *(transfer this value to the Data Table)*

Data for Observed Volume of 10mL TD graduated pipet:

_____10.00_____mL **observed** volume of water

________________% percent error for the 10mL graduated pipet *(transfer this value to the Data Table)*

Show your calculations:
Answers will vary – check that sig figs on % error are correct

Volumetric flask

E. To Contain volumetric flask (TC)

a. Record the precision of a 10mL volumetric flask by locating the printed value on the front of the flask.

b. Record the mass of the empty dry 10mL volumetric flask in the table below. The flask must be completely dry before weighing. Ask your instructor for acetone if you need to dry the volumetric flask.

c. Add exactly 10.00mL of water by filling to the mark on the neck of the flask.

d. Record the mass of the flask + water on the table below.

e. Calculate the mass of the water by subtracting the mass of the empty flask from the mass of the flask + water. ($\text{mass}_{\text{water}} = \text{mass}_{\text{flask + water}} - \text{mass}_{\text{cylinder}}$)

f. Convert the mass of water to mL of water, using the density of water from Step 2 above. (mL of water = $\text{mass}_{\text{water}}$ / density of water)

g. Calculate the percent error for the 10mL volumetric flask (TC). Consider the observed value to be the mL reading on the cylinder and the "true" value to the mL value determined from the mass and density.

h. DO NOT pour out the water in the volumetric flask.

Data for True Volume of 10mL TC volumetric flask:

Precision: ±__***0.02*** __mL

________________g mass of flask + water

________________g mass of empty flask

________________g mass of water / ____________ g/mL density of water

________________mL **true** volume of water *(transfer this value to the Data Table)*

Data for Observed Volume of 10mL TC volumetric flask:

_____10.00_____mL **observed** volume of water

________________% percent error for the 10mL volumetric flask *(transfer this value to the Data Table)*

Show your calculations:

Answers will vary – check that sig figs on % error are correct

F. To Deliver volumetric flask (TD)

a. Record the mass of an empty 50mL Erlenmeyer flask in the table below.
**DO NOT ASSUME that the flask has the same mass empty as before. There are likely small drops of water remaining in the flask from the previous step. That is OK. Reweigh the empty flask and record the new mass empty below.*

b. Pour the contents of the 10mL volumetric flask into the Erlenmeyer flask.

c. Record the mass of the flask + water on the table below.

d. Calculate the mass of the water by subtracting the mass of the empty flask from the mass of the flask + water. ($\text{mass}_{\text{water}} = \text{mass}_{\text{flask + water}} - \text{mass}_{\text{cylinder}}$)

e. Convert the mass of water to mL of water, using the density of water from Step 2 above. (mL of water = $\text{mass}_{\text{water}}$ / density of water)

f. Calculate the percent error for the 10mL volumetric flask (TD). Consider the observed value to be the mL reading on the cylinder and the "true" value to the mL value determined from the mass and density.

g. When you have completed all calculations, pour out the water to empty the flask.

Data for True Volume of 10mL TD volumetric flask:

_______________g mass of flask + water

_______________g mass of empty flask

_______________g mass of water / ___________ g/mL density of water

_______________mL **true** volume of water *(transfer this value to the Data Table)*

Data for Observed Volume of 10mL TD volumetric flask:

_____10.00_____mL **observed** volume of water

_______________% percent error for the 10mL TD volumetric flask *(transfer this value to the Data Table)*

Show your calculations:

Answers will vary – check that sig figs on % error are correct

Buret

G. 50 mL Buret (burette)

a. Set-up a 50mL buret with a ring stand and buret clamp.

b. Make sure the stopcock at the bottom of the buret is closed (perpendicular to the buret). Add approximately 15-20mL of distilled water to the buret using a 50mL graduated cylinder to avoid spilling.

c. Open the stopcock all the way (parallel to the buret) and allow the water to flow out into an empty beaker. Make sure that any bubbles trapped in the stopcock flow out of the tip of the buret. Close the stopcock when the water drops below the 50mL mark, but before it reaches the stopcock.

d. Repeat this rinsing process two more times.

e. Fill the buret with distilled water to above the zero mark. Open the stopcock slowly and adjust the volume to read exactly 0.00mL on the buret. Record this as "Volume Initial" in the 0-10 column.

f. Record the mass of an empty 50mL Erlenmeyer flask in the table below as "Grams Initial" in the 0-10 column.

g. Place the 50mL Erlenmeyer flask under the tip of the buret and dispense 10mL of water into the flask. Allow the water level in the buret to slowly fall from 0mL to 10mL. Close the stopcock when the water level reads as close to10.00mL on the buret as possible. Record the exact volume reading on the buret as "Volume Final" in the 0-10 column

h. Calculate observed mL added by subtracting the Volume Initial from Volume Final.
($mL_{observed}$ = $Volume_{final}$ – $Volume_{initial}$)

i. Record the mass of the flask + water on the table below as "Grams Final" in the 0-10 column.

j. Calculate the mass of the water delivered by subtracting the Grams Initial from Grams Final.
($mass_{water}$ = $Grams_{final}$ – $Grams_{initial}$)

k. Convert the mass of water to mL of water, using the density of water from Step 2 above.
(mL of water = $mass_{water}$ / density of water)

l. Calculate the percent error for the 0-10 portion of the 50mL buret. Consider the observed value to be the "mL observed" and the "true" value to the mL value determined from the mass and density.

m. Before adding the next portion of water to the flask, record the "Grams Final" from the 0-10 column as the "Grams Initial" in the 10-20 column. Also record the "Volume Final" from the 0-10 column as the "Volume Initial" in the 10-20 column.

n. Place the 50mL Erlenmeyer flask under the tip of the buret and dispense an additional 10mL portion of water into the flask. Repeat steps g - l for recording volume final, volume observed, weighing the flask, calculating mass of water delivered, converting to mL of water, and calculating the percent error.

o. Continue to add 10mL portions of water to flask following steps g – m, until a total of 50.00mL of water has been added to the flask

p. Calculate an average percent error by adding the percent errors for each portion of water together and dividing by five.

Data for True Volume of 50mL Buret:

mL Portion	(0-10)	(10-20)	(20-30)	(30-40)	(40-50)
volume final	↘	↘	↘	↘	
volume initial		↘	↘	↘	↘
mL observed					
grams final	↘	↘	↘	↘	
grams initial		↘	↘	↘	↘
grams delivered					
density of water					
true mL delivered					
percent error					
average percent error	*(transfer this value to the Data Table)*				

Show your calculations:

Answers will vary – check that sig figs on % error are correct

Temperature	*Density*
22.0 ˚C	*0.99774*
23.0 ˚C	*0.99750*
24.0 ˚C	*0.99727*

DATA TABLE

Observed temperature_______________ Density at observed temperature

Fill in the blanks in the table below using the **results from previous pages:**

	Apparatus	Precision	Observed mL	True mL	% error	Rank
A	10 mL grad.	± ***0.02***	10.00			
B	100 mL grad.	± ***0.1***	10.0			
C	50 mL beaker	± ***1***	10			
D	10 mL Pipet	± ***0.01***	10.00			
E	Volumetric flask (T.C.)	± ***0.02***	10.00			
F	Volumetric flask (T.D.)		10.00			
F	50 mL Buret	± ***0.01***	10.00			

mL, % error, and ranking will vary

QUESTIONS:

1. In the last column of the table above, rank each of the volume measuring apparatus from most accurate (1) to least accurate (7). ***Check that ranking matches % error***

2. Explain the difference between "to contain" and "to deliver" volume measuring apparatus.

   contain – measured value is used within the container
   deliver – measured value is dispensed into another container

3. For each of the following situations, determine which type of glassware would be most appropriate: 150mL beaker, 10mL graduated pipet, 50mL buret, 100mL volumetric flask, 100mL graduated cylinder. Each will be used only once.

   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 2g of $CuSO_4$ to make a total of 100.00mL of solution.
   100mL volumetric flask

   b. A lab calls for adding small amounts of a solution of hydrochloric acid to a solution of sodium hydroxide until a color change is detected. The amount of hydrochloric acid added must be recorded.
   50mL buret

   c. A lab calls for adding approximately 50mL of water to a solution.
   150mL beaker

   d. A lab calls for adding 50.0mL of water to a solution.
   100.0mL graduated cylinder

   e. A lab calls for delivering 10.00mL of a solution of NaCl to an Erlenmeyer flask.
   10mL graduated pipet

4. The diameter of a volumetric apparatus is related to its accuracy and precision.
   a. Which would give the least error - a small diameter or a large diameter? ___ ***small*** ____
   b. Explain your answer.

   Small diameter glassware has more divisions between printed values and the divisions are spread farther part, so they are easier to read with greater accuracy, less estimating

5. Given the data – 12.02, 12.03, and 12.01; true value = 18.634. Describe both the precision and accuracy of the data.

   The data is precise, the values are close to each other. The data is not accurate, the values are not close to the true value

6. A plastic company produced a 1 L measuring cup. Five students each filled the cup to the 1 L mark and measured the mass of water needed to reach the mark. Here are the masses they recorded:

978.6 g	977.2 g	981.3 g	980.2 g	977.7 g

a. Calculate the volume of water each student used to fill the cup up to the mark. The density of the water is 0.9973 g/mL at the temperature they were working. Show your work.

981.2	***979.8***	***984.0***	***982.9***	***980.3***

b. Calculate the average volume of water used to fill the cup to the mark. This could be considered the "true" volume of water needed to fill the cup to the mark. How does this compare with the "observed" volume of 1 L?

Average = 981.6mL
Compared to the "observed" should show a % error calculation

$$\frac{\mathbf{1000 - 981.6}}{\mathbf{981.6}} * \mathbf{100 = 1.87\%}$$

c. Calculate the deviation (difference) of each individual measured volume from the average volume. Are the deviations large or small? This is an indication of the precision of the measuring cup.

-0.4	***-1.8***	***2.4***	***1.3***	***-1.3***

The deviations are small, an average of 1.4mL, compared to the total volume of 1000mL
% error is only 0.14%

7. Use interpolation to determine the density of He (helium) at a temperature of 7.00 K.

Temperature (K)	Density (g/L)
5.00	11.75
10.0	4.956

$$\mathbf{11.75 + \frac{(7.00 - 5.00)(4.956 - 11.75)}{5}}$$

$$\mathbf{= 11.75 + (-2.72) = 9.03\ g/L}$$