MEASUREMENT IN THE LABORATORY

INTRODUCTION

Today's experiment will introduce you to some simple but important types of measurements commonly used by the chemist. You will measure lengths of objects, masses of objects, and volumes of both solid and liquid samples. Your purpose for performing these measurements is to learn to use the tools used in making these measurements and to learn how to recognize the significance of the digits you record in your measurements.

SIGNIFICANT FIGURES

If you were to measure the longest side of a dollar bill, you would probably find it to be a little bit more than 15.6 centimeters. The smallest graduations on the ruler are 0.1 cm (1 mm) apart, so your observation of length implies that you are sure that the bill length is between 15.6 and 15.7 centimeters. At this point you may be asking, "How do I express this little bit over 15.6 that I observed?" The answer is, "You mentally subdivide the smallest divisions on the ruler into tenths, and estimate how many of these are needed to give the length." In this case the dollar bill length is an estimated seven tenths of a division greater than the certain value of 15.6 centimeters. Adding the certain plus the estimated values of length together gives us a reading of 15.67 cm.

Let's look at this measurement, 15.67 cm, a little more closely. Assuming that every dollar bill is the same size, it is still possible that other people would report different values for this same measurement: 15.65 cm, 15.68 cm, or 15.66 cm. These measurements all differ in the last digit, in the "estimated" place. Instead of estimating the bill as being seven-tenths longer than 15.6 as you did, these students estimated it as being five-tenths, eight-tenths or six-tenths longer. All of the students are certain of the first three digits of the measurement. Only the estimated last digit varies. We say that the measured value 15.67 cm has four significant figures. Three are certain and one is estimated. Any additional digits added onto the end of this number would be insignificant. We're not even sure of the estimated "7" let alone any other digits to follow. When we see a measured number like 15.67 cm, we assume that the person making the measurement is doing it correctly; that is, that **all but the last digit are certain, and only the last digit is estimated.** With this in mind we can make some simple rules which will enable us to determine how many significant figures a measured quantity has. This will be important when we begin doing calculations involving these numbers.

Rule 1 All non-zero digits are significant. This makes sense since all non-zero digits are measured and all of our measured numbers are assumed to be measured correctly and therefore significant.

Examples 2.938 meters has 4 significant figures
624.82 liters has 5 significant figures

Rule 2 Zeros are significant only if they are measured. This too is sensible, but how can we tell whether or not a zero in a number is a measured one? If the zero falls between two non-zero digits, it must have been measured and is therefore significant.

Examples 206 calories has 3 significant figures
700.08 kilograms has 5 significant figures

Rule 3 If the zero comes after the decimal point and after some non-zero digits, it is significant. For instance, in the measurement 4.0 inches, the person making the measurement was able to estimate that the length of the object was not enough longer than 4 inches to be 4.1 inches. The zero is an estimate and therefore significant. Someone measured it.

Examples 16.30 grams has 4 significant figures
400.0 gallons has 4 significant figures

Rule 4 If the zero is the first digit in a number, it is not measured and is not significant. Its only role is to note the position of the decimal place.

Examples 0.0032 liters has 2 significant figures (the zeroes only tell us where the decimal point is).
0.0408 kilograms has 3 significant figures (the first two zeroes are not significant).

Zeroes which are the last digits in a number but which come before the decimal point may be significant. This depends on whether they are measured or not. For instance, 400 yards may have as many as three or as few as one significant figure depending on how accurately it is measured. One way to remove the uncertainty about whether such a zero is significant is to write the number containing it in scientific or exponential form, showing only those zeroes which are significant.

400 yards	4.00	$\times 10^2$ yards	(3 significant figures)
	4.0	$\times 10^2$ yards	(2 significant figures)
	4	$\times 10^2$ yards	(1 significant figure)

When in doubt about the meaning of a number like 400 yards, assume that all of the zeroes are ***not*** significant.

Examples

46.030 grams has 5 significant figures
6.000 millimeters has 4 significant figures
.0003040 milliliters has 4 significant figures
260 pounds has 2 significant figures

MATHEMATICAL OPERATIONS INVOLVING SIGNIFICANT FIGURES

During the semester, you will be measuring things for every experiment. For many of these experiments you will be performing calculations with your measurements. It is important to know how to do these calculations so that your results are as meaningful as possible. We can divide our calculations into two groups, addition-subtraction and multiplication-division. Each of these groups has a significant figure rule to govern its calculations. These rules are based on one simple premise - that no calculated result can be more accurately known than the measurements used in the calculation.

Addition-Subtraction

In adding and subtracting numbers we are not concerned with the total number of significant figures in a measurement or calculated answer. Rather, we are concerned with the number of decimal places a number has.

Rule: When adding or subtracting numbers, the number of decimal places in the answer can be no greater than the least number of decimal places present in a number being added or subtracted.

Examples

6.41	inches	
2.326	inches	
+19.1	inches	(least number of decimal places)
27.836	inches	round off to 27.8 inches (one decimal place)

16.3046	liters	
- 4	liters	(least number of decimal places)
12.3046	liters	round off to 12 liters (no decimal places)

Multiplication-Division

Multiplying and dividing measured numbers follow an even simpler rule. We are concerned only with the total number of significant figures, not the number of decimal places.

Rule: When multiplying or dividing numbers, the answer can have no more significant figures than the number being multiplied or divided which has the fewest significant figures.

Examples: (6.43 cm) X (19.61 cm) = 126 cm^2
3 s.f. 4 s.f. 3 s.f.

4 s.f. $\frac{.9849 \text{ grams}}{.0023 \text{ liters}}$ = 430 grams/liter 2 s.f.
2 s.f. (0 is not significant
(fewest) but is needed to hold the decimal point)

It may seem from these rules that we are changing the rules of arithmetic. For example, 4.1 + 2.638 = 6.738. We aren't worried about significant figures here. These are pure numbers. But 4.1 kg + 2.638 kg = 6.7 kg. We are concerned about significant figures only for measurements. Likewise, 2.634/1.8 = 1.4633333 just as the calculator says it does. But, 2.634 cm^2/1.8 cm = 1.5 cm.

We want our measurements to make sense. Reading your laboratory measuring devices correctly and applying these few simple significant figure rules will give your experimental results their greatest possible meaning. If you stick with it, you will soon be observing the rules unconsciously.

EXPERIMENTAL

For all parts of this experiment, write down and label all measured data and show all calculations. You do *not* need to do the parts of the experiment in numerical order.

1. On one of the lab tables you will find three graduated cylinders with some liquid in them. The cylinders have different sizes and are graduated differently.

   a. Choose one set of cylinders. Record the letter of the set. Record in your notebook the volume of liquid in each graduated cylinder. Be careful to read the volumes to the correct number of significant figures. *Remember, the measurement should contain all of the digits you are certain of plus one digit which you estimate.*

   b. What is the total volume of the liquid in these three cylinders?

   c. What is the difference in volume between the largest and smallest volumes of liquids?

   d. How many times larger than the smallest volume is the largest volume?

2. Using the analytical balances in the lab, measure the weights of two objects in your pockets or pocketbook. Add these weights together to get a total weight. (Do <u>not</u> use the balances until you have been instructed in their use by an instructor.)

3. On another lab table there are some small cylindrical metal blocks.

   a. Weigh one of these blocks on the analytical balance. Be sure to note the composition of the block. It is stamped on one of the flat sides of the cylinder.

   b. Using the rulers provided, measure the height and diameter of the block in centimeters. Find the volume of the block by using the volume formula for a cylinder, $V = \pi r^2 h$, where r is the radius of the circular face of the cylinder, h is the height of the cylinder and π is 3.1416.

   c. Remeasure the volume of the block by the "displacement of liquid" method. Take a 100 ml graduated cylinder and partially fill it with water. Record the volume of the liquid. Without spilling any liquid, *carefully* drop the metal block to the bottom of the graduated cylinder. Record the new volume of the liquid. The difference in liquid levels is the volume of the block in milliliters or cubic centimeters. Remove the metal block and dry it off thoroughly.

d. Calculate the density of the metal block using the mass and the two differently measured volumes. Compare the two values of density with the density for the substance given in the Handbook of Chemistry and Physics. Which value is closer to the book value?

Considering the possible errors in measurement, suggest some reasons why one of your experimental density values is more accurate.

4. On one of the lab tables are some large rectangular pieces of metal. Using information available in the CRC Handbook of Chemistry and Physics and some measurements that you must make, determine the thickness of the piece of metal.

Note: The metal rectangle is too large to fit into a graduated cylinder to determine its volume by displacement of water and too thin to measure with a ruler. You will have to find its volume another way.

The chemical identity of the metal will be given to you. Show calculations you used to calculate the thickness.

5. On one of the tables you will find thermometers. Using one of them, measure room temperature in the lab. Report your temperature with the correct number of significant figures.

Measurement In the Laboratory -- Report Form

Name ______________________________ Partner ______________________________

Part 1 - Volume of Water

DATA

a. Volume of water in 1000-mL cylinder __________ mL

Volume of water in 100-mL cylinder __________ mL

Volume of water in 10-mL cylinder __________ mL

CALCULATIONS *(Show your work completely and include units)*

b. Total volume

c. Mathematical difference in volume between the largest and smallest volumes

d. How many times larger than the smallest volume is the largest volume?

Part 2 - Mass

DATA

Mass of object 1 (_____________________) __________ g

Mass of object 2 (_____________________) __________ g

CALCULATION *(Show your work completely and include units)*

Total mass

Part 3 - Density

DATA

Metal used: __________

a. Mass of metal cylinder __________ g

FINDING VOLUME USING A RULER

b. Height of metal cylinder __________ cm

Diameter of metal cylinder __________ cm

FINDING VOLUME BY WATER DISPLACEMENT

c. Original volume of water __________ mL

Volume of water + metal __________ mL

CALCULATIONS *(Show work completely and include units)*

Volume (as determined in part b - for a cylinder, $V = \pi r^2 h$)

Volume (as determined in part c)

d. Density

1) using volume from ruler measurements

2) using volume from water displacement

ANALYSIS OF RESULTS

Accepted value of your metal's density (find online)__________ g/mL

Which measured value is closer to the accepted value?

Considering the possible errors in measurement, suggest some reasons why one of your experimental density values is more accurate.

Part 4 - Thickness of a metal

YOU decide how to do this, and determine what data is needed. Note that this sheet of metal is too thin for accurate ruler measurement. Organize your data appropriately. Show your calculations clearly and include units.

Metal used: __________

Part 5 – Temperature Room temperature __________ ^{o}C

Conclusion/Summary: Summarize the work that you did in today's measurement lab. Explain briefly the importance of significant figures and then comment on which measurements were difficult to record with one estimated digit and which were relatively easy.

MEASUREMENT IN THE LABORATORY
Pre-lab Assignment

1. Read this experiment carefully from start to finish.

2. Explain the educational purpose of today's measurement lab.

3. Complete each of these operations. Follow significant figure rules and give correct units where necessary.

A.
```
     4.9    mm
    19.29   mm
   800.02   mm
    10.959  mm
+   39      mm
```

B.
```
   30.26  L
-   6.905 L
```

C. (1.853 m)(7.03 m) =

D. $\frac{31.749\ g}{6.2\ mL}$ =