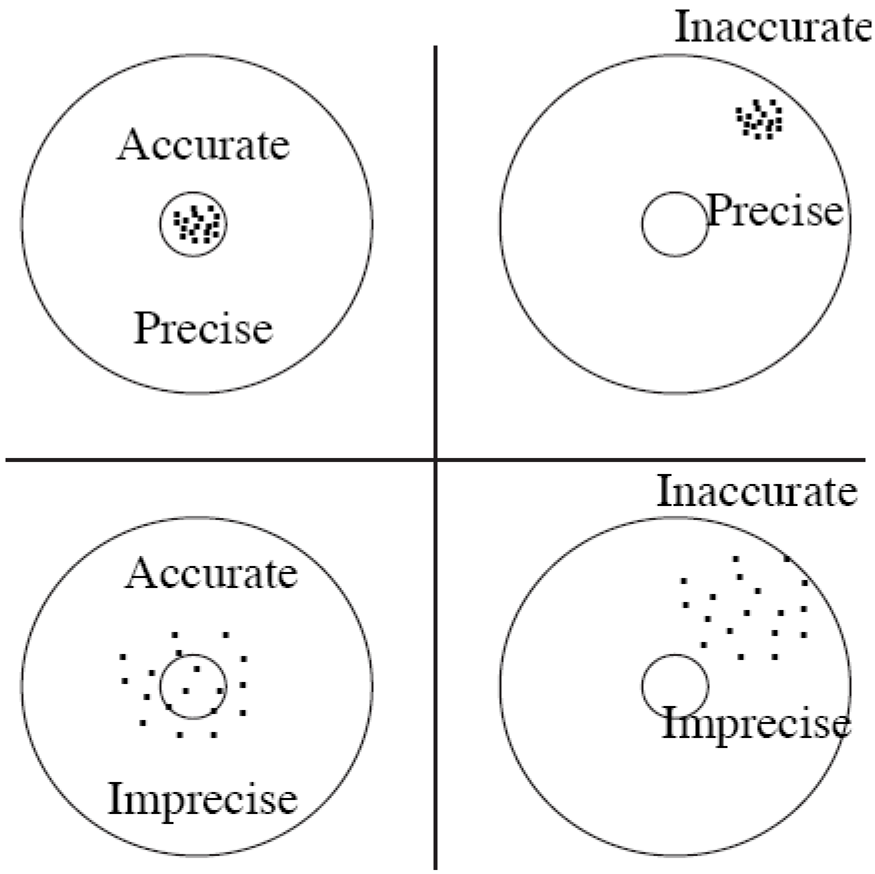
CHEM-01A

Measurements and Significant Figures

Introduction

Measurements are made with tools. The tool can be as simple as a ruler or as complex as the Hubble Space Telescope. It is typical that the finer the measurement required, the more expensive the tool becomes which must be used to make the measurement. For example, we have two types of electronic balances in this laboratory. One is a decigram balance, and the other is a milligram balance. The first is capable of measuring to the nearest 0.1 g, while the other will measure to the nearest 0.001 g. The first costs about $125, the other costs about $1000.

A general principal with regard to making measurements and recording the results is: ***Always record the measurement to the full capacity of the tool used. Never record the measurement with more than the capacity of the tool used.*** For example: If you were to weigh a penny on a decigram balance, you might see *2.4 g* on the display. If you used an electronic milligram balance, you might see something like *2.413 g* for that same penny appearing in the display window. If you see a display given to the nearest milligram, ***then record the mass to that level of accuracy.*** It might be that the display showed *2.400 g* in the display window. Then record 2.400 g on the data sheet. The manner in which the data is recorded indicates the accuracy of the tool used to make the measurement. If you record 2.4, it is assumed that the balance used can only give readings to the tenth place. If, in fact, you used a balance that shows 2.400 g, make sure you write 2.400 as the recorded mass.
(Note: It is a common beginning student error to only record the first few numbers appearing on the display, and then to fill in zeroes when the instructor reminds the class of the need to record to the nearest milligram. A series of measurements that all end in zero is highly unlikely, unless there has been student carelessness involved.)
Balances can give readings different from the true value if they lose their calibration. If the same object is weighed a series of times on a milligram balance, and a series of times on a decigram balance, the results could look like this: (each dot represents one of the weighings)



The top drawings are for the milligram balance. The right hand drawings would be for balances out of calibration. Be familiar with the way the words *accurate* and *precise* are used.

Significant Digits

When making a measurement, the last digit always involves some estimation. You will notice on the electronic balance that the last digit will sometimes flicker back and forth. There are rules for working with numbers obtained from measurements that take this estimation into account and preserve us from making foolish calculations. An example of such a calculation is that of the tour guide in Egypt who told visitors that one of the pyramids was 5006 years old. When asked how he knew that, he replied "When I first came to work 6 years ago, I was told that it was 5000 years old!" Of course, his error lies in adding an accurate 6 years to a roughly estimated 5000 years. Your textbook gives the rules for significant digits and many examples of their use. Here is a summary of the rules.

1. In numbers without zeroes, the rule for counting **significant digits (sd)** is simple: the number of significant digits equals the number of digits. So, 63.44 has four sd. 25,444 has five sd.

2. Zeroes in the midst of other digits are always significant. So, 6.023 has four sd.

   For numbers with decimals and preceding or trailing zeroes, counting sd's requires more care. Preceding, place-holding zeroes are not significant. So, 0.00345 has three sd (not 5 or 6). Writing such numbers using scientific notation makes this clear. 3.45×10^{-3} clearly has three sd. Trailing zeroes are always significant. So, 0.0034500 has five sd. This number would be written 3.4500×10^{-3} in scientific notation.

3. Zeroes at the end of a number without a decimal cause the most trouble. The number 1010 has 3 sd. If it is written with a decimal following the last zero, 1010., it has 4 sd. If the number 1000 is good to 3 sd, it will be written as 1000, or sometimes as 1000 ± 10. Remember, the reason a number is good to any amount of sd lies in the tool used to measure it.

4. When multiplying or dividing, the number with fewer significant digits determines the amount of significant digits in the result. So, 13.1 x 14.566 = 191. Your calculator will show 190.8146, and you would round it out to 3 sd. If you are performing consecutive calculations, don't round off until you reach the final number.

5. When adding or subtracting, line up the decimal points, and then, looking at each number from left to right, pick out the column with the number that has the shortest range of significant digits. That is, for the numbers 4340 and 5126, the first number's sd ends in the 10's column, the second number's sd ends in the 1's column. For these two numbers, the 10's column contains the final sd. Your answer cannot continue past the ten's column with significant digits.

$$\begin{array}{r} 4340 \\ \underline{+5126} \\ 9470 \end{array}$$

You see that the sum is rounded to the 10's column. Remember the Egyptian guide adding 5000 and 6. He should have points taken off of his grade for not rounding properly. Here is another example:

$$\begin{array}{l} 12.3402 \\ \underline{+6.22} \\ 18.56 \end{array}$$

Since the second number ends in the hundredth's column, the 02 ending of the first number is rounded off. Notice that this is considerably more complicated than multiplication or division. The answer has 4 sd, while the two numbers used had 6 and 3 sd. The rules of rounding should be followed consistently, and rounding should be done after a series of steps, not for each step. Some calculators can be set to follow the degree of accuracy of the measurements used. Consult your calculator's manual.

6. With logarithms, only the number of digits following the decimal count as significant digits. For example, log(5687) would be written 3.7549. The reason for this becomes evident if we show the number in scientific notation. Then, log(5.687 x 10^3) becomes 3.7549, where the 3 is derived from the exponent on ten.

Name ____ **Date** _________ **Grade** _______

(Show all your calculations in space provided)

Q1. The speed of light is 3.0×10^8 m/s. How many milliseconds does it take for a light signal from earth to reach and return from a satellite that is in orbit 30 miles above the earth? (1 millisecond = 10^{-3} seconds.

Q2. Isopropyl alcohol, commonly known as rubbing alcohol, boils at 180.°F. What is the boiling point in kelvins?

Q3. A rectangular wooden block, 22 cm x 13.2 cm x 4.4 cm, has a mass of 1562.0 g. What is the density of the wood in kg/m^3.

Q4. The density of magnesium is 1.7 g/cm^3, while that of iron is 7.9 g/cm^3. A block of iron has a mass of 819 g. What is the mass of a block of magnesium that has the same volume as the block of iron?

Q5. If a rectangle measures 4.00 inches by 5/6 inch, what is its area in square centimeters?

Q6. How many significant digits are in each of the following numbers?

45.8736 ___________ 0.00239 __________ 48,000 __________

93.00 __________ 3.982×10^{6} __________ 1.70×10^{-4} __________

0.00590 __________ 1.00040 __________ 4.00000 __________

3800 __________ 23000 ± 10 __________

Q7. Round each of the following numbers to 3 significant figures. Do not change their values (that is, if a number is in the thousands before rounding, it will be in the thousands after rounding).

1367 __________ 0.0037421 __________ 1.5587 __________

12.85 __________ 1.6683×10^{-4} __________ 1.632257 __________

Q8. Perform each of the following indicated operations and give the answer to the proper number of significant digits. Watch the order of operation when both addition/subtraction and multiplication/division are involved in the same problem. When adding or subtracting numbers written in scientific notation, it often helps to rewrite the numbers so each one has the same index (that is, power of ten). For example, to add 3.42×10^{-3} and 5.223×10^{-4}, first rewrite the second number as 0.5223×10^{-3}. Remember, if you make the number smaller, you make the power bigger, and vice versa. 0.5223 is smaller than 5.223, and 10^{-3} is bigger than 10^{-4}.

32.27 x 1.54 _____________

3.68/0.07925 _____________

1.750 x 0.0342 _____________

0.00957/2.9465 _____________

$(3.2650 \times 10^{24}) \times (4.85 \times 10^{3})$ _____________

7.56 + 0.153 _____________

8.2198 - 5.32 _____________

10.052 - 9.8742 _____________

$(6.75 \times 10^{-8}) + (5.43 \times 10^{-7})$ ______________

$0.01953 + (7.32 \times 10^{-3})$ ______________

$(8.52 + 4.1586) \times (18.73 + 153.2)$ ______________

$(8.52 \times 4.1586) + (18.73 \times 153.2)$ ____________

$(8.32 \times 10^{-3})^{1/2}$ _____________

$(3.84 \times 10^{-2})^{3}$ ______________

$(0.000738 - 8.3 \times 10^{-5}) / (6.298 \times 10^{-8})$ _____________

$\log(22.6)$ ______________

$\ln(12.55)$ ______________