The Chemistry Diaries

A Student Reference Book

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Chapter 1: Math & Measurement Diary

Quantitative vs. Qualitative Measurement

Measuring in chemistry is necessary part of the scientific method. Tools such as thermometers, electronic balances, rulers, etc. allow scientists to make quantitative measurements. Quantitative data deals with numbers and data that can be measured. Examples of quantitative measurements are length, height, area, volume, weight, speed, time and temperature. Quantitative measurements always have units associated with them. Without units the numbers have no meaning. Both numbers and proper units are necessary. Examples include 197 pounds, 23.45 grams, 10.0 mL, 13.546 g/cm^3 and 6.02 x 10^{23} molecules.

A qualitative and observed data. No numbers or units are required. Colors, textures, smells, tastes, appearance, beauty, etc. are all examples of qualitative data.

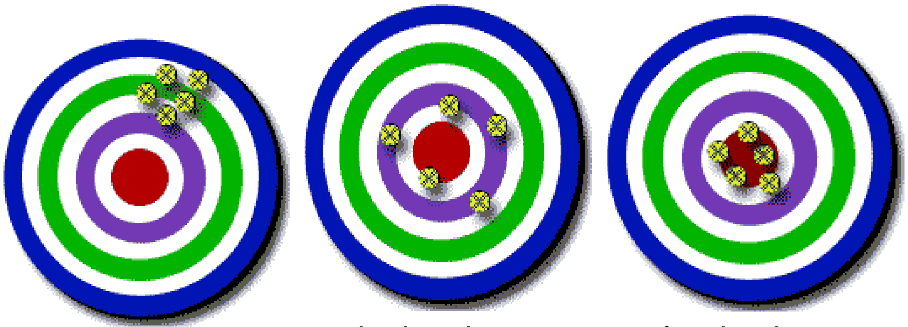
There are special devices that in fact can measure the quality of color in solutions, and give it a quantifiable number with units, but we won't use them in this course.

Precise and Accurate Measurements

When we measure in chemistry, we hope to make perfect measurements. That means we do our best, using our instruments correctly, to get measurements that are close to true, so we can prove to ourselves that the chemistry works the same in the lab as we'd expect from figuring out chemical reactions on paper.
The better our measuring, the closer our experiments will match our paper & pen expectations.

When you make a measurement that is in fact very close or perfectly correct, that measurement is said to be accurate. An accurate measurement is the same as the ACTUAL VALUE. This is what we strive for.

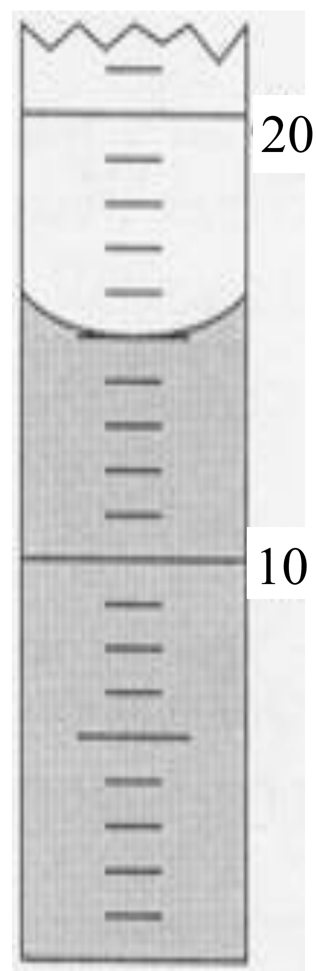
If we can repeat our measurements and always get the same (or very close to the same) results, these measurements considered to be precise. Precise measurements do not have to be precise and accurate (like the middle yellow circle below). If you get repeated measurements that are all the same, but all slightly wrong, it



might be that your tool is broken. You're doing it right, but you can't get to an accurate measure. In chemistry we'd hope to be accurate and precise (every time we measure we get very close to the actual value). This drawing represents darts shot at a target. At left the darts are all together but not near the center (precise but not accurate). In the center we have high accuracy and low precision. At right the darts are all very close to perfect (precise and accurate — the best way to measure in chemistry).

When we're not paying close attention to our work, we might find our measurements to be all over the place, not accurate or precise. When this happens, especially in lab, review your procedure and repeat from the beginning to find your errors. If that does not solve the problem then ask your teacher to help you figure out why you're having problems like this.

Significant Figures



When we make measurements in chemistry, or use formulas to convert measurements, our calculators will "do the math" for us. It is very important to understand the significance of significant figures, they "keep you honest" in your measuring.

When you measure something, such as how many milliliters of water are in a graduated cylinder, you can see the lines and make a measurement. We read the bottom of the meniscus. This cylinder close up at right shows us that the tube contains 15 mL of water. Each line represents 1 mL. But what if the meniscus was between the 15 and 16 mL line. We could estimate the volume to be 15.5 mL. We have the ability to estimate one place past the value that our equipment measures to. This gives us a more accurate reading. If you were to try to estimate past that number, however, you would be wrong. You can not see to the thousandth of a mL with your eyes! The measurements made in the chemistry lab require scientists to measure to the best capabilities of the equipment and observable information. A scientist measures properly in order to keep measurements as accurate as possible. This is why significant figures are used. The rules of significant figures are as follows: All digits 1 to 9 are always significant. All zeros between significant figures are also significant. Zeros on the right end of a number, after a decimal point are also significant (25.0 mm for example). Zeros at the right end of a number, before a decimal point are also significant (100. meter dash). Zeros at the right end of a number without a decimal point are NOT significant (100 yard swim).

When manipulating measurements in formulas, using multiplication and division, the answer must have the same number of significant figures as the least number of significant figures in the problem.

Example:

3.67mm x 2.0mm = a two digit answer. 3.67 x 2.0 = 7.34, but
3.67mm x 2.0mm = 7.3 mm^2.

Your answer cannot be "more accurate" or have more significant figures than your least accurate measurement.

When adding or subtracting, perform the operation as usual, but restrict your result by rounding to the smallest number of *digits past the decimal* in any term. When measurements are added or subtracted, the answer can contain no more decimal places than the least accurate measurement.

Example:

150.0 g H_2O (using significant figures)
+ 0.507 g salt
150.5 g solution

The last part of significant figures is the easiest part (or hardest if you think too much). Sometimes we have what are called equivalent values, say 454 grams is equal to 1 pound, or 212°F = 100°C. When two or more values are known to be equal, you understand that they are perfectly equal. You could just as easily state that 454.00000000 grams is equal to 1.000000000000 pounds because they are equal exactly. Equalities have what are called UNLIMITED significant figures. You could add as many zeros after the decimal point as you want, to either or both sides of the equality, so they are going to be significant as you want them to be. When you use an equality in your conversion math, they do not limit your answer's significant figures in any way.

Scientific Notation

In chemistry we will talk a lot of atoms and molecules. Atoms are the smallest parts of an element (the limited number of pure substances that make up all matter, are listed on the Periodic Table of Elements). Molecules are the smallest parts of compounds, which are made up of 2 or more atoms that are chemically combined into new substances, with new properties, such as water or carbon dioxide. Molecules are bigger than atoms that make them up, but both are nearly unimaginably small. It takes so many of them to be measured. We talk about numbers of atoms and molecules larger than billions and billions. To express these huge numbers (or tiny ones) we use scientific notation.

10^2 means 10 x 10 = 100 10^3 means 10 x 10 x 10 = 1000

10^{23}
=10x10x10x10x10x10x10x10x10x10x10x10x10x10x10x10x10x10x10x10x10x 10x10 = 100,000,000,000,000,000,000,000 Numbers that big require exponents to become more easily written.

The number out front is called the coefficient, coefficient. It is followed by a power of ten. The significant figures rules apply to the coefficients only. we always make our coefficients between 1.00 and 9.99.

It is true that 1.00 x 10^9 is the same as 10 x 10^8, or 100 x 10^7, we will always adjust our exponents so
that our coefficients are one or more, but less than ten.

If you have one million atoms, you would write 1 x 10^6 atoms.

If you have 1 million, 3 hundred thousand atoms, it would be written as
1.3 x 10^6 atoms. That has 2 significant figures (the 1.3)

To multiply in scientific notation, say (2.0 x 10^5)(3.0 x 10^4) =
You multiply the coefficients, 2.0 x 3.0 = 6.0 (with two sig figs only in answer)
Then add the powers of ten (5 = 4 = 9)
The answer would be 6.0 x 10^9.

When doing Division using scientific notation, divide the coefficients, then subtract the powers of ten.
9.00 x 10^8 divided by 3.0 x 10^5 = 3.0 x 10^3.
Note that 9.00 has 3 sig figs and 3.0 has 2 sig figs, your answer must have two sig figs as well—the same as the least number of sig figs in your math problem.

Addition and subtraction rules take an additional get ready step, that is getting the getting the exponents to match. For example,

$$\begin{array}{r} 2.35 \times 10^7 \\ \underline{+1.34 \times 10^6} \end{array}$$

This can't be done until you match the exponents to either both being 7th or 6th power (both ways give the same answer). Then just work with the coefficients.

Change them to: or to this instead:

23.5×10^6 $\underline{+1.34 \times 10^6}$ 24.84×10^6 changes to **2.48×10^7** with 3 sig figs	2.35×10^7 $\underline{+0.134 \times 10^7}$ 2.484×10^7 changes to **2.48×10^7** with 3 sig figs

Subtracting powers of ten rules are the same as for addition, except you subtract the coefficients instead of adding them.

Temperature Scales

We live in America, we use the Fahrenheit scale of temperature almost everywhere but science class. We'll almost never use it in chemistry, except in comparison to what we more intuitively know. Centigrade is the same as Celsius. The third scale we'll learn is Kelvin, created by the famous chemist Lord Kelvin of England. It was created to define Absolute zero. Absolute zero is a theoretical temperature, im-measurable actually. It is the temperature so low that all atomic motion stops. Scientists have gotten close to, but cannot ever get to absolute zero
As shown in this chart, the three scales are related as follows…

	F	C	K
water boils	212	100	373
water freezes	32	0	273
absolute zero		-273	0

Water freezes at STANDARD TEMPERATURE. On table A of your reference tables this is pointed out.

To convert from centigrade to Kelvin, or vice versa, use this formula:

$$K = C + 273$$

That formula is also on your reference table, table T on the back page.

Since we use the metric system in science, you may need to, Celsius to Kelvin.

Example: What temperature in Kelvin is steam at 105°C?

K = °C + 273

K = 105°C + 273 = 378 Kelvin. Kelvin units are Kelvins, NOT DEGREES. No little circles indicating degrees as is the case for centigrade or Fahrenheit.

Dimensional Analysis

In science, or math, we can label different measurements using various units, however, they can all be referring to the exact same thing properly.

In school you call me Ms. Randall, sometimes Ms. R., but never Terri which is my first name. You don't call me Mom, but my own children do. I'm not Aunt Terri to you either, but many kids call me that correctly. I'm not Grandma Terri either, but someday I might be. I am a woman with many names, but I am still the same person.

I might be five feet ten inches tall. Or you might say 68 inches tall. Or you might measure my full height in meters, centimeters, millimeters, or even miles! Each number would be different and each would have a different unit too. All would be equal to each other (with units attached).

To convert from one unit to another mathematically is called unit conversion, or dimensional analysis. It's actually sort of fun, but requires you write every single unit or else you will make big mistakes in the math. With the units, you really can't make a mistake.

If you multiply any number by one, you get the same number.

12 x 1 is still 12
10000 x 1 is still 10000 etc.

But 1 can be written in many different ways.

$\frac{2}{2}$ Is the same thing as 1 $\frac{12 \text{ inches}}{1 \text{ foot}}$ Is the same thing as 1

$\frac{157}{157}$ Is the same thing as 1 $\frac{60 \text{ seconds}}{1 \text{ minute}}$ Is the same thing as 1

When we create a conversion fraction, with equivalent units in the numerator as in the denominator, we are essentially creating a new way to write "1".

Since these fractions are one, we can multiply by them and change units, but not the actual value. For example, how do you convert from inches to feet? How many feet is 5700 inches? Most students could figure this out, but there is an easy way to convert that many inches to feet, just convert using dimensional analysis.

5700 inches x 1 = 5700 inches

$\frac{\text{1 foot}}{\text{12 inches}}$ Is the same as one, so

$$5700 \text{ \cancel{inches}} \times \frac{1 \text{ foot}}{12 \text{ \cancel{inches}}} = \mathbf{475\ feet}$$

Cancel your inches in the numerator of your starting measurement with the inches in the denominator of your conversion factor, do the math and apply the remaining unit. Since the one foot over 12 inches are equal to each other, multiplying by this conversion factor is really like multiplying by one. You get a different number and unit, but you have not changed the length. This is dimensional analysis, or unit conversion math.

Now let's try this with Chemistry. Example: Convert 1.50 pounds to grams. Pounds in the numerator cancel pounds in the denominator of the conversion factor, do the math, keep the unit you need in your answer, check sig figs.

$$1.50 \text{ \cancel{pounds}} \times \frac{454 \text{ grams}}{1 \text{ \cancel{pound}}} = 681 \text{ grams}$$

To do this you need to know many conversion factors. Some of these you must know, some you should know. We'll practice many of them all year.

Sometimes multiple steps and multiple conversions are necessary to convert a value.

Example: An elephant weighs in at 6.5 tons. Convert to grams in scientific notation.

$$6.5 \text{ tons} \times \frac{2000 \text{ pounds}}{1 \text{ ton}} \times \frac{454 \text{ grams}}{1 \text{ pound}} = 5902000 \text{ grams}$$

$5902000 \text{ grams} = 5.9 \times 10^6 \text{ grams}$

6.5 tons has only 2 significant figures. Both conversion factors have numerators equal to their denominators, so they both have UNLIMITED significant figures. Your answer is limited to have just 2 sig figs. That is how to "round" in chemistry class. You can't be more accurate than two significant figures here.

Example: Convert 2.5 years into seconds.

$$2.5 \text{ years} \times \frac{365 \text{ days}}{1 \text{ year}} \times \frac{24 \text{ hours}}{1 \text{ day}} \times \frac{60 \text{ minutes}}{1 \text{ hour}} \times \frac{60 \text{ seconds}}{1 \text{ minute}} =$$

78840000 seconds

This time it takes four different conversion factors to convert all the way from years to seconds. It could take just one step, but you would need to know the number of seconds in one year, which is unlikely!

Since we're limited to 2 significant figures (from 2.5 years)
your answer is 78,000,000 seconds,
or written in scientific notation 7.8×10^7 seconds

Remember, all conversion factors have equal numerators and denominators, so they have UNLIMITED significant figures.
If you make a crazy error and put a conversion factor upside down, say

$\frac{1 \text{ day}}{24 \text{ hours}}$ That's still equal to one, but your units will NOT CANCEL, so your answer will be zany. You'll always get these problems correct if you write units neatly.

Sometimes to see if you're really thinking the Regents will test you in dimensional analysis using make believe units. The units are there to set up the math, to cancel each other out, and to get the proper answer, with proper significant figures . Don't sweat the strangeness of some problems. It's a math game, but an excellent tool to solving bigger chemistry problems, as we'll see.

Example:

1.0 pigs equal 1.6 dogs
2.2 dogs is equal to 0.95 cats
1.9 cats is equal to 3.1 birds
1.0 bird is the same as 11.0 spiders
and finally, 3.7 spiders is the same as 8.5 bugs

If this is true, how many bugs make up 1.0 pig?
Convert one pig into bugs this way:

$$1.0\ \cancel{\text{pig}} \times \frac{1.6\ \cancel{\text{dog}}}{1.0\ \cancel{\text{pig}}} \times \frac{0.95\ \cancel{\text{cat}}}{2.2\ \cancel{\text{dogs}}} \times \frac{3.1\ \cancel{\text{birds}}}{1.9\ \cancel{\text{cats}}} \times \frac{11.0\ \cancel{\text{spiders}}}{1.0\ \cancel{\text{birds}}} \times \frac{8.5\ \text{bugs}}{3.7\ \cancel{\text{spiders}}} =$$

Do the math, cancel all units in order, make sure you watch out for significant figures (you're limited to the 2 significant figures in 1.0 pigs from the question. All other significant figures in the conversion factors are unlimited.)

So, $$\frac{1.0 \times 1.6 \times 0.95 \times 3.1 \times 11.0 \times 8.5}{1 \times 1.0 \times 2.2 \times 1.9 \times 1.0 \times 3.7} = \frac{440.572}{15.466} = 28.48648649 \text{ bugs}$$

Finally by checking significant figures, 28.48648649 bugs really means 28 bugs which has two significant figures. A wacky problem, but is shows a proper dimensional analysis set up, proper use of units, proper cancelling of units, and proper significant figures. If you can follow this, chemistry dimensional analysis will be a cinch!

Density

Density is the relationship between the mass and the volume of matter.
The formula is…

$$\text{Density} = \frac{\text{mass}}{\text{volume}}$$

Which is often abbreviated to...

$$D = \frac{m}{v}$$

Mass and volume have a specific mathematical relationship. As the mass of your matter increases, the volume increases within a set proportion. Because this is true, no matter how much mass you have, your proportional volume will work out in the formula to be a CONSTANT. Therefore, for any specific kind of matter, density is constant.

That means that no matter how much water you have, the density will always work out to be 1.00 g/mL.

- If *you have 57 grams of water it will have 57 mL volume, density = 1.00 g/mL*
- *If you have 9,825 grams water, it's volume is 9,825 mL, density = 1.00 g/mL*
- *If you have 0.000356 g water, the volume is 0.000356 mL, density is the same.*

Units for density are either grams/milliliter (g/mL) or grams/centimeter cubed (g/cm^3). Since these volumes, 1 mL is the same as 1 cm^3, we can interchange them whenever we want (which helps with some formulas).

You will be required to use the formula above to solve for density, mass or volume.

1. Your mass is 89.00 grams and your volume is exactly 10.00 cm3.
   What element could it be? Using the formula,

$$D = \frac{m}{v} \qquad D = \frac{89.00\text{g}}{10.00\ \text{cm}^3} \qquad D = 8.900\text{g/ cm}^3$$

Which is cobalt

2. Your piece of cobalt has a volume of 25.00 cm^3. What is its mass?

$$D = \frac{\text{mass}}{\text{volume}} \qquad 8.900 \text{ g/cm3} = \frac{m}{25.00 \text{ cm}^3}$$

Solve for "m" by multiplication, 8.900 x 25.00 (cm^3 both cancel) = 222.5 grams

3. Another piece of cobalt has an irregular shape too big for a graduated cylinder. It has a mass of 983.4 grams. What is its volume?

$$D = \frac{\text{mass}}{\text{volume}} \qquad 8.900 = \frac{983.4}{x}$$

Do the algebra to solve for "x" volume -cross multiply, (8.900 x) = 983.4

Solving for x, x = 110.494382 which becomes 110.5 with 4 SF, so, 110.5 cm^3 is the volume.

Density is a physical constant. Every element you will need to know about has the density listed in Table S. Water, when pure has a density of 1.00 g/mL. Ice, which of course is solid water has a density slightly less than that, therefore ice floats in water. Only rarely does a solid float in its own liquid phase.

When you have more than one liquid, the denser one goes to the bottom of a container, while the less dense one floats above, as with oil floating on vinegar, or gasoline floating on water. If there are multiple liquids, they will arrange into layers, most dense at the bottom, least on top. The image on the right is oil on vinegar. The picture on the left are five different layers of solutions, all of different density. The most dense is the bottom red one, the clear in the middle is the 3rd densest, and the beige one atop is the least dense.