Measurement Diary

This section of chemistry is the basis of all the ways and rules to measuring, and the mathematics we'll need to do proper science. There will be more (for sure) but this is our starting point.
Everything in the diary notes is important. It is written and provided for you as a supplement to your notes, your labs, your Classwork, and, your reading of the textbook. Don't rely ONLY on the diary, or your teacher. Science is about seeking knowledge. This is another good source for you, but not the only source.

Basic Measurement

Measuring in chemistry is multifaceted. Measurements that use tools, such as thermometers, electronic balances, rulers, etc. will require you to make quantitative measurements. They have numbers with units. Quantitative measurements will be made in lab nearly all the time. Without units all you have are numbers. 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.

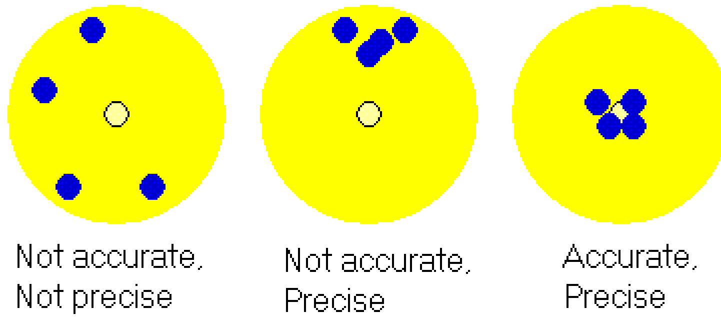
A qualitative measurement is one that uses descriptions only, no numbers or units are required. Such as the solutions here are blue and yellow. "How blue" or "how yellow" are not described by such qualitative measurements.

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. The chemistry always works properly, if we can be careful enough in lab we'll be able to show that to ourselves.

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 right, it is the same as the ACTUAL VALUE. This is what we strive for.

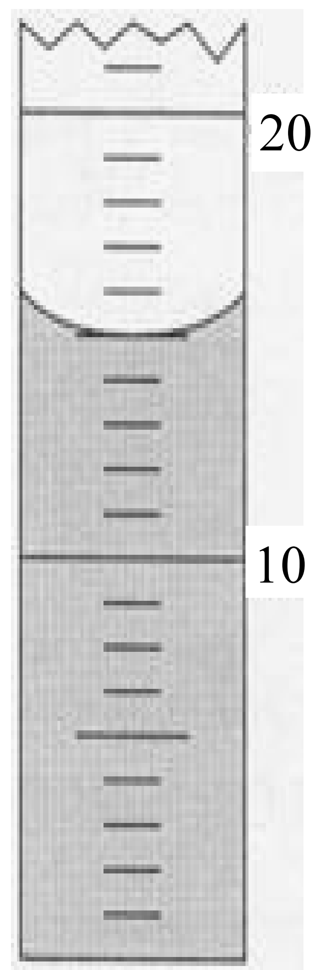
If we can repeat our measurements and always get the same (or very close to the same) results, these measurements are said to be precise. Precise measurements do not have to be precise and accurate (like the middle yellow circle below). If you get repeated measurements that are all the same, but all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



When we're not paying much attention we might find our measurements to be all over the place, not accurate or precise. When this happens, especially in lab, ask your teacher to help you figure out why you're having problems like this.

This drawing represents darts shot at a target. At left, the darts are random, not accurate (near center) nor each other (imprecise). Center the darts are all together but not near the center (precise but inaccurate). At right the darts are all very close to perfect (precise and accurate — the best way to measure in chem).

Significant Figures



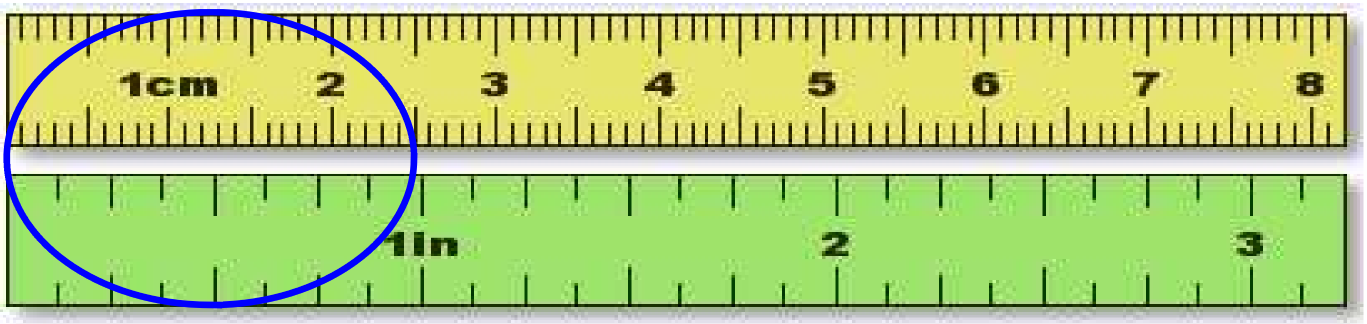
When we make measurements in chemistry, or use formulas do convert measurements as needed, our calculators will "do the math" for us. It is very important to understand the significance of significant figures, they "keep you honest" in your measuring.

When you measure something, say how many milliliters of water are in a graduated cylinder, you can see the lines and make a measurement. This cylinder close up at right shows us that the tube contains 15 mL of water. Each line represents 1 mL.

It turns out that the rules of measuring require a bit more energy on your part. You can see 15 mL, but you are required to estimate one more place to the best of your ability. This tube really shows 15.0 mL of water. You are going to have to estimate one place more than your tool shows you to get the most accurate measurement.

If you thought it was 15.00 mL that would be wrong. Your eyes can never "see" that accurately. 15.000 mL would be an even worse measure, because you just can't really see to the thousandth of a mL unit.

35 mL is too casual a measure, you must estimate out one place.
The measurements you make require you to measure to the best your tools and eyes can work, no more and no less. The number of units you measure to are called the significant figures. There are rules to significant figures (outlined in great detail on the handout called the Significance of Significant Figures on our website). Rules for measuring, and rules for mathematics as well. Once you



measure properly, you must keep your measurements as accurate as possible in the math you do to them, not gaining accuracy, nor giving away your accuracy.

In this close up of two rulers, top metric in millimeters and centimeters, the bottom in English, with eighth inches and inches. If we try to measure the blue oval, we could say it's about 1 inch long. Or we could measure it to be 2.5 cm, or 25.0 mm. The smaller the increment, the more accurate the measurement. If we look at the significant figures here, 1 inch, 2.5 cm, or 25.0 mm, the number of significant figures is one, two, and three. The more significant figures, the closer the measurement it to the actual value.

Quickly, 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 math, the one rule to follow is this: the answer must have the same number of significant figures as the least number of significant figures in the problem.
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.

If you measure a piece of metal to be 23.5 grams but it's really 23.1 grams, your percent error would be –1.73% even though your calculator can figure out your "answer" to be –1.731601732%. You are scientifically limited to three significant

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.

Lastly, and used rarely in chemistry, the idea of a normal hand having five fingers would have just one significant figures. But since we are not "measuring" that, we know that, and we know that all normal hands have five fingers, 5 fingers has unlimited significant figures as well.

A piano player, who is proficient, knows a piano has 88 keys. All pianos have 88 keys. If it's a piano it must have 88 keys. If something looks like a piano, sounds like a piano and plays like a piano, but has a different number of keys than 88, they it's not a piano.

So, for some of you, 88 keys on a piano is unlimited. (you could know it has 88.0, or 88.000000000000000 keys just as well) If you have to count the keys because you are a tuba player, or a non-musician, then 88 keys is a real quantitative measurement, 88 keys has 2 significant figures.

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, all 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 amount 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} is 10x10x10x10x10x10x10x10x10x10x10x10x10x10x10x10x10x10x10x10x10x10x10 =

100,000,000,000,000,000,000,000 which is a number I can't actually describe in English. Numbers that big require exponents to become more easily written.

There are rules to follow using these numbers. Usually we'll only use ten to a power. And we'll multiply a number in front of the ten, so 1000 would be written as 1×10^3. The number 66,500 would be 6.65×10^4.

The number out front is called the coefficient, coefficient to the power of ten. The significant figures rules apply to the coefficients only.

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

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

When doing math, the answers are limited to the lowest number of significant figures are the lowest number in the coefficients in the math problem.

To multiply in scientific notation, say $(2.0 \times 10^5)(3.0 \times 10^4)$ =
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 6.0×10^9.

Division makes you divide the coefficients, then subtract the powers of ten.
9.00×10^8 divided by $3.0 \times 10^5 = 3.0 \times 10^3$.
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 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:

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

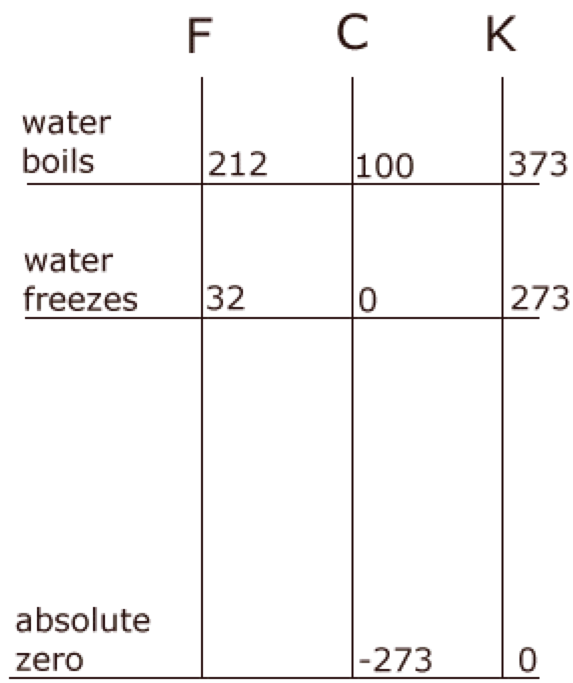
The last "rule" for us in chemistry is that we always make our coefficients between 1.00 and 9.99.

It is true that 1.00×10^9 is the same as 10×10^8, or 100×10^7, we will always adjust our exponents so that our coefficients are one or more, but less than ten. We'll call it the "teapot" rule, watch your teacher sing his little song about this!

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, but your teacher almost always will say centigrade. The third scale we'll learn is Kelvin, created by the famous chemist Lord Kelvin of England.

As shown in this chart, the three scales are related as follows…



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.

We will not need to convert to or from Fahrenheit temperatures in our class. If you need to, convert to centigrade then Kelvin.

Example: What temperature in Kelvin is steam at 105°C?
K = C + 273
K = 105 + 273 = 378 Kelvin. Kelvin units are Kelvins, NOT DEGREES. No little circles indicating degrees as is the case for centigrade or Fahrenheit.

Absolute zero is a theoretical temperature, immeasurable actually. It is the temperature so low that all atomic motion stops. Scientists have gotten close to, but cannot ever get to absolute zero, but it involves a lot of talk that is not part of our course, especially now.

Dimensional Analysis

I find sometimes students learn complex topics with funny examples. I like to say in school you call me Mr. Arbuiso, sometimes Mr. A, but never Charlie which is my first name. You don't call me Dad, but my own children do. I'm not Uncle Charlie to you either, but many kids call me that correctly. I'm not Grandpa Charlie either, but someday I might be. I am a man with many names, but I am still the same person.

In science, or math, you can label different measurements with different units, all different, but all measuring the exact same thing properly.

I might be five feet eight 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

$\frac{157}{157}$ Is the same thing as 1

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

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

When we create a sort of 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

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

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.

A bit more chemical now… 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.

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

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

Sometimes there are multiple steps, multiple conversions, to go from tons to grams for instance. There is a conversion factor of 1 ton = some number of grams, but I don't know it. I do know others, but it will take multiple steps to do the math.

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 grams = 5.9×10^{6} 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.

Last real problem, convert 2.5 years into seconds.

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

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!

Doing the math, watching for significant figures = 78840000 seconds

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. Paper is cheap, knowledge is valuable.

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 sig figs. 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.

Last problem:

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? (wow)
convert one pig into bugs this way:

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

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

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

But checking sig figs here, 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!

At left is a great book, which you should have read already. It's the only place I really know of where spiders and pigs come together in any real way.

Read lots of books, it's good for you.

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...

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

Because the mass and volume are in a particular relationship, it needs to be clear that the more mass of matter you have, the same proportion of volume increase is needed. Because this is true, no matter how much mass you have, your proportional volume will work out in the formula to a 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.

For any specific kind of matter, density is constant.

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?

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

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, or even water floating on mercury (neat to see even though mercury is dangerous to our health).

If there are multiple liquids, they will arrange into layers, most dense at the bottom, least on top. At right is oil on vinegar.

At left are five different layers of solutions, all of different density. Most dense is the bottom red one, clear in the middle is the 3rd densest, and the beige one atop is the least dense.

Very neat photograph, and real too!