Things You need to Know Before You Study Chemistry

What is Chemistry?

One definition might be that *Chemistry is the study of matter, the reactions and interactions of matter and the energy associated with those reactions and interactions*. This is a good working definition and will be used to define the direction that this text will take. However this definition is useless if you don't understand what it all means.

Let's break it down. The first word that most people don't understand (at least as well as they think they do) is **Matter**. In simplest terms, matter is stuff. That means that water, table salt, mud, orange peels, air, smoke and tennis rackets are all matter. More scientifically, matter is defined as anything that has **mass** and **volume**. Unfortunately that definition brings us two new ideas to define: having mass and having volume.

Mass is a measure of the amount of stuff in something. On earth, this is generally the same as weight. The more something weighs, the more mass it has. However, mass and weight are not exactly the same. Weight requires gravity—it is actually a measurement of the effect of gravity on something, which of course depends on the amount of mass. But even in space, things have mass. In addition, in chemistry you will study gases which don't seem to have any weight, yet are matter and do have mass.

A better test for whether something has mass is that you can feel mass when it hits you. This definition works in space, since a weightless hammer would still hurt if it hit you in the head. More importantly, the definition works for gases here on Earth. Just ask anyone who has ever been through a hurricane, felt the wind and seen destruction that moving air can cause.

This also means that anything which you can't feel hit you, doesn't have mass, and therefore isn't matter. Light, for instance is massless. This can be easily shown. Put on a blindfold and then have someone point a flashlight at your fingertips (the most sensitive part of the hand). Have them move the light beam on and off of your hand. You will not be able to feel when the light is there and when it is not. Thus, light does not have mass and is not matter.

The other half of the definition of matter is that it has volume. Having volume means that it takes up space. Again, gases tend to muddle people. If you walked into a house under construction, you might say that all of the rooms are empty, but of course they aren't—they're filled with air. You can easily prove that they are by, say, breathing. You can show that air takes up space simply by inflating a balloon. Even better, push an inverted cup under water. The inside of the cup will stay dry. This is because the air in the cup fills the space of the cup and will not allow the water into the cup.

Matter therefore is anything that you can feel when it hits you and that has takes up space.

Reactions and interactions are the things that happen all the time around you and inside of you. Salt dissolving in water, plants using sunlight to make food and oxygen, static electricity making your socks stick together in the dryer, and candles burning are all examples of reactions and interactions.

Interactions involve changes in the **physical properties** of matter. Physical properties are those that can be measured or experienced without altering the identity of the matter. Physical properties include size, volume, density, color, odor, taste, and texture. Physical properties also include things such as phase (solid, liquid or gas), particle size and ability to dissolve.

Physical properties can be observed, measured and even changed through **physical changes**. In other words, physical changes are those that alter the appearance of matter, but not the identity of matter. For example, melting ice and then boiling the water produced causes a change in the appearance of water, but both ice and steam are water. Dissolving salt in water is another physical change. The salt can still be tasted in the mixture created will still taste like salt and if the water evaporates the salt regains its original form.

Reactions involve changes in the **chemical properties** of matter. Chemical properties are those that can only be measured or experienced by altering the identity of matter. For instance, paper burns. This can only be seen by lighting the paper on fire, resulting in the loss of the paper and the creation of water, carbon dioxide and ash. Changes of this nature, those that demonstrate chemical properties, are called **chemical changes**.

Energy is defined as the ability to do work which is a really useful definition…in physics. In chemistry it is better to think of energy in terms of what it can do. Energy is something that can change matter, but isn't matter. Changing matter can be as simple as changing it's shape (think of molding clay), it's appearance (dissolving salt in water), or changing what it is (burning wood to produce carbon dioxide and water).

Energy comes in two flavors, Kinetic Energy and Potential Energy. **Kinetic Energy** is energy associated with motion. This form of energy is the reason that a speeding car can change the matter of a fence or tree if it leaves the road.

A special form of kinetic energy is called **heat**. This is kinetic energy when the things moving are too small to see. In other words when a baseball is thrown at a wall it has kinetic energy. After the baseball hits the wall, the invisible vibrations it created in the wall when it hit are heat.

Potential Energy is energy that is not associated with motion. It is common to think of potential energy as stored energy, but this is <u>not</u> a terrible helpful idea. In chemistry, it is better to think of Potential energy as energy associated with position. Imagine a cartoon character who has just run off the edge of cliff. They will certainly change their own matter and the matter of the ground when they fall, but in the cartoon moment before they realize that they are about to fall, they do not yet have kinetic energy because they are not yet falling.

Conservation of energy is the idea that energy is never lost. In other words, energy can be transferred from one thing to another or from one type to another but never goes away. When our cartoon character falls from the cliff he falls faster and faster (gaining kinetic energy) while getting closer and closer to the ground (losing potential energy). When he hits the ground and stops, the energy is still not lost (even though he cannot fall further and is no longer moving). At that point the energy is transferred to the ground as vibrations that spread out until they are so small that they can no longer be felt (heat).

The character has potential energy because they are attracted to the earth and they are not currently on it. These are the two pieces needed—an attractive **force** and a distance separating the attracted things—for potential energy. Thus anything that is in a position to fall has potential energy and the further it would need to fall to reach the earth, the more potential energy it has. In chemistry, the potential energy we focus on is not created by gravity, but rather by charge.

Charge is a property of matter that causes either an attractive of repulsive force between two things. We will discuss in much more detail what causes charge later, but for our purposes now, all you need to know about charge is that there are two types (called positive and negative) and that opposite charges attract, while similar charges repel. Thus, when something with a positive charge is separated from something with a negative charge they have potential energy.

A **force** is something that can cause matter to start moving, stop moving, speed up or slow down. In other words, if a force is applied to some piece of matter it will change the way it is moving or not moving.

The problem with this is that it seems to violate our common experience. We see moving objects slow down and stop all of the time without any apparent force applied. To make matters worse, there are lots of times that we know a force is being applied and yet objects don't start moving at all. To appreciate forces, and to understand how they work, we need to imagine an "ideal" world—that is a world where we can control *all* forces.

As a simple example, think about a puck on an air hockey table. This essentially eliminates friction, the force that slows things down as they slide along the floor or a table. Now, imagine the puck moving along the table. It glides, not speeding up, not slowing down and not changing direction until some force is applied, that is until something pushes it or pulls on it in some way. This could be when it bangs into the wall, when it gets hit by a paddle or even if you blow on it. Any of these things could stop the puck, change its direction, slow it down, speed it up, or some combination of these. What is important to recognize is that once the puck is moving, force no longer needs to be applied to keep it moving, but that to change the movement in any way (speed or direction) a force must be applied.

Now imagine that both you and your opponent are pushing on the puck at the same time. If you push in the same direction, the puck will move faster and faster in that direction. However, if you push in opposite directions, and if you both push equally hard, the puck will not move. In this instance we say that there are equal and opposite forces on the puck. Now, here's the weird part. If both of you were invisible, there would be no way for someone looking at the puck, seeing it not moving, to tell whether it was being pushed in opposite directions, or not being pushed at all.

The upshot of this is that when something is not moving, there are two possibilities. One, that there is no force acting on it at all, and two, that there are equal and opposite forces acting on it. In our very real world with friction, gravity, etc. the second is much more common.

The Metric System

The Metric system is the measurement system used by people in virtually every nation of the world except the United States. Even within the United States, scientists use the metric system almost exclusively and we will use it for all measurements in chemistry. That means you will not be measuring length in inches, mass in pounds, or volume in gallons or ounces. Since we will be using only the metric system it is not terribly important that you learn any conversions between metric units and their English counterparts, except to get a rough feeling for the size of the units.

The units:
The metric unit of mass is the **gram**. This is approximately the mass of a small paperclip or a newly minted dollar bill. The abbreviation for gram is **g**.

The metric unit of length is the **meter**. A meter is roughly the same distance as a yard. The abbreviation for meter is **m**. It is important that this be a lower case m, as capital M has a very different meaning in chemistry.

The metric unit of volume is the **liter**. This is, rather obviously, the amount of soda in a one liter soda bottle. The abbreviation for liter is **L**. Some texts (and people) use a lower case L, but when typed it is difficult, if not impossible, to distinguish between a lower case L and the numeral one so we will use a capital L exclusively in this text.

The metric unit of time is the **second**. This is exactly the same as a second in the English system. The abbreviation for second is **s**.

Temperature is measured in **degrees Celsius**. A degree on the Celsius scale is larger than a Fahrenheit degree. To begin to get a feel for the Celsius scale you should know the following relationships: $-40^oC = -40^oF$, $0^oC = 32^oF$ (the freezing point of water), $37^oC = 98.6^oF$ (normal body temperature), and $100^oC = 212^oF$ (the boiling point of water). A room is that is 23^oC is nicely comfortable, Any temperature below 0^oC makes a bitterly cold winter day and a 35^{o}C day is horribly hot. We will discuss another temperature scale later in the text.

There are other units for measurements such as energy, force, pressure, etc. Those that are relevant for this text will be addressed as needed.

The metric prefixes:
Since not everything weighs about the mass of a paper clip, we need to be able to describe masses (and for that matter, volumes, times, and lengths) that are much larger or smaller than the standard unit. The prefixes most commonly used in chemistry and their relationships to the base unit are shown below. There are, of course, lots of other prefixes, but in this text we will attempt to focus on what you need to know, not all information that might be considered related.

1 *Mega*unit	=	1,000,000 units
1 *kilo*unit	=	1000 units
100 *centi*units	=	1 unit
1000 *milli*units	=	1 unit
1,000,000 *micro*units	=	1 unit
1,000,000,000 *nano*units	=	1 unit

These prefixes can be used for any of the metric units described above. Thus, 37 kilometers is the same distance as 37,000 meters, and 4.89 liters is the same as 4,980,000 microliters, etc.

The Reliability of Numbers

The number 1 million can mean very different things in different contexts. For instance, if you met a friend who had been away and they told you they saw a lake with “like a million ducks,” and then told you that three more ducks landed on the lake, you would know that there probably weren’t 1,000,003 ducks on the lake but only a lot—“like a million”. By the same token, if someone told you that they counted 999,997 fruit flies over the summer and then found three more, you could be pretty sure that there really were a million fruit flies.

Someone who says “like a million” is telling you by their choice of words that the number is somewhat suspect. Someone who tells you that they counted a specific number of things is using their choice of words to state that the number is reliable. Numbers in science alos have varying levels of reliability.

In science, numbers are sometimes the result of counting, but more often, and almost exclusively in chemistry, the result of measurements. It is important to understand that no measurement is perfect and the reliability of the measurment depends on the device used to make the measurement. For instance, bathroom scales often measure to the nearest half pound. That is more than accurate enough to let you know how your diet is going, but would be a horrible way for a pharmaceutical company to determine how much medicine to put into a capsule. On the other hand, if you stood on the incredibly precise scales used by pharmaceutical companies your weight would destroy them. Generally speaking, the larger something is, the less precise the measurement device will be.

It is important to distinguish, at this point, between accuracy and precision. **Accuracy** is simply correctness. If you weigh 114 pounds and your bathroom scale says 114 pounds when you stand on it, then it is accurate. If it says 127 pounds when you stand on it, it is not accurate.

Precision can be defined in several ways. In the context of measurement, precision is how detailed the measurement is. If a small pebble is weighed twice on two different scales and one scale says that the weight is 1 gram and another says that the weight is 0.9937 grams the second is more precise, that is it gives us more detail. That does NOT mean that the first is not accurate. If that scale weighs only to the nearest gram, then 1 gram is the correct measurement, it just isn't as precise as the other.

An important thing to understand is that the last digit of any measurement is always an approximation or estimate. This is true even for an electrical device that has a digital diplay that gives you a reading. If you take your pencil and put it on an accurate electronic balance the mass might be 8.65 g. If you remove the pencil and then place it down again the value reported might be the same, but it also might be 8.64 or 8.66 g. This could be because you placed the pencil on a different part of the balance pan, because some dust fell, because there are oils on your hands that were transferred to the pencil, or for any number of other reasons. What that means is that the 8.6 portion of the measurement is quite dependable, but that the 5 is a little "iffy."

Precision, Reliability and Significant Figures

In the same way that speakers use word choice to indicate the reliability of their numbers, scientists show the precision of their measuring devices in the way they write numbers, and the key to the system is the decimal point. The further to the right a number ends (relative to the decimal point) the more precise the number is. That means that 2.367 g is more precise than 45887.1 g. The first number comes from a device that measures to the nearest 1000^{th} of a gram while the second number is only measured to the nearest 10^{th} of a gram, and is therefore less precise.

To determine how precise and reliable a number is you can do one of two things. (Actually, you need to be able to do both.) You need to be able to count decimal places and count significant figures. **Decimal places** are simply the number of digits to the right of the decimal point in a number. Thus 1.993 has three decimal places, 0.00004 has 5 decimal places and 387 has zero decimal places.

Significant figures are the digits in a number that report the reliability. It is this idea that makes 1,000,000 when described as “like a million” different from the number 1,000,000 when described as a counted quantity. Significant figures are trickier to count than decimal places, because they can be both before and/or after the decimal point and they depend on the decimal point and on the placement of non-zero numbers. You should understand that significant in this context does NOT mean important and non-significant does NOT mean unimportant. Significant means only that the digit in question is probably a reliable digit and not only a place holder.

The first and easiest rule is that any non-zero number is counted as significant. Thus the number 356 has three significant figures (sig figs), 24.996 has five sig figs and .33 has two.

Zeroes are more complicated. They are sometimes counted and sometimes not depending on their placement in the number. Zeroes that are between two non-zero numbers are always counted. Thus 307 has three sig figs, and 1.0042 has five sig figs. This is because estimates rarely, if ever include zeros anywhere but at the end. As an example, the news might tell you that 250,000 people attended a parade (an estimate with the zeros at the end). On the other hand if you attend a baseball game they might announce that 4,093 people attended the game. The zero here is reliable, because nobody would go to the trouble of counting the last 93 people if they were unsure whether it was 4000 or 4100 people before that last 93.

Zeros to the left of all non-zeroes are never counted. This is true whether or not there is a decimal point in the number and no matter where that decimal point may be. The number 0000234 (perhaps from the odometer of a car) has three sig figs, the number 0.45 has two, and the number 0.00000000000005 has only 1 sig fig. Again, this does NOT imply that the zeroes don’t matter, they are very important place holders, but that is their only purpose. The zeroes here are not part of the measurement. Another way to look at this is to imagine a measurement of 1 m. That distance is the same as 0.001 km. Neither of these measurements is more reliable (or less) than the other. Therefore the extra zeroes serve only to mark the place of the 1. They are not “significant.”

Lastly, zeroes to the right of all non-zero numbers count if, and only if, there is a decimal point in the number. The zeroes do not need to be after the decimal point or even near it. So the number 20.00 has four sig figs, the number 300. has three and the number 2.990 has four. This idea is how a scientist would distinguish between the counted fruit flies and the ducks mentioned before. “Like a million” would be written 1,000,000 (no decimal point and therefore only one sig fig) and the counted million would be written 1,000,000. (with a decimal point and therefore with seven sig figs).

Math with decimal places and significant figures

When we do math with measurements it is important to take into account how precise the numbers are. Simply put, the answer to a math problem cannot be more precise than the numbers in the math problem.

To help you see how the reliability and precision of numbers becomes important when doing math, consider the following. If one chemistry teacher has about a dozen students in a class and two other teachers also each have about a dozen, there are not necessarily 36 students total. Each teacher might have 10 students (about a dozen) and the total would therefore be only 30. Or each teacher might have 14 students (also about a dozen) in which case the total number would be 42 students. In this case 3 * 12 = somewhere between 30 and 42. By the same token and using an earlier example, “like a million” + 3 is probably not equal to 1,000,003.

As a result, there are two rules that we follow when doing math to take the precision of measurements into account.

Addition and Subtraction Problems
The rule for addition and subtraction is simple, although it makes a lousy English sentence. Count the number of decimal places in each number in the problem. The answer will have the same number of decimal places as the smallest number of decimal places in the problem. For example, 20.663 + 32.1 = 52.763 on your calculator, but the correct answer is 52.8 (this is 52.763 rounded to one decimal place). Two more examples: 30.1 + 0.00334 = 30.1 and 38 + 4.77 = 43.

Multiplication and Division Problems
The rule for multiplication and division is similar to that for addition and subtraction, but uses significant figures instead of decimal places. Specifically, you count the number of significant figures in each number in the original problem. The answer will have the same number of significant figures as the smallest number of significant figures in the problem.

For example, 20.663*32.1=663 (this is 663.2823 rounded to 3 significant figures). Two more examples: 30.1*0.00334552 = 0.101 and 38*4.771=180

These rules often produce answers that seem wrong, but they are the correct way to deal with measurements.

Keep in mind that when you need to “trim” a calculator answer down to follow these rules that if the digit after the last number being kept is 0-4 we do NOT change the number. If the digit following the last “kept” number is 5-9 we round up. In other words 3.642 rounded to the second decimal place is 3.64, while 3.647 rounded to the second decimal place is 3.65.

The Factor Label Method of Problem Solving
The factor label method of problem solving (also known as dimensional analysis) is the backbone of most chemistry calculations. This method can be used to do everything from converting 16.8 feet to meters to determining the mass of sodium sulfate needed to precipitate all of the barium from 120.0mL of 3.88 M solution of barium nitrate. (No, you aren’t supposed to have any idea what that means right now. I bring it up because I want you to be just scared enough to pay attention to this section, since it is, perhaps, the most important part of this chapter.)

There are several ideas behind the Factor Label method. The most important is that if you have an amount of something (say 18 g of table salt) and you want to change the unit (perhaps determine how many milligrams of table salt that is) you do NOT want to change the amount of salt. That means that the only thing you can multiply by (or divide by) is the number 1. Any other math will change the amount.

The next idea is that a fraction that has the same thing on the top and bottom is equal to 1. In other words, $\frac{3}{3}=1$, and $\frac{17.6}{17.6}=1$. Also, $\frac{house}{house}=1$, and $\frac{3.6\,dogs}{3.6\,dogs}=1$.

The last idea behind the Factor Label method is that things don't have to look the same to be the same. In other words 1 dozen donuts = 12 donuts, or 1 hundred cents = 1 dollar. That means that the fraction $\frac{1\,dozen\,donuts}{12\,donuts}=1$ and the fraction $\frac{100\,cents}{1\,dollar}=1$.

The last idea is that when the same thing (like a unit) appears on the top and bottom of an algebraic or mathematical equation it can be divided (or cancelled) out.

Now let's try to apply these ideas to the problem suggested above: How many milligrams of table salt are in 18 grams of table salt?

Step 1: Set up the problem with the given information on the left side and the unit that you need to find on the right.

$18\,g\ table\ salt \qquad\qquad\qquad mg\ table\ salt$

Now multiply by a fraction, putting the unit you are trying to cancel on the bottom (to cancel it out) and putting the unit you want to replace it with on the top.

$$18\,g\ table\ salt \times \frac{mg}{g} = \qquad mg\ table\ salt$$

Now place numbers in to the fraction so that the top and bottom of the fraction are equal (making the fraction equal to 1).

$$18\,g\ table\ salt \times \frac{1000\quad mg}{1\quad g} = \qquad mg\ table\ salt$$

Now do the math, multiplying by any number on the top of a fraction and dividing by any number on the bottom of a fraction. In this case the math is $18 \times 1000 \div 1 = 18\,000$ so the problem looks, in the end, like this:

$$18\,g\ table\ salt \times \frac{1000 \quad mg}{1 \quad g} = \ 18\,000\ mg\ table\ salt$$

This method of calculations can be used for virtually all conversions that have a linear relationship. (A notable exception is the conversion from Celsius to Farenheit which is linear but has an added factor.)

Let's look at a more complex example: How many kL are in 3.76 ML? Start by setting the problem up as before with the given information on the left and the desired form on the right:

$$3.76\,ML \qquad\qquad\qquad\qquad = \qquad kL$$

Now add in a fraction. Place the unit you want to get rid of on the bottom (so that it cancels):

$$3.76\,ML \times \frac{\qquad}{ML} \qquad\qquad\qquad = \qquad kL$$

The question now is what unit should be placed on the top of the fraction? It is certainly possible to determine the relationship between ML and kL, but it is not one of the basic metric relationships. In addition, determining this relationship separately give you another chance to make a mistake. Instead, convert first to the "basic" unit, in this case liters, and then covert to the unit you want:

$$3.76\,ML \times \frac{L}{ML} \times \frac{kL}{L} \quad = \qquad kL$$

Now fill in the numbers for each fraction that give it a numerical value of 1:

$$3.76\,ML \times \frac{1000\,000\,L}{1\ ML} \times \frac{1\ kL}{1000\ \ L} \quad = \qquad kL$$

Finally, do the math, multiplying by any number you find on the top and dividing by any number you find on the bottom: 3.76 x 1 000 000 ÷ 1000 = 3760 kL.

The method also works in cases where the units appear on the bottom as well as the top, as in density: A substance has a density of 2.87 g/mL. What is the density in Mg/L?

In this case you "fix" one unit and ignore the other, then ignore the first and "fix" the other:

$$2.87\ \ {}^{g}\!/_{mL} \times \frac{1\ Mg}{1000\,000\,g} \times \frac{1000\,mL}{1\,L} = 0.00287\ \ {}^{Mg}\!/_{L}$$

The first fraction above "fixes" the g (turning the g into Mg) while the second fraction "fixes" the mL (turning it into L).

We can use the method for units that have exponents as well: How many cm^2 are in 36.4 km^2?

Two things are crucial to understand here: a) The "^{2}" in the number 36.4 km^2 applies to the unit only—not the number, and b) the unit km^2 is really just km x km. As such it is just two normal units and can be treated that way.

$36.4\,km^2\ x\,\frac{1000\,m}{1\,km}\,x\,\frac{1000\,m}{1\,km}\,x\,\frac{100\,cm}{1\,m}\,x\,\frac{100\,cm}{1\,m}=3.64x10^{11}\,cm^2$ In this case, the first fraction "fixes" one of the kilometers (converting it to meters), the second fraction "fixes" the second km. Then each of the two meter units are converted to centimeters, one by one.

Of course this looks a little silly and it is certainly a little cumbersome. We can combine the like fractions as follows. Just remember that if the fraction is squared, then the numbers in the fraction are squared too, and the math must be done that way.

$$36.4\,km^2\ x\left(\frac{1000\,m}{1\,km}\right)^2\ x\left(\frac{100\,cm}{1\,m}\right)^2=3.64x10^{11}\,cm^2$$

This knowledge allows us to use the VERY useful idea that 1 cm^3 = 1 mL. This fact allows us to convert from cubic distance units into volume units as follows: How many liters of water will fit into a 3.0 m^3 box?

$3.0\,m^3\ x\left(\frac{100\,cm}{1\,m}\right)^3 x\,\frac{1\,mL}{1\,cm^3}\,x\,\frac{1\,L}{1000\,mL}=3.0\,x10^3\,L$ The math here is 3.0 x 100^3 ÷ 1000. If you forget to cube the 100, you get a very different (and very wrong) answer.

The factor label method of problem solving also allows us to solve problems that seem more like logic problems than math problems. For instance: If a picture is worth 1000 words and every word contains (on average) 4.6 letters, how many pictures are equal to 81 million letters?

We'll start the problem the same way: what we know on the left and what we want on the right:

$$81{,}000{,}000\,letters \qquad\qquad = \qquad pictures$$

Now fill in the fractions needed, one to convert letters to words and one to convert words to pictures:

$$81{,}000{,}000\, letters\ x \frac{word}{letters}\ x \frac{picture}{words} \quad = \quad pictures$$

Now, add in the numbers that make each fraction equal to 1 and do the math:

$$81{,}000{,}000\, letters\ x \frac{1\ word}{4.6\, letters}\ x \frac{1\ picture}{1000\, words} = 18{,}000\ pictures$$ (Note the use of significant figures here in the answer. Your calculator should have given you something like 17608.6956521.

At Last…

At this point, you should know what chemistry is, including having a decent understanding all of the words in the definition. You should know a little bit about matter, properties, energy and forces. You should be able to use significant figures in math problems and to use the factor label method to solve problems. All of which means that you are finally ready to begin to study chemistry.