Matter Basics

Chemistry is the study of matter. What it is, what is it made up of and how does matter react with other matter. Matter is the "stuff" that makes up the whole universe. It's the stuff that takes up space and has mass. Matter is measurable, and matter reacts in predictable ways that we will be learning about all year.

This topic has a fair amount of vocabulary words, words that will allow us to speak to each other properly all year. Please take the time to memorize the words and their definitions. Without a proper working vocabulary it will be hard to move on in our study. All new words are yours to remember.

The simplest forms of matter are the elements which are listed in the Periodic Table. Elements are the unique types of matter that cannot be broken down into simpler substances by any chemical or physical process. Examples include (the famous) mercury, iron, carbon, and uranium. The smallest bit of an element is called an atom.

We'll learn more about atoms and atomic structure in the next portion of our class, but you may already know that atoms are made up of neutrons, protons, and electrons. If you "split" an atom into those smaller parts you still have matter, but you no longer have an element, just sub-atomic particles.

Each element on the periodic table has unique properties that can be measured by us in class, or by scientists. Each element reacts in ways that are known, and which can be relied upon. We will learn later in the year how the atoms of certain elements can chemically combine, or bond, with other atoms to form new substances called compounds. The smallest part of every compound is called a molecule (or a formula unit in some cases). These new substances have their own measurable properties which are different from the properties of the atoms that make them up. Compounds can only be broken back down into elements by a chemical reaction, usually requiring energy as well.

Pure substances are types of matter made up of only one kind of matter. Examples include elements which are each made up of only one kind of atom. Another example are the compounds. Compounds are made up of a specific ratio of at least 2 different kinds of atoms. Examples include water (H_2O), or table sugar ($C_{12}H_{22}O_{11}$).

Pure substances are always the same throughout, which is called homogeneous. The properties of the elements are always the same in every sample, and within any one sample. All samples of pure water have the same density (for example), and all of the properties water has are the same for all samples of pure water.

Some of the properties of matter that we'll be measuring, and that you will need to be familiar with are density, boiling point, melting point, solubility, and particle size. A physical property of matter is a quality that can be changed, or measured, without changing the chemical properties of the matter itself.

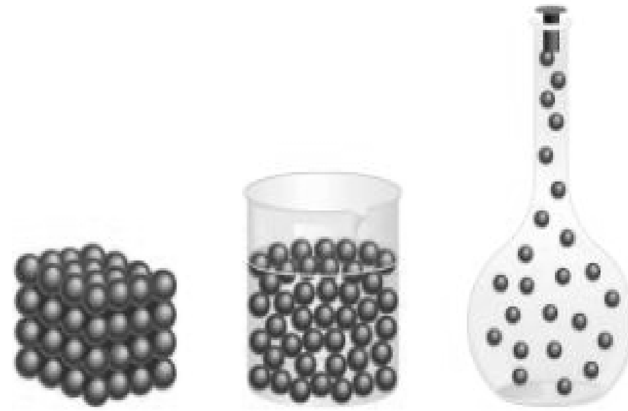
PURE Matter comes in 3 states, or phases: Solids, liquids and gases.

Solid matter has it's atoms (or molecules) packed in very close together. These particles are in a rigid arrangement that does not change. Because of this the solids are hard, and hold their shape and volume. Solids cannot be compressed practically at all because of the closeness of the particles.

Liquids also have their atoms (or molecules) packed close together, but they are not locked in place, rather they constantly move, or flow over each other. The closeness of the particles means that liquids have a definite volume. Liquids do not hold their own shape, they take the shape of any container they are put into. Liquids cannot be compressed because of how close the particles are to each other.

Gases are very different than either solids or liquids. Most different is the proximity of the atoms (or molecules). Gas particles are very far apart from each other, always moving very rapidly, bouncing around off of each other and the walls of any container that holds them. Gases have no definite shape and will expand to fill any size container they're put into. Gases have no definite volume either, they can be greatly compressed into small containers, there is plenty of room between the particles.

Here is a diagram of a solid, liquid, and a gas.
Each little ball represents a particle.



The atoms of a solid are very close together, and have a definite shape and volume.

The liquid has close packed particles - moving around, but take the shape of the container.

The gas has a lot of space between the particles, and fills any shape or sized container it's put into.

Matter that is dissolved into water has a 4th phase, which is called AQUEOUS. Solids, like salt, that dissolve into water are in the aqueous phase, written as $NaCl_{(AQ)}$ which is salt dissolved into water.

Aqueous solutions are homogenous mixtures of a substance in water (which is another substance). This is not a "pure" substance, it is a mixture. Homogeneous mixtures are mixed the same throughout.

Matter can be chemically combined into compounds, or just mixed together, into mixtures. A mixture is a physical blend of pure substances. Two or more elements can be mixed, two or more compounds can be mixed, or elements and compounds together can be mixed.
Mixtures have no definite ratio (no formulas) of the component parts like compounds have. Because of this mixtures are not always homogeneous. They can also be heterogeneous, or different throughout.

Mixtures are just stirred up, and the pure substances that make them up keep their properties. No new substances are formed, rather there is just a rearrangement of the atoms or particles. Compounds *are* new pure substances, with new properties.

Since these mixtures are just physical blends, they can be separated easily, by physical means (no chemical reactions required).

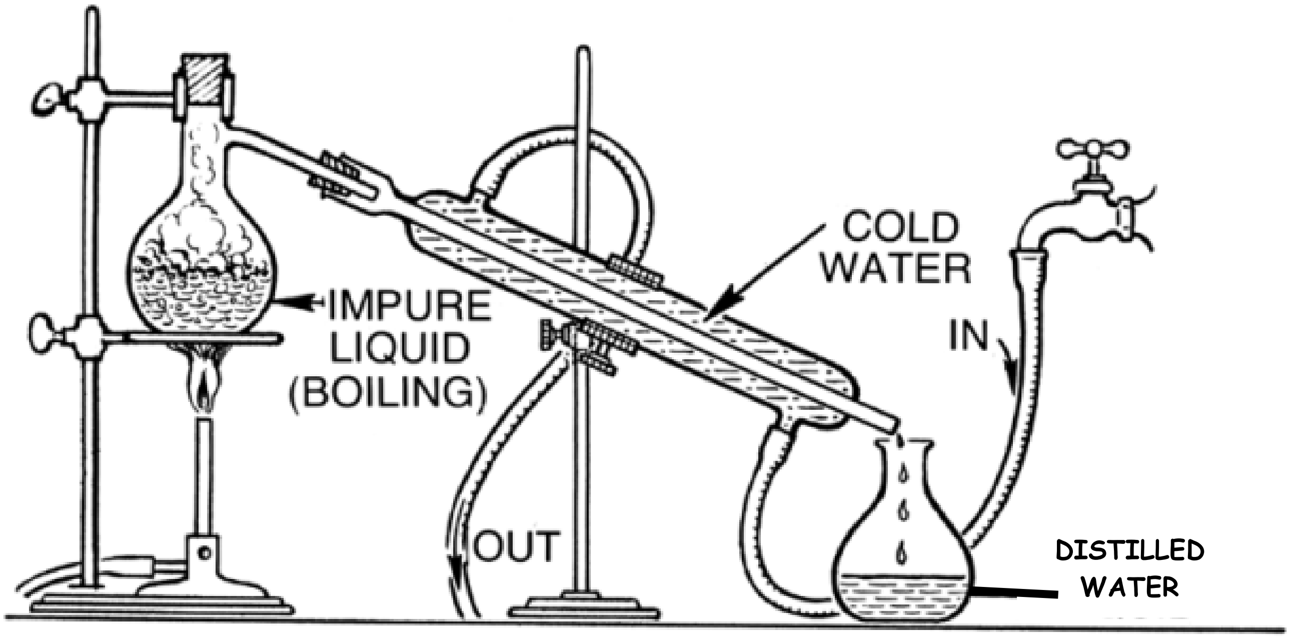
The processes used to separate these mixtures work because they take advantage of differences in certain physical properties of the parts of the mixture. Here are several examples…

Distillation

Distillation is used to separate a mixture called a solution (when a solute is dissolved into a solvent). If salt water is our solution, salt is the solute, water is the solvent. Since salt (sodium chloride) and water each have a different boiling point, 1465°C for the salt, just 100°C for the water.

Boiling salt water (impure liquid) causes the water change phase into steam (gas), which travels out the top into the tube towards the right. That tube is cooled with water, which causes the H_2O Gas to condense back into pure H_2O Liquid, which is captured in the round bottomed flask at right. The salt never reaches its own boiling point, it just gets warm, and it gets stuck in the distilling flask at left.

The mixture is separated by taking advantage of the differences in the boiling points of the parts of the mixture.



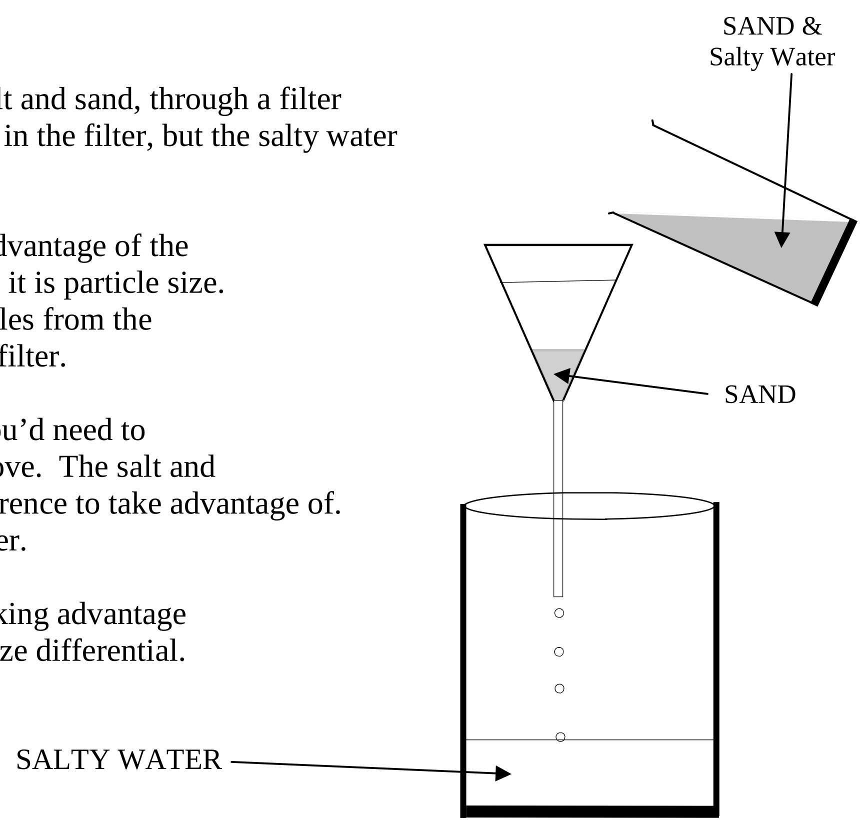
Filtration

If you pour beach water, containing salt and sand, through a filter as shown here, the sand will be caught in the filter, but the salty water will go right through.

To separate a mixture you must take advantage of the differences in physical properties, here it is particle size. The filter can separate the larger particles from the molecular sized ones that slip past the filter.

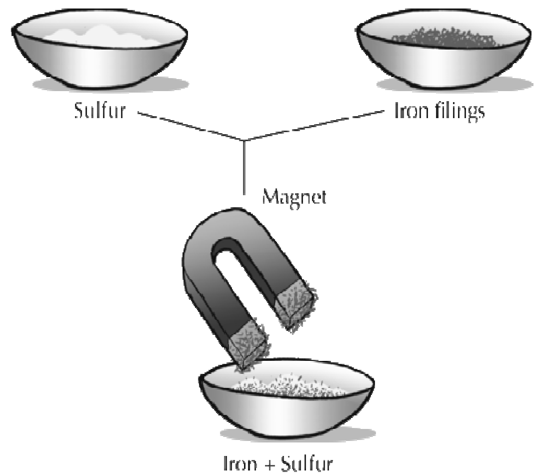
To get the salt apart from the water, you'd need to put it into the distillation apparatus above. The salt and the water has no real particle size difference to take advantage of. Filtering won't take the salt out of water.

Separating mixtures can be done by taking advantage of particle sizes only when there is a size differential.



Magnetism

If the mixture you have is iron filings and sulfur powder (or dirt) you couldn't run it through a filter, both the iron and the sulfur would be caught by the filter. You couldn't separate them with distillation either, they'd chemically react before one boiled away. You could use a magnet to separate out the iron. Iron is attracted to the magnet while the dirt is not. To separate a mixture requires you to take advantage of a difference in physical properties, in this case, if one is attracted to a magnet and the other part of the mixture is not.



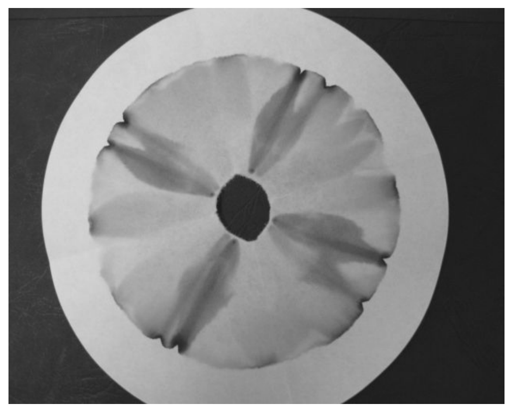
Paper Chromatography

We did this in class, taking advantage of the differences in both solubility and the density of the particles of color from our magic markers. We "think" our magic markers are one color, but they're made up of several different colors of particles, so close together, that they blur into one color to our eyes.

The water flowing through the filter paper dissolves some, and transports them color particles and takes them on a ride. The densest, or heaviest, drop out quickly, the lighter, or less dense travel further along on the paper.

Although this is "just colors", this is how paper chromatography works chemically as well. Our colors are really mixtures of colors, which we proved by our lab work.

Taking advantage of the different densities of the color particles allows us to separate this kind of mixture.



The most important thing to remember about separating mixtures is that since they are not chemically combined, you don't need to do "chemistry" to get them apart. They are physically blended, so you use physical means to take them apart. You need to find a difference in the physical properties of the substances that are mixed together, and take advantage of them to get them apart.

Mixtures do not have formulas, they do not have exact ratios of substances. Water has 2 hydrogen atoms bonded to one oxygen atom. An exact 2:1 ratio of atoms.
Some chocolate milk is very chocolatey, some is weaker. The mixture of chocolate and milk in not in an exact ratio.

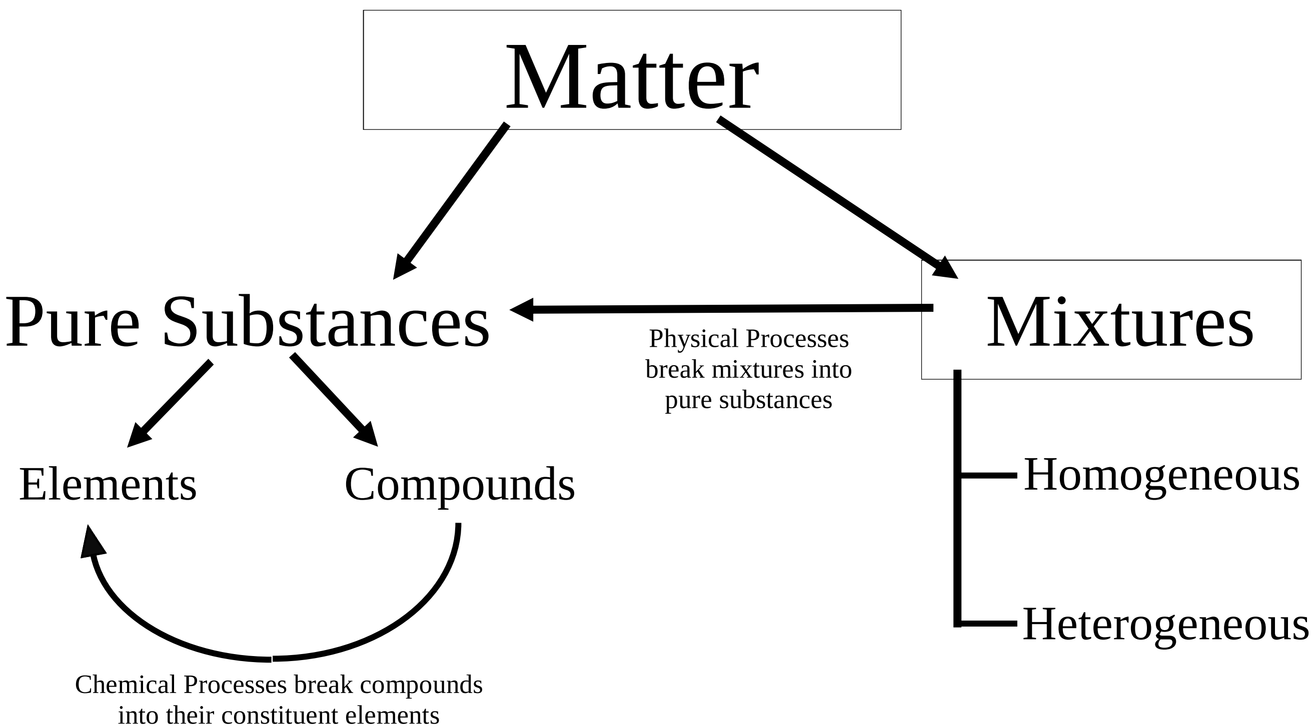
More about mixtures.

Solutions are mixtures where one part is dissolved into a liquid. The liquid part of this kind of mixture is called the solvent. The dissolved part is the solute. Water is a common solvent, although any liquid could be a solvent. With salty water, salt is the solute, dissolved in water which is the solvent. Solutions are homogeneous, which means they are the same throughout.

Not all solutes dissolve into all solvents. Solvents which do hold certain solutes have limits to how much solute they can hold as well. You can only put a certain amount of sugar in a cup of coffee before it falls out to the bottom of the cup. Solvents can become maxed out, or saturated. Adding more solute after the solvent is full up just drops the excess solute to the bottom of the container.

Gases can mix as well, creating gaseous mixtures. Air is a mix of nitrogen, oxygen and other gases. You could mix helium and carbon dioxide gases—if you had them in one container.

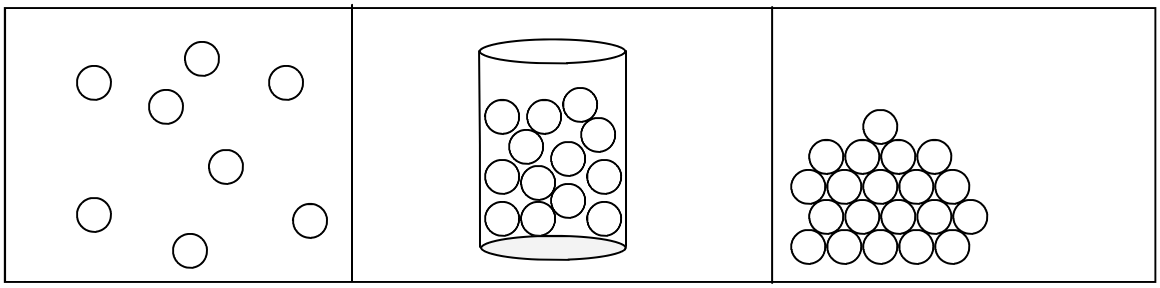
Solids can also be mixed together, but this usually requires you melt them so they can actually mix. Mixtures, or alloys of metals melted together include silver with some copper mixed is known as sterling silver. Copper and tin make bronze, while copper and zinc make brass. Carbon with iron is steel.



The study of matter will be our work all year. This chart, similar to the one we drew in our notes, shows the relationship between all the different kinds of matter. Make sure you understand these boxes and arrows, and that you could draw it from memory, with examples for each box.

Particle diagrams

Because our particles, our atoms and molecules, are much too small to see, there is a technique called particle diagramming that allows us to “cartoon” to create diagrams showing elements, compounds, and mixtures. Using different shapes, or colors, we’ll use pictures to express the relationships between atoms and molecules. These diagrams will also show solid, liquid, and gas phases.

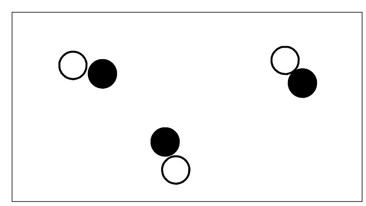


Above are little circles which represent one kind of particle. At left the particles are not touching, and all over the box. This represents gas particles, which do not have a definite volume or shape.

Center the particles all are close, and are contained by the bottom of a container, this is a liquid made up of the same kind of particles as the gas is.

At right, the exact kind of particles are stacked tightly, and have a definite shape. This represents a solid of the same kind of particles.

If the particles (little circles) were water molecules, at left is steam, in the middle is water, and at right is ice. If the particles are iron atoms, at left is very hot iron gas, center is melted iron, and at right is very metallic solid iron.

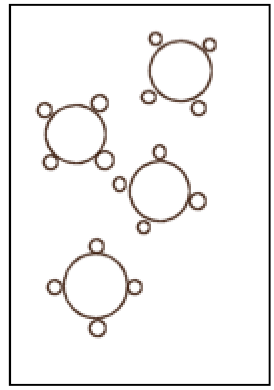


In this particle diagram we have a lot more going on. Each particle is made up of two kinds of atoms, black & white circles, which are touching. This means that the white circle is chemically bonded to a black circle. This represents 3 particles called molecules. If the white circles are oxygen, and the black are carbon, this shows a 1:1 ratio of carbon bonded to oxygen, which is called carbon monoxide (CO gas). Here are 3 molecules of $CO_{(G)}$. This is a pure substance, not a mixture.

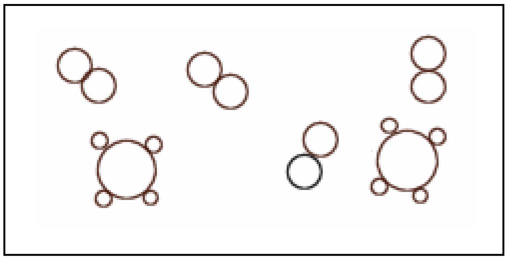
If you imagined the white circle to be sodium, and the black as chlorine, this could also represent 3 particles of sodium chloride which has a formula of NaCl and a 1:1 ratio as well. It would be unlikely that the NaCl would be a gas though, it has a terribly high boiling point.

If this diagram had a key to show you which atoms are represented by the shapes and colors, you could KNOW what it showed. Otherwise it could represent a variety of compounds.

In this next particle diagram we have a different situation. Here we have a big circle with four little circles attached to it. This could represent four molecules in a 1:4 ratio, for example, methane gas with a CH_4 chemical formula.
This particle diagram can't represent atoms, because different shapes are touching, therefore it must be a compound. All the molecules are the same, so it is a pure substance, not a mixture. The particles are not in any definite shape, rather they're floating around, so it's a gas as well. Methane in the gas phase is likely, while methane in the liquid or solid phase is not possible here.

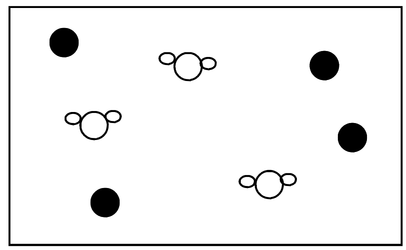


At left we have some more methane molecules mixed together with some other diatomic atoms. Diatomic means 2 of the same atoms, and we remember that seven of the elements on the Periodic Table usually are in twin, or pairs at normal temperatures.



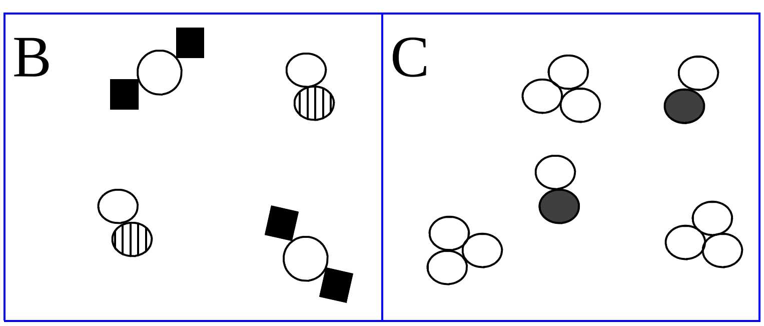
Maybe they're oxygen as O_2, or nitrogen as N_2, or even that beautiful purple iodine gas, as I_2.
Use your imagination. The 2 little touching circles could NOT be carbon dioxide, C + O are different atoms, they would have to be different colors or shapes. These are diatomic for sure!

At right our particle diagram shows one kind of an atom (black dots) mixed with one kind of compound (the triple circles). This could represent any one kind of atom, with carbon dioxide (CO_2) or maybe nitrogen dioxide (NO_2). Without a key it could be any atom and many different molecules. The diagram "represents" one kind of atom, and one kind of molecule in a 1:2 ratio.



Below is a challenge. What is represented in the "B" and "C" boxes?

Don't peek below until you try to figure this out!



"B" is two kinds of molecules, both in a 1:1 ratio, so this is a mixture.

"C" is one diatomic element, with one kind of molecule in a 1:1 ratio, so this is a mixture too.

Chemical Symbols

The symbols of the atoms of the periodic table of elements come from a variety of languages, and therefore do not always seem to match the common names of the elements. Hydrogen is H, helium is He, simple enough, but then sodium is Na, tin is Sn, and the famous mercury is Hg. Don't try to memorize these, use table S whenever you have any concerns.

The rules are easy. All element symbols are capitalized. If the symbol has more than one letter (many do) the second letter is never capitalized.

When compounds form, only certain ratios of atoms:atoms are possible. We'll learn later in the year how to figure that out, but for now we can still learn to count how many atoms are present in 1 molecule.

H_2O is water. The two indicates that there are 2 hydrogen atoms. The lack of a number next to the oxygen (O) means that only one atom of oxygen is present. So, H_2O has a total of three atoms.

NH_3 is ammonia. That's 1 nitrogen chemically bonded with 3 hydrogen atoms. Four total atoms here.

Methane gas is CH_4, which is 1 carbon, with 4 hydrogen atoms, for a total of five atoms.

$C_{12}H_{22}O_{11}$ is a much bigger molecule of sucrose (table sugar). A dozen carbons, twenty-two hydrogen atoms and eleven oxygen atoms for a total of 45 atoms!

$NH_4S_2O_3$ is ammonium thiosulfate. It's got one N, four H, two S, and three O atoms, for a total of 10.

Later in the year we'll learn all the naming rules, the ratio making rules, and the proper ways to deal with this. For now we want just to understand the subscript numbers and the elemental symbols.

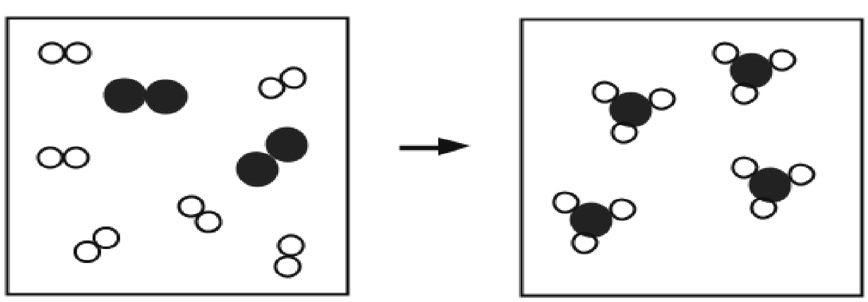
The Law of Conservation of Matter (or Mass)

Matter cannot be created or destroyed by any chemical reaction or physical change. Matter is conserved. A physical change is a phase change, like solids melting into liquid, or a gas condensing into a liquid.

If you start with 100 grams of reactants, you will end up with 100 grams of products. This is the law.

6 grams hydrogen react completely with 28 grams of nitrogen and form exactly 34 grams of ammonia. There can never be a loss of mass, or a gain of mass in a chemical reaction (or any physical change).

The cartoon shows 6molecules of H_2 and 2 molecules of N_2. They react and form 4 molecules of NH_3. Count the little ones, and the big ones. They are reorganized, but they are all there!



Chemical vs. Physical Changes

Physical changes are the result of a rearrangement of the atoms or molecules present, but not in the formation of new substances with new properties. They include changing the phase in any directions from S, L, G or AQ.

Chemical changes are the result of a rearrangement of atoms or molecules whereby new substances form, new properties form, and the original substances and their properties disappear. These are chemical reactions.

When methane gas reacts with oxygen, it releases much heat, carbon dioxide and water gas. The methane and oxygen are recombined into new molecules, they oxygen + methane "disappear" as pure substances, forming into the water & carbon dioxide. No loss of mass, but big changes have happened.

Some likely indicators that a chemical reaction has taken place (these are not always definite) are easily remembered with the acronym TOPIC-B.

T. Temperature changes. Often a chemical reaction will release energy or heat, or the opposite, will absorb energy, making the immediate environment cold. Heat release is an exothermic reaction, heat absorption is an endothermic reaction.

O. Odor release. New smells usually indicate something new has formed from the reactants at hand. Many kinds of matter have an odor, that's different from a new odor that was not present just previously.

P. Precipitates in solutions. Sometimes we mix solutions and form new compounds that cannot dissolve in the solvent. These compounds "fall out" of solutions as solids. Two clear solutions mix together, and a solid falls out is a good indicator that something chemical changed.

I. I stands for irreversibility, which needs some explaining. Just about every chemical reaction can be reversed, but to do so would require some chemistry knowledge and the input of energy. Once a reaction happens it will not spontaneously reverse itself. Chemical reactions tend to go one way and stay done. To reverse a chemical reaction is another chemical reaction.

C. For color changes. Matter is fairly stable, color is directly connected to the atoms or molecules present. A change in color often indicates a change in the particles.

B. Bubbles that were not there before also indicates that something has chemically changed. Opening up a warm can of soda means someone gets sprayed. Funny, but not a chemical reaction. Those bubbles were already present. New bubbles, like new odors, are different.

Physical vs. Chemical Changes

In a chemical change, there is a rearrangement of atoms or particles in a substance. This rearrangement includes the formation of new substances with their own new properties. Examples include all chemical reactions, with the TOPIC B indicators.

Physical changes also have a rearrangement of atoms or particles, but no new substances form, so all the original properties remain. Examples include all phase changes, bending of metals, shattering of crystals, ripping of paper, or stirring paint colors together.