Objective 3

The student will demonstrate an understanding of the structures and properties of matter.

My Notes

Through your studies in science, you should be able to demonstrate an understanding of the structures and properties of matter.

Remember!

Mass is the amount of matter in an object and is constant anywhere in the universe.

Volume is the amount of space that matter occupies.

What do we mean by "matter"?

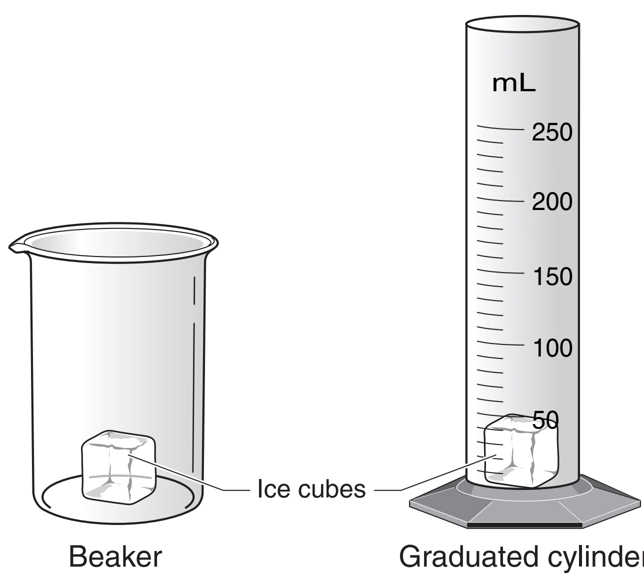
Matter is anything that has mass and takes up space (volume). Most of the matter in our everyday world is either solid, liquid, or gas. Solid, liquid, and gas are called states of matter.

Oh, you mean like ice, water, and water vapor?

Yes. Water is a solid (ice) at temperatures below 0°C. Water is a liquid at room temperature. Water is a gas (steam) at temperatures above 100°C. Water in a gaseous state is also called steam or *water vapor*.

So what makes these states of matter different?

Let's say I have two identical cubes of solid ice. If I put the ice cubes in separate containers that have different shapes, the ice will still be shaped like a cube. Each cube will have a definite volume. *Solids* have a definite shape and a definite volume.



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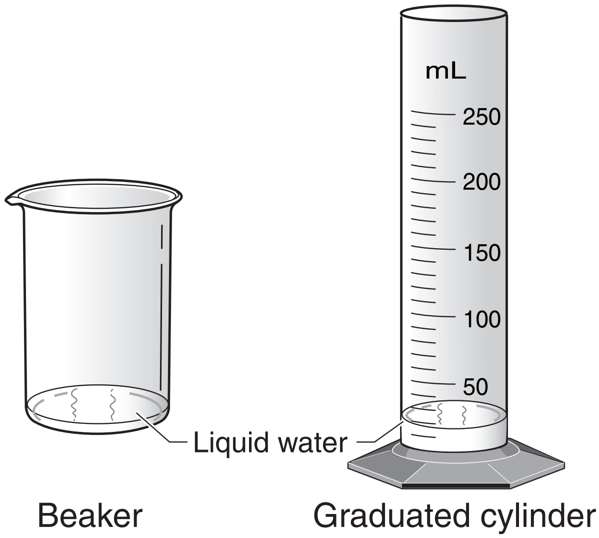
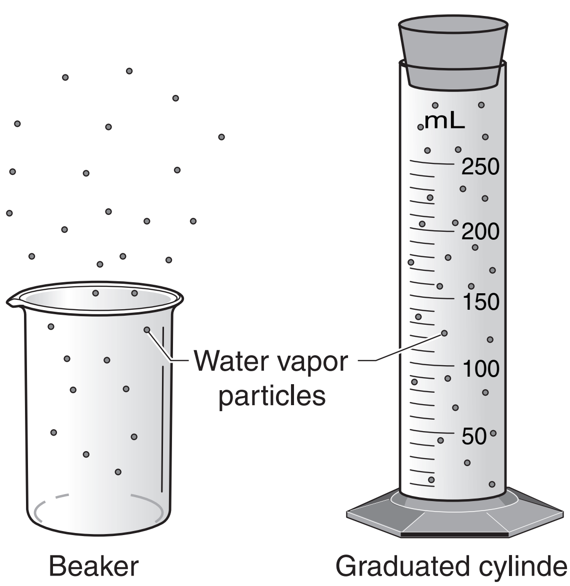
If we let the ice melt into liquid water, the shape of the water in the two containers will be different. *Liquids* have a definite volume, but not a definite shape. Their shape changes to match the shape of their container.



What if the water evaporates into a gas?

When water is heated, it gains energy. When water gains enough heat energy, it evaporates into a gas. It is composed of tiny particles too small for us to see. If we closed one of the containers with a stopper, the particles of water vapor in that container would spread out to fill up the available space. In the open container, many of the water vapor particles would escape and mix with the surrounding air.

Gases have no definite shape. Their shape changes to match the shape of their container. Gases also have no definite volume. Their volume can change so that they completely fill their container.



My Notes

You said gas is made of particles. What are these particles?

The tiny particles that compose most forms of matter are called *atoms*. An atom is the simplest unit of an element. An *element* is a substance that contains only one kind of atom. There are over 100 known elements.

When two or more atoms join chemically, a molecule may form. A molecule is a larger particle than an atom. It may be made up of atoms of the same element or of different elements.

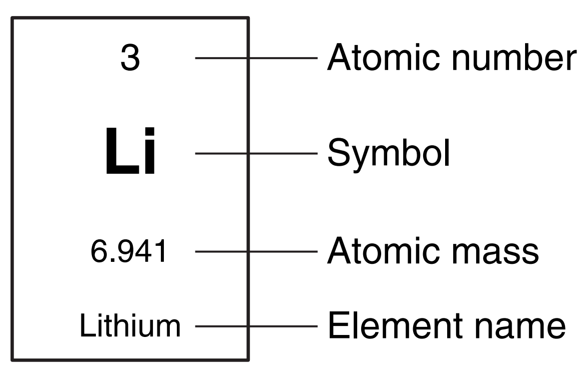
A compound is a substance made up of atoms of two or more elements joined chemically.

Is there something I can use to help me understand the elements?

Yes, you can use the periodic table of the elements. The periodic table is a tool that can help us predict the physical and chemical properties of elements.

What kind of information can I find in the periodic table?

Each element has a symbol, an atomic number, and an atomic mass. Look at the periodic table. The elements are arranged in vertical columns called groups or families. The elements are also ordered in horizontal rows called periods. Let's take the element lithium (Li) as an example. Find lithium (Li) on the periodic table. Note that lithium is located in Group 1 (the first column) and in Period 2 (the second row) of the table.



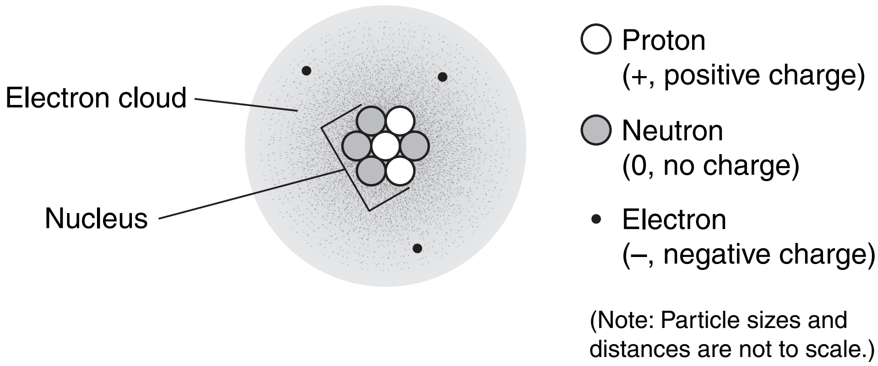
What do the different numbers mean?

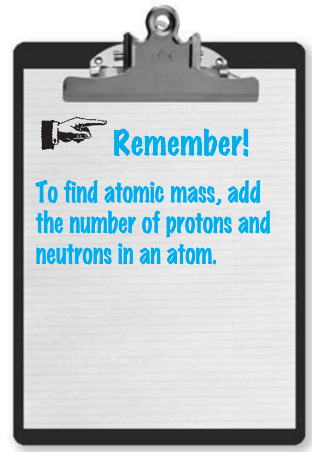
Good question! But first we need to know a little bit about the parts of the atom. The three basic parts are called protons, neutrons, and electrons. These parts, or particles, determine the characteristics of elements. The periodic table gives us information about how many of each of these particles are found in the atoms of each element.

Lithium, for example, has an atomic number of 3. This means that a lithium atom has three *protons*. Each proton has an atomic mass of approximately 1 unit and a positive charge. Protons are found in the nucleus of the atom.

My Notes

Lithium (Li) Atom Model





So the atomic number always tells us how many protons are in an atom of that element?

Correct. It tells us something else too. Since atoms have a neutral charge, the number of protons tells us how many negatively charged particles must also be present in an atom to make it neutral. Which particle carries a negative charge?

That would be the electron, right?

Right again. So in lithium three negatively charged *electrons* balance the three positively charged protons. Electrons are very small, have very little mass, and are found outside the nucleus. They constantly move in an area of mostly empty space surrounding the nucleus. This area is called the *electron cloud.*

What about the neutrons in the diagram?

Neutrons are particles with no electric charge. Neutrons have an atomic mass of approximately 1 atomic mass unit and are found in the nucleus along with protons. Protons and neutrons together make up most of the mass of an atom.

How do we know how many neutrons are in an atom?

To find the number of neutrons in an atom, we look again at the periodic table. Remember that protons and neutrons each have an atomic mass of approximately 1 atomic mass unit. On the periodic table we find the atomic mass of lithium. It is 6.941. First we will round this to the nearest whole number, which is 7. Since we know there are three protons in lithium, we can subtract 3 from 7 to find the number of neutrons in lithium. Since $7 - 3 = 4$, lithium has four neutrons. This is the procedure to follow for the elements you have studied in class.

My Notes

Let's summarize what we've learned about the basic parts of the atom in the table below.

Basic Parts of the Atom

Subatomic Particle	Approximate Atomic Mass (amu)	Electrical Charge	Location in Atom
Proton	1	Positive (+)	Nucleus
Neutron	1	None (0)	Nucleus
Electron	0	Negative (–)	Electron cloud

Did You Know?

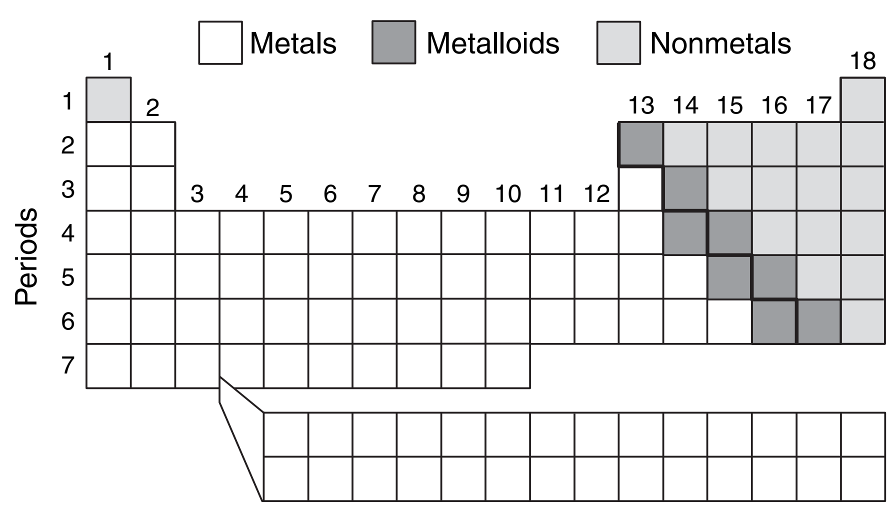
Protons and neutrons have nearly equal masses, but electrons have an extremely small mass. The mass of an electron is approximately 1/2000 the mass of a proton.

Wow! That's pretty amazing. What other information can I get from the periodic table?

The periodic table of the elements is the result of many observations of elements and their properties. Scientists all over the world have studied the physical and chemical properties of the known elements. Elements with similar properties were placed in the same group in the periodic table.

Look at the periodic table of the elements again. A stair-step line separates the elements into metals and nonmetals.

Periodic Table of the Elements



What is the difference between metals and nonmetals?

Most of the elements are *metals*. Metals are good conductors of heat and electricity. At room temperature most metals are hard, shiny solids that can be bent without breaking.

My Notes

The *nonmetals* are located on the upper right side of the periodic table. At room temperature some of the nonmetal elements are solids that crack or break easily. Others are gases at room temperature. Nonmetals at room temperature typically are not shiny and do not conduct heat or electricity very well.

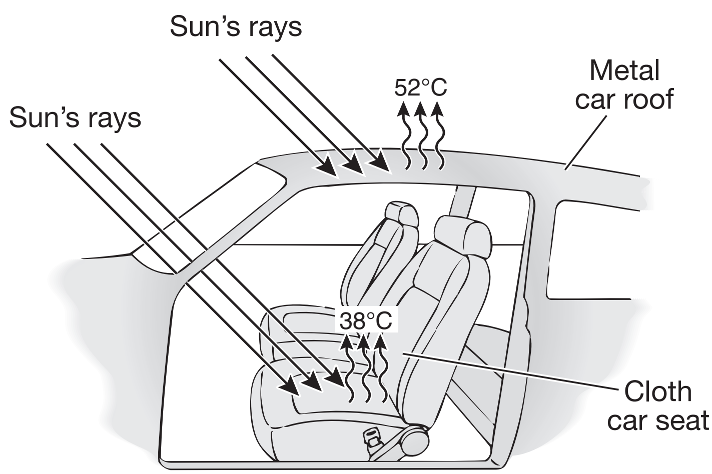
Along the line separating the metals and nonmetals is a third group of elements known as *metalloids*. Metalloids have some properties of metals and some properties of nonmetals.

Did You Know?

Dmitri Mendeleev overcame his own illness and family tragedies and created the first periodic table of elements in 1869.

You mentioned that metals are good conductors of heat and nonmetals are not. How do we know that?

Have you ever touched the door of a car on a hot afternoon? The metal door can get so hot that it hurts your skin. But once you open the car door and touch the cloth seat, you notice that the cloth isn't nearly as hot as the metal.



Not all substances heat up at the same rate. Some substances get hot very quickly when exposed to heat. Other substances do not rise in temperature very quickly when exposed to the same amount of heat. This is what keeps the car's cloth seat cooler than the metal door. This is caused by each substance's different ability to absorb and conduct heat.

Can we measure how much heat matter can absorb?

Now you're thinking like a scientist! Yes we can, and this measurement is called *specific heat*. It is the measure of how much heat energy it takes to make 1 gram of a substance rise 1°C in temperature. Heat energy can be measured in calories. A *calorie* is the amount of heat needed to make 1 g of water rise 1°C in temperature.

The higher a substance's specific heat, the harder it is to increase its temperature (as with the cloth car seat). The opposite is also true: a substance with a low specific heat increases in temperature very easily (as with the metal car door).

My Notes

Remember!

The temperature change of a substance depends on three things:

(1) mass of the substance

(2) the amount of heat added

(3) the specific heat of the substance

Wait, isn't that backward? If something stays cooler, how can its specific heat be higher?

Specific heat can be confusing because it is a measure of thermal energy, not temperature. Specific heat can be viewed as the resistance of a substance to a change in temperature. So a higher specific heat means that more energy is required to change that substance's temperature.

Low specific heat = Less energy to change temperature

High specific heat = More energy to change temperature

I think I get it now. If we wanted to keep the temperature of something from changing very much, we could build it out of a material with a high specific heat, right?

You've got it! The table below shows the specific heat of some common substances. Note that most metals have low specific heats, while nonmetal compounds and mixtures such as water, wood, soil, and air have relatively high specific heats.

Specific Heat of Some Common Substances

Substance	Cal/g • °C
Water	1.00
Wood	0.40
Soil	0.25
Air	0.25
Aluminum	0.22
Iron	0.11
Copper	0.09

Wow! Water has a really high specific heat. Does that affect the conditions on Earth?

It sure does. Oceans cover about two-thirds of Earth's surface. Water's characteristic of retaining heat is important to our climate. It means that our climate stays much more stable than it would if there were less water on Earth.

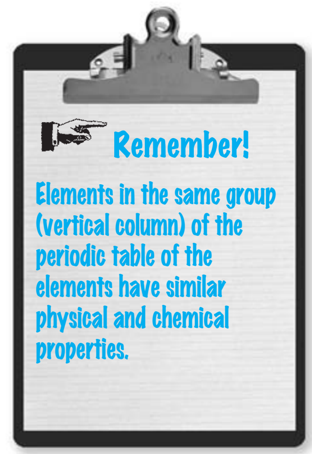
My Notes

Iron and copper gain heat very quickly. Are they metals?

Yes! Look back at the periodic table. Remember the line that separates the metals and nonmetals? Find iron (Fe) and copper (Cu) on the periodic table. They are both located to the left of this line, indicating that they are metals.

Didn't you say that elements in the same group also share common properties?

Yes, elements in the same group of the periodic table often share many of the same physical properties. For example, copper (Cu), silver (Ag), and gold (Au) are three of the best conductors of electricity out of all the elements. Notice that they are all found in Group 11 of the periodic table.



Elements within a group or family also share chemical properties. For example, the elements in Group 17 are called halogens, which means "salt-formers." When they react chemically with other elements, the product is often a type of salt. An example of this is when sodium (Na) reacts with the Group 17 element chlorine (Cl). The product of this reaction is sodium chloride (NaCl), or the table salt we put on food. The elements in each group have certain common properties that make them different from the elements in the other groups. We'll talk more about physical and chemical properties later.

O.K., I think I understand atoms and elements now. But what are molecules?

Molecules are formed when two or more atoms chemically join, or bond together. With over 100 elements there are millions of possible combinations.

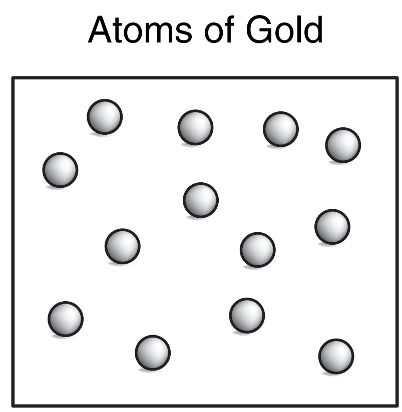
What kinds of substances are made of molecules?

If two or more atoms of the same element bond together, we have a molecule of a pure element. Oxygen (O_2) is an example of a commonly occurring molecule that is also a pure element.

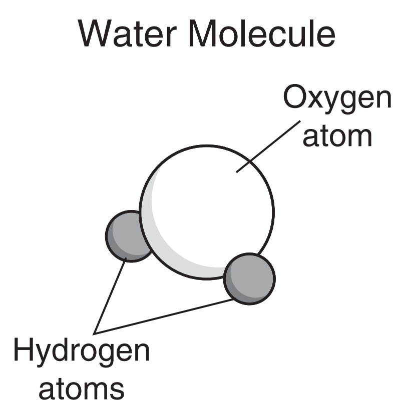
But if atoms of different elements are joined chemically, they form a *compound*. The properties of compounds are different from the properties of the individual elements they contain.

My Notes

Samples of matter that are made up of all the same atom or all the same molecule are called *pure substances*. For example, pure gold is made up only of atoms of the element gold (Au).



Since water is a compound, it is made up only of molecules of water. Each water molecule has two atoms of hydrogen and one atom of oxygen.



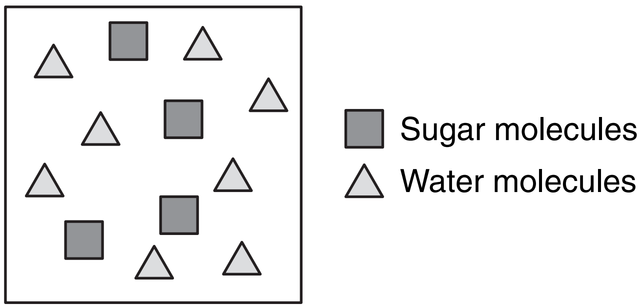
Oh, I see. Then all substances are either compounds or elements?

Well, that's true for pure substances, which are made of only one element or compound. But it's not quite the whole picture. Many substances are actually *mixtures*. Mixtures are a combination of two or more pure substances. These substances have been mixed together but have not reacted to form any new molecules.

My Notes

For example, sugar (a compound) dissolves in water (a compound) to form a mixture. The molecules of sugar and water do not change chemically. They just become mixed together.

Mixture of Sugar and Water



I remember when we separated some mixtures in science class. Can all mixtures be separated into their original parts?

Yes, that is a characteristic of mixtures. We could separate the sugar-water mixture by putting the mixture in an open container and allowing the water to evaporate. Sugar crystals would be left in the container after the water evaporates.

If the solid particles in a mixture are different sizes, we can separate the mixture using a filter. For example, suppose we mix gravel and sand together. We could then separate them by pouring the sand-gravel mixture through a certain kind of screen. The sand would fall through the screen, but the gravel would collect on top of the screen.

O.K., there are over 100 elements and millions of different compounds and mixtures. This is getting wild! If there are so many different kinds of matter, how can we tell the difference between them?

That's a good question. When we examine a substance, we are interested in its properties. A *property* is something about a substance that can help to define it. Let's look at water, for example.

Some Properties of Water

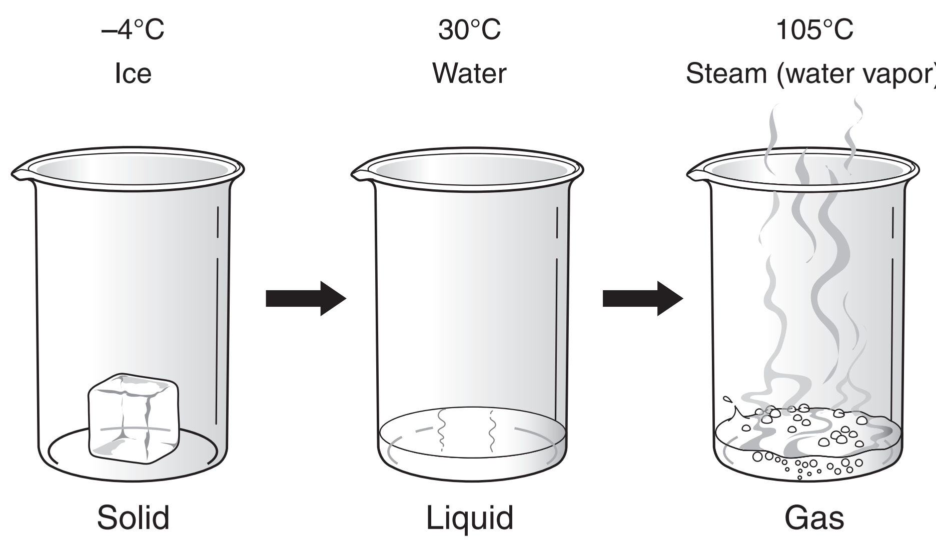
- It is a liquid at room temperature, so it takes the shape of its container.
- It is transparent, because light passes through it.
- It will freeze at about 0°C and boil at about 100°C.

My Notes

There are two main types of properties that help us classify substances. *Physical properties* can be observed without changing the substance into a different substance. There are many different physical properties we might observe. The properties of water listed in the box are all physical properties.

When a substance changes but doesn't become a new substance, we say that a physical change has occurred. Remember water's different states of matter? Each change in state of matter as water passes from solid to liquid to gas is a physical change.

Physical Changes in Water



What about chemical properties?

Chemical properties are characteristics of a substance that are observed when it reacts (changes) to produce one or more different substances. For instance, water can be changed into hydrogen gas and oxygen gas using an electric current. When water molecules change chemically into hydrogen gas and oxygen gas, we say that a chemical change has occurred. Hydrogen gas and oxygen gas each have a different set of properties. Substances change into different substances through chemical reactions.

How do chemical reactions cause substances to change into other substances?

The atoms in the original substances are rearranged during a *chemical reaction*. During a chemical reaction, bonds in the original substance may be broken and new bonds may be formed between different atoms. This produces one or more different substances. The substances produced may be either pure elements or compounds. The products of

My Notes

a chemical reaction always have different chemical and physical properties than the original substance or substances.

Could you show me an example of a chemical reaction?

O.K. Have you ever noticed a dark coating of tarnish on silver jewelry that hasn't been used in a while? This coating is the product of a chemical reaction between the silver metal and the hydrogen sulfide gas in the atmosphere. The reaction produces silver sulfide (tarnish) and hydrogen gas.

silver (metal) + hydrogen sulfide → silver sulfide (tarnish) + hydrogen gas

Here is the chemical equation for this reaction:

$$2Ag + H_2S \rightarrow Ag_2S + H_2$$

Here is a table to show all the parts of this chemical equation:

Reactants and Products in a Chemical Equation

2Ag	+	H_2S	→	Ag_2S	+	H_2
2 atoms of silver	reacted with	1 molecule of hydrogen sulfide	to produce	1 molecule of silver sulfide	and	1 molecule of hydrogen gas

Remember!

An arrow in a chemical equation shows that the substances on the left side (reactants) react chemically to form the substances on the right side (products).

Before the reaction, silver exists as individual atoms in the silver jewelry. Each molecule of hydrogen sulfide contains two hydrogen atoms bonded to a sulfur atom.

After the reaction, each molecule of silver sulfide produced contains two silver atoms bonded to one atom of sulfur. Each molecule of hydrogen gas produced contains two atoms of hydrogen bonded together.

What do the letters and numbers mean in the chemical equation?

The letters tell us what substances are involved in the reaction. The numbers tell us how many atoms or molecules are in the equation. The equation also tells us how the atoms of each substance are rearranged. Let's look first at how we name the substances.

Scientists have developed a system using symbols to represent different elements. The symbol for each element is either one or two letters. These symbols can be found on the periodic table of the elements.

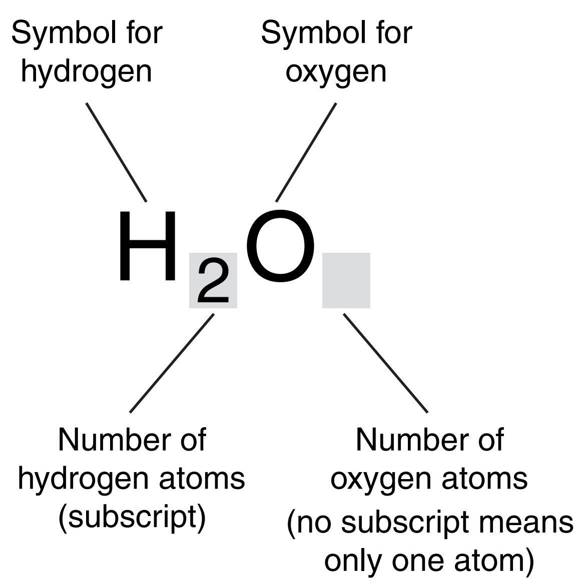
Objective 3

My Notes

What does it mean when there is more than one symbol in a substance, such as the Ag and the S in silver sulfide?

Compounds are represented by a formula that uses symbols for all the elements present in the compound. A formula for a compound shows the number and types of atoms in one molecule of the compound. In addition to the element symbols, numbers called *subscripts* are used. Subscripts tell us how many atoms of each element are in a molecule and are written to the right and slightly lower than the element symbol.

The diagram below explains the formula for one water molecule.



O.K., the formulas make sense to me. Now I want to see how the equation was written. Can you show me?

Sure. We start by writing the formulas for silver, hydrogen sulfide, silver sulfide, and hydrogen gas.

Silver: Ag

Hydrogen sulfide: H_2S

Silver sulfide: Ag_2S

Hydrogen gas: H_2

Next we write the formulas for the original substances. The substances that exist before a reaction takes place are called *reactants*. The reactants are separated by a plus sign (+). In this case, silver and hydrogen sulfide are the reactants. An arrow comes next to show us that a chemical change has occurred.

My Notes

What goes on the right side of the equation?

The formulas for the *products* are written on the right side of the arrow. The products are the substances that are made as a result of the chemical change. Products are also separated by a plus sign (+). In this case, silver sulfide and hydrogen gas are the products.

Reactants			→	Products		
Ag (metal)	+	H_2S (hydrogen sulfide)	→	Ag_2S (silver sulfide)	+	H_2 (hydrogen)

I see that there is a number 2 in front of silver (Ag) in the equation written earlier. What does this number 2 represent?

In this case the number 2 tells us that there are two atoms of silver (Ag) present on the reactant side of this equation. These numbers (called coefficients) are put in front of reactants or products to tell us how many atoms or molecules occur on each side of a reaction. When there is no number written in front of a reactant or product, we understand that number to be 1 (one). So, in this equation, there are two atoms of silver and one molecule of hydrogen sulfide (H_2S) on the reactant side of the equation and one molecule of silver sulfide (Ag_2S) and one molecule of hydrogen gas (H_2) on the product side of the equation.

$$2Ag + H_2S \rightarrow Ag_2S + H_2$$

Now we can count the number of atoms on each side of the equation. There must be the same quantity of each type of atom on each side of a reaction. In chemical reactions matter is neither created nor destroyed, so the same types and quantity of atoms must be in the reactants and in the products of the reaction.

Atoms in reactants:	→	Atoms in products:
2 Ag	→	2 Ag
2 H	→	2 H
1 S	→	1 S

Did You Know?

The number in front of an element symbol or compound formula in a chemical equation is called a coefficient.

Remember!

A balanced chemical equation has the same number of atoms of each element on both sides of the reaction arrow. This shows that all the atoms in the reactants are found in the products.