NTI Day 7 Lesson
Content Standard: Chemical Reactions
Class: Chemistry **Teacher: K. Kelly**

Chemical Reactions

Chemical changes *occur when a material changes from one substance to another.* ***Chemical reactions*** *describe the processes by which these changes take place.*

Chemical reactions are the processes by which materials are changed from one substance into another. Chemical reactions can be represented by chemical equations that follow the laws of conservation of matter, mass, and energy.

Whenever a chemical reaction occurs, the reactants have different properties than the products. These properties can be tested and include density, melting point, boiling point, solubility, flammability, and odor.

There are a number of indications that a chemical reaction has occurred within a given sample. These include a change of color, a temperature change, the production of a gas, and the formation of a solid.

Chemical Changes

When paper is burned, a chemical change occurs because the substance that is produced is no longer paper. When water reacts with metal, a chemical change occurs because the water and metal transform into different substances—a metal oxide and hydrogen gas.

There are several indications that a chemical change has occurred:

- **Color Change**
  One way to tell if there has been a chemical change is to notice any color change. For example, when copper metal oxidizes, or reacts with oxygen, it turns from a copper-red color to a green color. The Statue of Liberty is one example of copper oxidizing.

Although the Statue of Liberty now looks green, its original color was copper-red. This color change is the result of copper and oxygen reacting and transforming into copper oxide.

- **Temperature Change**
  Another way to tell if there has been a chemical change is to measure and detect any temperature change of the substances involved. For example, when combining ammonium nitrate (NH_4NO_3) and water, the temperature of the combination goes down because heat is absorbed in the chemical reaction. On the other hand, when water is combined with calcium chloride ($CaCl_2$) the temperature of the combination goes up because heat is released in the chemical reaction.
- **Production of a Gas**
  When baking soda and vinegar are combined, the production of gas provides evidence for a chemical change. Many bubbles form as the reaction takes place. Other chemical changes that produce gases include burning wood, baking a cake, and putting effervescent tablets in water.
- **Formation of a Solid**
  Formation of a solid is another indication of a chemical change. Rust is a solid that forms when metal, such as a nail or a screw, reacts with water.

A rusted screw shows evidence of a chemical change.

When chemical changes occur, new substances with different characteristics from the original substances are produced.

Chemical Reactions & Equations

Chemical reactions are the processes by which materials are changed from one substance into another. Chemical reactions are represented by *chemical equations*.

Chemical equations take the following general form:

$$\text{reactants} \rightarrow \text{products}$$

Reactants are the starting substances in a reaction. *Products* are the substances that starting substances are transformed into; they are the substances that are produced by the reaction.

- *Examine the following reaction:*

$$2\ H_2 + O_2 \rightarrow 2\ H_2O$$

In the above reaction, two molecules of hydrogen gas react with one molecule of oxygen gas to produce two molecules of water. In this case, the reactants are hydrogen gas and oxygen gas, and the product is water. The arrow always points toward the products.

The *coefficients*, or the numbers in front of each substance, indicate how many molecules of that substance are present. The *subscripts*, or the small numbers that follow particular elements, indicate how many atoms of that element are present in a substance.

So, in the above example, the two in front of the H_2 indicates that there are two molecules of hydrogen gas (H_2). The two that follows the H indicates that there are two atoms of hydrogen in each hydrogen molecule. If no number appears in front of a substance, assume that only one molecule of that substance is present. So, in the above example, the lack of a coefficient indicates that there is only one molecule of oxygen gas. The two that follows the O indicates that there are two atoms of oxygen in the oxygen molecule.

- *Examine another reaction:*

$$HCl + NaOH \rightarrow NaCl + H_2O$$

In the above reaction, an acid (hydrochloric acid) reacts with a base (sodium hydroxide) to produce a salt (sodium chloride) and water. This type of reaction is known as a *neutralization* reaction.

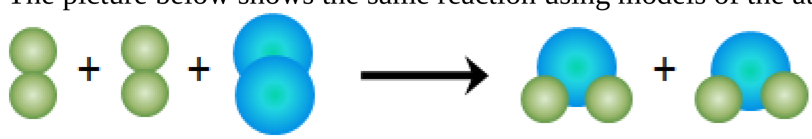
Conservation in Chemical Reactions

There are several conservation laws that apply to chemical reactions.

- **The Law of Conservation of Matter**
  According to the law of conservation of matter, matter cannot be created or destroyed; it can only change forms. So, if one atom of chlorine is present on the reactant side of an equation, one atom of chlorine must be present on the product side of the equation. The chloride atom can combine with different atoms and form new substances, but it can't disappear from the equation.
  For example, consider the reaction of hydrogen gas and oxygen gas to form water:

$$2H_2 + O_2 \rightarrow 2H_2O$$

  The picture below shows the same reaction using models of the atoms in the reaction.



  Although the atoms rearrange, there are four hydrogen atoms and two oxygen atoms on each side of the equation. This shows that atoms were not created or destroyed, only rearranged. That is, matter is conserved in the chemical reaction.
- **The Law of Conservation of Mass**
  According to the law of conservation of mass, mass cannot be created or destroyed during ordinary physical or chemical changes. So, if there are 100 grams of reactant, 100 grams of product must be produced. The mass stays the same during a chemical reaction.
- **The Law of Conservation of Energy**
  According to the law of conservation of energy, energy cannot be created or destroyed; it can only change forms. So, if heat energy is released during a chemical reaction, that heat energy must have been stored in the reactants; it cannot simply materialize. Alternately, if heat energy is absorbed during a chemical reaction, that heat energy must be stored in the products and, accordingly, it must be added as a reactant.

  For a reaction that gives off energy, the energy of the reactants is equal to the energy of the products plus the energy released as heat. For a reaction that absorbs heat, the energy of the reactants plus the heat energy absorbed from the surroundings is equal to the energy of the products.

Ion Formation

***Ions** are charged atoms. This means that ions have unequal numbers of protons and electrons.*

*If there are more electrons than protons, the ion has an overall negative charge and is called an **anion**. If there are more protons than electrons, the ion has an overall positive charge and is called a **cation**.*

Ions

Neutral atoms have no charge. In order to be neutral, an atom must possess the same number of positively charged protons and negatively charged electrons. The number of neutrons does not affect the charge of an atom since neutrons do not have a charge.

Ions are charged atoms. An ion forms when an atom gains or loses electrons. If an atom gains electrons so that it has more electrons than protons, the atom forms an ion that has an overall negative charge and is called an *anion*. For example, if an oxygen atom gains two electrons, it forms the following anion:

$$O^{2-}$$

Or, if a chlorine atom gains one electron, it forms the following anion:

$$Cl^{-}$$

A negative sign in the superscript indicates that that atom has gained electrons. The number next to the sign indicates how many electrons that atom has gained. For ions with a plus one or minus one charge, the one is usually omitted in the notation.

If an atom loses electrons so that it has more protons than electrons, the atom forms an ion that has an overall positive charge and is called a *cation*. For example, if an aluminum atom loses three electrons, it forms the following cation:

$$Al^{3+}$$

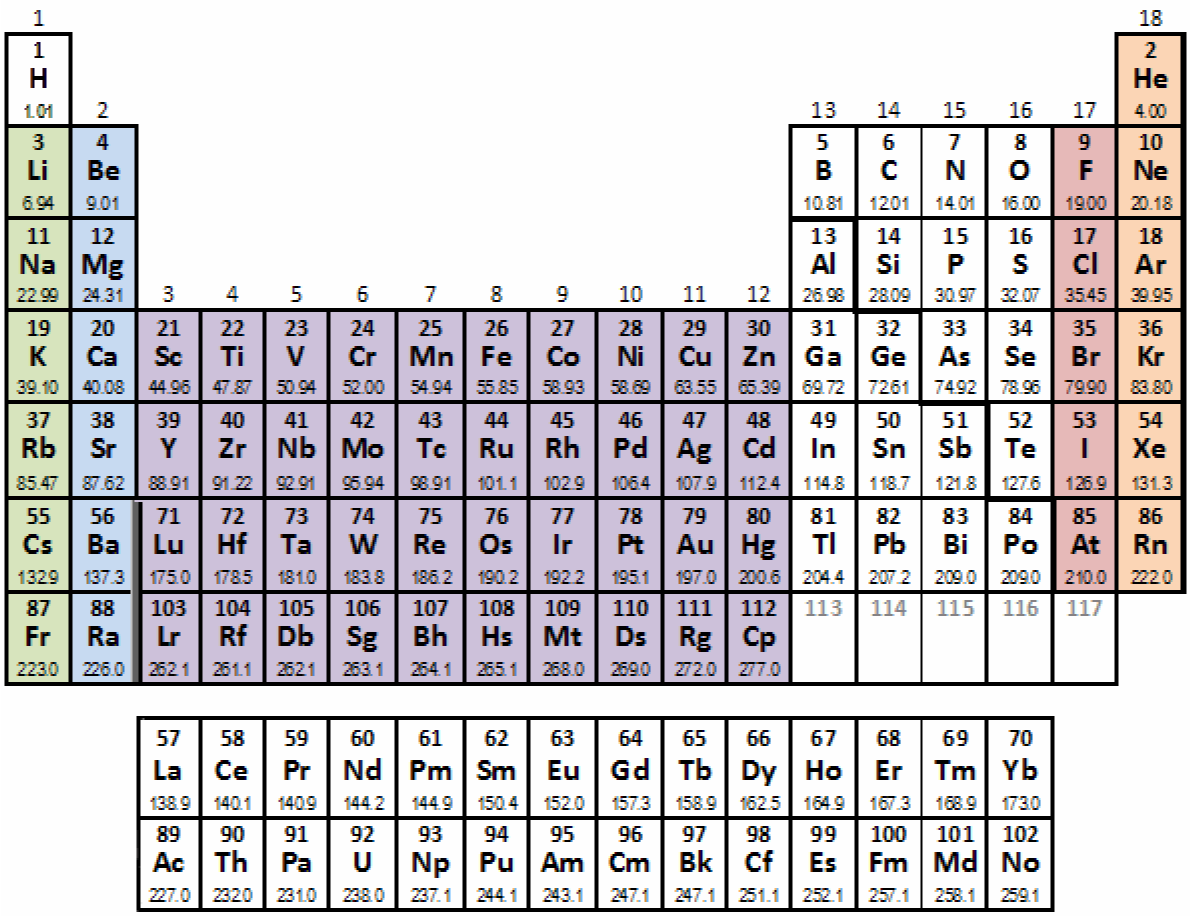
Or, if a potassium atom loses one electron, it forms the following cation:

$$K^{+}$$

A positive sign in the superscript indicates that the atom has lost electrons. The number next to the sign indicates how many electrons the atom has lost. Again, when the charge is plus one, the one is omitted in the notation.

Predicting Ionic Charges

The periodic table may be used to predict the ionic charges of elements.



The following table summarizes the periodic trends for ionic charges of main group elements:

Group	Elements	Number of Outer Electrons	Ionic Charge
1	H, Li, Na, K, Rb, Cs, Fr	1	1+
2	Be, Mg, Ca, Sr, Ba, Ra	2	2+
13	B, Al, Ga, In, Tl	3	3+
14	C, Si, Ge, Sn, Pb	4	4+ or 4-
15	N, P, As, Sb, Bi	5	3-
16	O, S, Se, Te, Po	6	2-
17	F, Cl, Br, I, At	7	1-
18	He, Ne, Ar, Kr, Xe, Rn	8	0

Transition elements (elements in groups 3 through 12) tend to be able to form multiple kinds of ions. For example, iron may form ions with a 2+ or 3+ charge, and manganese may form ions with a 2+, 3+, 4+, or 7+ charge. So it is not as easy to use the periodic table to predict the ionic charges of transition elements. For this reason, predicting ionic charges for these elements is out of the scope of this course.

Ions and Stability

Atoms tend to form ions in order to achieve a noble gas electron configuration. Noble gases have the ideal configuration for stability because their outer s and p orbitals are completely filled. For helium, this means having two valence electrons. For the other noble gases, it means having eight valence electrons.

As demonstrated in the table shown above, the ionic charge of an element is related to its number of valence electrons. For example, elements in group 1 have one valence electron. So, in order to achieve a noble gas configuration, they must either lose one electron or gain seven more. It requires less energy to lose one electron than to gain seven more, so elements in group 1 tend to form ions with a 1+ charge.

Noble gases do not tend to form ions at all, since they already have the most stable electron configuration.

Chemical Reactions

*During **chemical reactions**, reactants combine or rearrange to form new products that have different compositions and properties.*

There are five main types of chemical reactions: synthesis, decomposition, single replacement, double replacement, and combustion.

Synthesis Reactions

In a synthesis reaction, two or more reactants combine to form a single product. The general form of a synthesis reaction is:

$$A + B \rightarrow AB$$

For example:

$$\mathrm{S}(s) + \mathrm{O_2}(g) \rightarrow \mathrm{SO_2}(g)$$

Decomposition Reactions

In a decomposition reaction, a single compound is broken down into two or more products by the action of heat, electricity, or light. The general form of a decomposition reaction is:

$$AB \rightarrow A + B$$

For example:

$$2\mathrm{H_2O}(l) \rightarrow 2\mathrm{H_2}(g) + \mathrm{O_2}(g)$$

Single Replacement Reactions

In a single replacement reaction, an uncombined element displaces an element that is part of a compound. The general form of a single replacement reaction is:

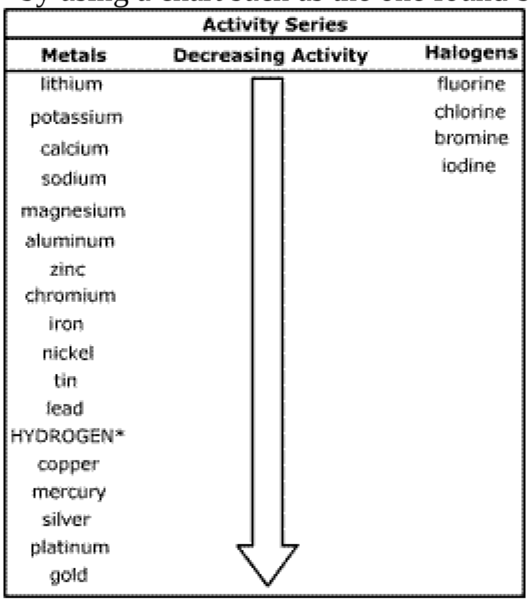
$$A + BC \rightarrow AC + B$$

For example:

Zinc replaces the copper from copper(II) chloride to form zinc chloride and copper.

$$Zn + CuCl_2 \rightarrow ZnCl_2 + Cu$$

Note that a single replacement reaction will only occur if the uncombined element/reactant is *more active* than the combined element/reactant. The relative activities of certain metals and halogens can be determined by using a chart such as the one found below.



More active halogens may also replace less reactive halogens in single replacement reactions. For example, fluorine replaces iodine in potassium iodide and forms potassium fluoride and iodine gas:

$$F_2 + 2KI \rightarrow 2KF + I_2$$

Double Replacement Reactions

In a double replacement reaction, two ionic compounds in an aqueous solution switch anions and produce two new compounds. The general form of a double replacement reaction is:

$$AB + CD \rightarrow AD + CB$$

For example:

Sometimes, a solid, insoluble product results from double replacement reactions. These solids are known as *precipitates*, and their formation may be predicted by applying the following solubility rules.

- All group 1 salts are soluble.
- All chlorides, bromides, and iodides—except silver, lead, and mercury—are soluble.
- All fluorides—except group 2, lead (II), and iron (III)—are soluble.
- All hydroxides—except group 1, strontium, barium, and ammonium—are insoluble.
- All sulfides—except group 1, 2, and ammonium—are insoluble.
- All oxides—except group 1—are insoluble.

Neutralization reactions are a special type of double replacement reaction. During neutralization reactions, an acid reacts with a base to produce a salt and water.

$$\text{acid} + \text{base} \rightarrow \text{salt} + \text{water}$$

For example:

$$HCl(aq) + NaOH(aq) \rightarrow NaCl(aq) + H_2O(l)$$

Combustion Reactions

In a combustion reaction, a substance burns in the presence of oxygen and releases energy in the form of heat and sometimes light. This is the reason why hydrocarbons, such as octane and propane, are used as fuels.

When the reacting substance is a hydrocarbon or other organic molecule, the products will include carbon dioxide and water. The general form of a combustion of a simple hydrocarbon is:

$$\text{hydrocarbon} + \text{oxygen} \rightarrow \text{carbon dioxide} + \text{water}$$

For example:

$$2C_2H_6 + 7O_2 \rightarrow 4CO_2 + 6H_2O$$

Laws of Definite & Multiple Proportions

The grouping of atoms in a compound follow two scientific laws: the law of multiple proportions and the law of definite proportions. These laws provide the foundation of stoichiometry.

The Law of Multiple Proportions

The law of multiple proportions states that when chemical compounds form, atoms always combine in a ratio of small, whole numbers. For example, nitrogen and oxygen can combine in many ways to create different compounds. Some of the compounds that exist are:

- NO - nitric oxide or nitrogen monoxide
- NO_2 - nitrogen dioxide
- N_2O - nitrous oxide or dinitrogen monoxide
- N_2O_3 - dinitrogen trioxide
- N_2O_4 - dinitrogen tetroxide
- N_2O_5 - dinitrogen pentoxide

Notice that each compound above consists of a specific ratio of nitrogen atoms to oxygen atoms. Molecules of dinitrogen pentoxide, for example, always consist of two nitrogen atoms bonded to five atoms of oxygen. So, the ratio of nitrogen atoms to oxygen atoms is 2:5.

This law basically states that only whole atoms can combine. Therefore, a compound of $NO_{2.5}$ is not possible. Though it still has the same ratio of nitrogen to oxygen, only whole atoms can combine to form compounds.

The Law of Definite Proportions

The law of definite proportions states that a chemical compound always contains the same ratio of elements by mass. For example, water is a compound. Regardless of the size of the sample, water will always contain 88.8% oxygen and 11.2% hydrogen by mass. In contrast to compounds, a mixture can vary in the ratio of its components.

Balancing Chemical Equations

***Chemical reactions** are processes through which one or more substances are changed into new or different substances. Chemical reactions are represented by chemical equations.*

***Chemical equations** are expressions in which symbols and formulas are used to represent a reaction.*

General Equation Format

In chemical equations, *reactants* appear to the left of the arrow. These are the substances that enter the chemical reaction; they are the starting materials. For example:

$$Zn + 2HCl \rightarrow ZnCl_2 + H_2$$

Products appear to the right of the arrow. These are the substances that are produced by the chemical reaction; they are the ending materials.

The *law of conservation of matter* requires that matter is neither created nor destroyed in chemical reactions. The existing atoms are just rearranged. This means that there are the same number of each kind of atom before a chemical reaction as after a chemical reaction.

Recognizing an Unbalanced Equation

Balanced chemical equations are equations in which the number of atoms of each element is the same on both sides of the equation. For example, the equation:

$$Mg + O_2 \rightarrow MgO$$

is unbalanced because there are two oxygen atoms on the reactant side but only one on the product side. However, this equation:

$$2Mg + O_2 \rightarrow 2MgO$$

is balanced because there are the same number of magnesium and oxygen atoms on the reactant and product sides.

Procedure for Balancing Equations

1. Write a chemical equation with the correct symbols and formulas.

$$H_2O \rightarrow H_2 + O_2$$

2. Count the number of atoms of each element on the reactant side of the arrow.

   There are two hydrogen atoms (H) and one oxygen atom (O) on the reactant side of the equation.

3. Count the number of atoms of each element on the product side of the arrow.

   There are two hydrogen atoms (H) and two oxygen atoms (O) on the product side of the equation.

4. If the numbers in step 2 and step 3 are not equal, add coefficients until the number of atoms balances out.

$$2H_2O \rightarrow 2H_2 + O_2$$

5. Check your work by recounting the number of atoms on both sides of the arrow.

   4 hydrogen atoms + 2 oxygen atoms → 4 hydrogen atoms + 2 oxygen atoms

Note that:

- When balancing equations, you can only change the coefficients.
- Never change the chemical symbols or formulas.
- Never change the subscripts of correctly written formulas.
- If there is no coefficient written, assume the coefficient equals 1.