Interactive Chemistry Multimedia Software

Chemical Reactions
Program Supplement

Chemical Reactions
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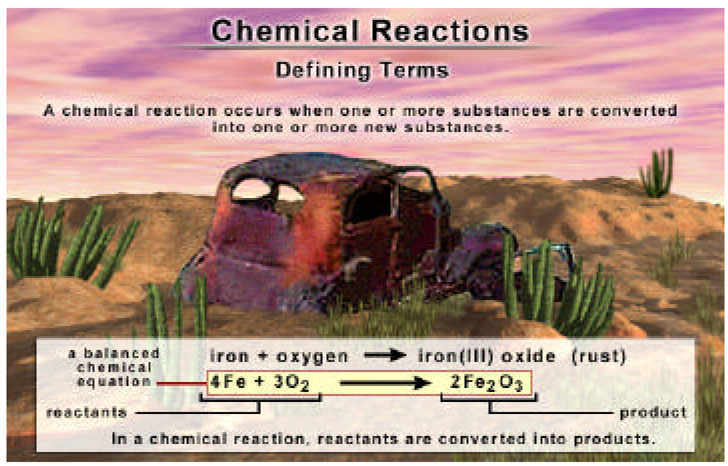
Introduction and Review

Scene 1

At a recent celebration, you may have seen fireworks. The fireworks' display of color and sound was the result of chemical reactions. Chemical reactions constantly take place all around you, though many are less dramatic than fireworks exploding. A car rusting in a field, the hardening of concrete at a construction site, and the digestion of food inside the human body are all examples of chemical reactions. The careful, systematic study of what happens during chemical reactions has provided chemists with much of their knowledge about chemistry. This program shows how to balance chemical equations, such as the one for the reaction of potassium metal and water. Knowing how to balance equations is a valuable skill that will help you understand chemical reactions. You will be shown a classification system that describes several types of reactions. Before exploring chemical reactions, the program will start with a definition of terms that will be used, a brief review of compounds, and an overview of solutions.

Scene 2



A **chemical reaction** occurs when one or more substances are converted into new substances having different chemical and physical properties. For example, when a car rusts, iron and oxygen combine and form iron(III) oxide. The substances present at the start of a reaction are called **reactants**. In the rusting car example, iron and oxygen are the reactants. The substances that result from a chemical reaction are called the **products**. In the previous example, the product is iron(III) oxide. In a chemical reaction, reactants are converted into products. A balanced chemical equation provides a shorthand method for representing the number and types of atoms involved in a reaction.

Scene 3

The following scenes provide a brief review of chemical bonds and the nature of ions. There are two different types of bonds in various chemical compounds; **covalent** and **ionic.** Covalent bonds result from the sharing of **electrons** between atoms. The sharing of electrons in covalent bonds creates **molecules**. A molecule is a collection of covalently bonded atoms that behaves as a unit, such as the water molecule. As anyone who has seen the ocean is aware, bodies of water can be quite large, but each water molecule is a discrete entity, with specific hydrogen atoms attached to a specific oxygen atom. Because of this, molecules are represented by **molecular formulas**, in which the symbol of each element in the molecule is followed by a subscript indicating how many atoms of that element are in the molecule. No subscript after an element's symbol indicates that just one atom of that element is present in each molecule. For example, water is H_2O, because two hydrogen atoms and one oxygen atom are covalently bonded. Hydrogen peroxide is a molecule in which two hydrogen atoms and two oxygen atoms are covalently bonded, and thus is symbolized H_2O_2.

Scene 4

Ionic bonds form from the attraction among oppositely charged ions**. Ions** are atoms or groups of atoms that have lost or gained electrons and thus taken on a positive or negative charge. An atom is electrically neutral because it has as many electrons surrounding the nucleus as protons in the nucleus. Since electrons are negatively charged, gaining electrons gives an ion a negative charge. For the same reason, losing electrons gives the ion a positive charge, because there are less negative charges to balance the positive charges of the nucleus. The charge on an ion equals the number of electrons it has gained or lost. A superscript placed after an ion's symbol indicates the magnitude of the charge and its sign, either positive or negative. For example, magnesium tends to lose two electrons, forming the Mg^{2+} ion. Ions possessing a single charge are indicated by the appropriate sign for positive or negative, and the number one is implied and not written. This is illustrated by chlorine, which tends to gain one electron, forming the chloride ion, Cl^-.

Scene 5

The elements on the left side of the **periodic table**, known as the **metals**, tend to lose electrons, and form **cations**. A cation is an ion with a positive charge. The elements to the right side of the periodic table, the **nonmetals**, tend to accept electrons, becoming negatively charged. A negative ion is known as an **anion**. A group of atoms covalently bonded together that possesses a charge is called a **polyatomic ion**. Examples of polyatomic ions are carbonate, sulfate, and ammonium ions. In chemical reactions, polyatomic ions tend to act as single units. This means that in many reactions they are not broken up and rearranged and are present in the same grouping in the products and the reactants. For example, when sodium sulfate and cesium carbonate react, the polyatomic sulfate ion is transferred from sodium to cesium, and the polyatomic carbonate ion switches from cesium to sodium. In both cases, each polyatomic ion makes the switch as an intact group.

Scene 6

Knowing which charges individual elements assume when they form ions is important when balancing equations of chemical reactions. You may have already learned that an atom tends to form an ion or covalent bond that gives it eight electrons in its **valence shell**, or outermost shell of electrons. This is known as the **octet rule**. The representative elements are the elements in Groups 1A through 8A on the periodic table. Each representative element tends to form an ion with an octet by gaining or losing the number of electrons that gives them the **electron configuration** of the **noble gas** nearest in atomic number. The noble gases are the elements in Group 8A, which have filled valence shells. Since each noble gas has an octet, there is nothing driving it to gain, lose, or share electrons and therefore they tend not to react or form ions. The oxygen atom, which has six electrons in its valence shell, achieves an octet by gaining two electrons. This means that the resulting oxide ion has a charge of minus two due to the negative charge on each of the two extra electrons. The sodium atom only loses one electron to achieve an octet; therefore the sodium ion has a plus one charge. The charges formed in elements 1B through 8B are not as predictable, and many have more than one ionic state. The **Stock system** of naming ions shows the oxidation number of elements that can form more than one type of ion. While oxidation number is a complex subject, for the purposes of this program, oxidation number is equal to the charge on an ion. When using the Stock system, the Roman numeral following the name of an element gives the number of the charge, for example iron(II) and iron(III). The Stock system is only used with elements that commonly form more than one ion.

Scene 7

Unlike covalent bonds, which were discussed earlier and result from a sharing of electrons, ionic bonds are formed when atoms or groups of atoms lose electrons to other atoms or groups of atoms. The opposite electrical charges of the ions formed lead to the attraction that forms the ionic bond. Ionic compounds are electrically neutral because the number of positive charges equals the number of negative charges. When they are in the solid phase, ionic compounds exist as repeating units of cations and anions forming what is known as a **crystal lattice**. The nature of the crystal lattice means that most ionic compounds do not exist in discrete units, like covalently bonded molecules. For example, a chlorine atom in a diatomic chlorine molecule is covalently bonded to another specific chlorine atom forming a discrete unit, but a chloride anion in a sodium chloride lattice is equally attracted to all of its neighboring sodium cations by ionic bonds.

Scene 8

Ionic compounds are represented by **formula units**, the smallest whole number ratios of each ion in the compound. For example, the formula unit for calcium oxide is CaO, because there are equal amounts of calcium cations and oxide anions. The formula unit for barium chloride is $BaCl_2$ because there are twice as many chloride anions as there are barium cations within the crystal lattice. Notice that the cation is named first in a formula unit. The subscript in a formula unit indicates how many ions of that element are present per formula unit. As in molecular formulas, lack of a subscript indicates there is one ion in each formula unit. In neither of these examples is there a charge on the formula unit. This is because the charges of all the cations and anions in a formula unit will always cancel, leading to electrical neutrality. For example, in barium chloride the single negative charges of each of the two chloride anions cancel the two positive charges of the barium cation.

Scene 9

In a chemical reaction between ionic compounds, cations and anions are exchanged between reactants in the appropriate proportions to lead to electrical neutrality. This means that when writing the formula unit for an ionic product or reactant, the charges present on the anions in the compound must cancel the charges on the cations. If you are only given the name of the compound, you can determine the formula by using what is known as the crisscross method. What is the formula for iron(III) oxide? First, look at the charges on the cation and anion. When compounds are named using the **Stock system,** as they will be throughout the program, the number in parentheses is equal to the charge on the ion. Since the cation is always named first in a formula unit, you know that iron has formed an ion with a plus three charge. Earlier you learned how to determine that the oxide ion has a charge of minus two by looking at the periodic table. To determine the formula unit, crisscross the absolute value of the charge of the anion to the subscript position of the cation, and the absolute value of the charge of the cation to the subscript position of the anion. Then reduce the subscripts to their lowest whole number ratio. Since the subscripts in this case are three and two, they are already in the lowest ratio.

Scenes 10-14
Solutions

Scene 10

In the lab, many reactions are performed in solution, so it is important to have a basic understanding of the properties of solutions. Solutions can exist in any combination of solid, liquid, and gas; a few examples of which are shown on your screen. A **solution** is a **homogeneous** mixture of more than one substance. To say a solution is homogeneous means it is uniform throughout, and a sample taken anywhere in the solution will be chemically identical to a sample taken anywhere else in the solution. While solutions can exist as solids, liquids or gases, in the lab, solutions are generally liquids or gases. A **solvent** is the substance into which other substances, called **solutes**, dissolve. Water is a very common solvent, both in everyday life and in the lab.

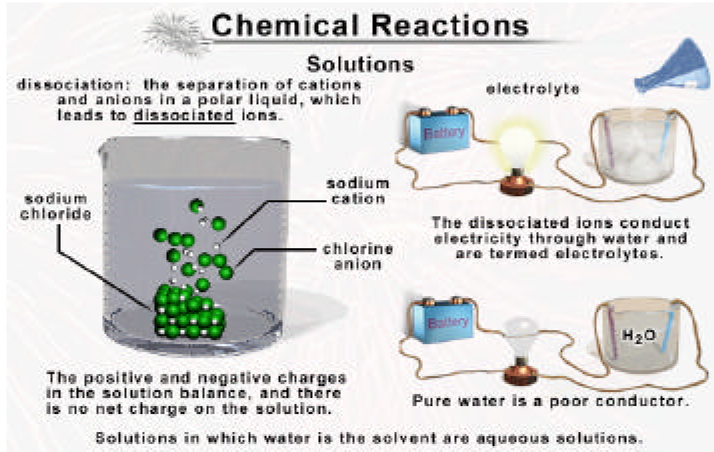
Scene 11

The measure of the amount of a substance that goes into solution is called its **solubility**. Solubility differs for each combination of solvent and solute and also varies with increasing temperature. If a substance, such as sand, will not go into solution, it is termed **insoluble**. Salad oil is insoluble in water, which is demonstrated by the fact that the two liquids do not mix, and the oil floats on the water's surface.

Scene 12

To illustrate why solutions are often used in the study of reactions, look at a common example of a solution, dissolved table salt in water. Once the salt is stirred into solution, there is a uniform distribution of the solute, salt, which breaks up into sodium ions and chloride ions in solution, throughout the solvent, which is water. The reason that liquid solutions and gases are used so often to perform reactions is that the reactants are brought into contact much more frequently in these states than they are in solids. This is because molecules and ions in solution move faster and farther than those in a solid. As you will learn when you study reaction rates later in your chemistry studies, bringing reactants together more frequently greatly increases how quickly a reaction occurs, and faster reactions are often more practical to study than slower reactions.

Scene 13



Solutions in which water is the solvent are known as aqueous solutions. When an ionic compound dissolves into aqueous solution, the cation and the anion separate from each other. This process of separation is called **dissociation,** and results in separated ions moving freely throughout the solution. Ions that have undergone dissociation are said to be **dissociated**. Although there are many charged particles in the solvent, the solution has no net charge, because the positive and negative charges balance, just as they did in the crystal lattice prior to dissociation. The separation of ions in solution makes them much more available to react than they would be if they were in a solid. Separated ions conduct an electrical current in solution as they move towards the electrode of opposite charge. Pure water does not conduct electricity well, so it is possible to tell if a compound has dissociated by determining if a current flows through the solution. The separated ions are known as **electrolytes**. If a current is conducted in aqueous solution, the compound has dissociated to form electrolytes.

Scene 14

Some molecular substances also form solutions in water. Many, such as table sugar, dissolve in water, but do not undergo dissociation. They do not conduct electricity through water and therefore are not electrolytes. The reason that sugar goes into aqueous solution is related to the **polarity** of sugar molecules and water molecules, which will not be discussed in this program. Other molecules, especially molecular **acids** and **bases**, do dissociate in water and produce ions, and are consequently electrolytes. As in the previous scene, the separation of ions increases the ability of the aqueous solution to react, making it easier to study.

Scenes 15-23
Chemical Equations

Scene 15

To understand how chemical reactions take place, it is necessary to have a thorough understanding of chemical equations. Chemical equations are a shorthand way of describing both the composition and amounts of all reactants and products. A common example of a chemical reaction occurs when hydrogen gas and oxygen gas combine to form water. When this balloon, which is filled with hydrogen gas, is ignited, it reacts with oxygen in the atmosphere to produce water vapor, heat, and light. In this case, hydrogen and oxygen are the reactants and water is the product. We can make an equation that states, in words, what is happening.

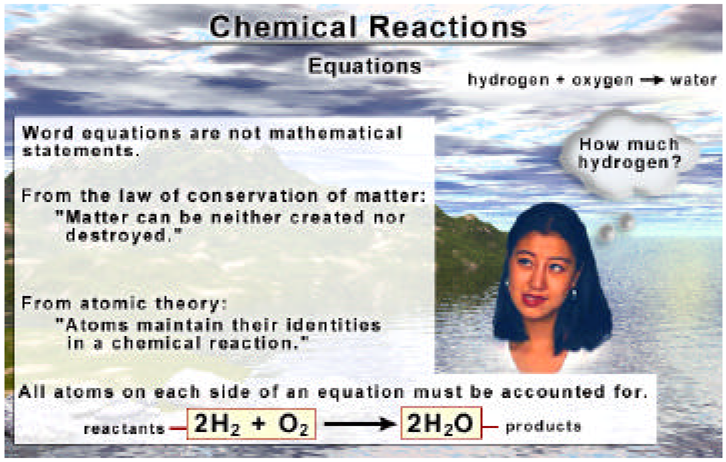
$$\text{hydrogen} + \text{oxygen} \rightarrow \text{water}$$

This is known as a word equation. While a word equation is an accurate statement, it has some drawbacks. First, it is not a universal statement; a French chemist would not necessarily understand the meaning of these English words. Second, a word equation is a qualitative statement, but not a quantitative one. This means that the statement tells us in broad terms what is happening, but it does not tell us how much of each substance is involved. In the next scenes, you will see what chemists have done to solve these problems.

Scene 16

The first problem with word equations is their lack of universality. Chemists have surmounted the language barrier by creating chemical symbols for each of the elements, such as H for hydrogen and O for oxygen. In addition, chemists have developed a system of nomenclature that allows each substance to be represented by a formula. This can be a molecular formula or a formula unit. For example, the word water might not make sense to a French chemist, but the molecular formula, H_2O, would be instantly recognizable. The chemist would immediately know that a water molecule consists of two atoms of hydrogen and one atom of oxygen. If you need more information on chemical formulas, consult a textbook.

Scene 17



The other problem with word equations is that they are not mathematical statements. From the statement “hydrogen plus oxygen yields water,” there is no way of telling how many atoms of hydrogen and oxygen are involved. The law of conservation of matter states that matter can be neither created nor destroyed. Atomic theory says that atoms maintain their identities in a chemical reaction. Taken together, these statements mean that any equation for a reaction must balance, meaning there must be as many atoms of each element on the products side as there are on the reactants side. Therefore, all of the atoms on both sides of the equation must be accounted for. The next few scenes will show you techniques for balancing equations and accounting for the atoms involved in chemical reactions.

Scene18

The first step in balancing a chemical equation is to replace the names of the compounds with their correct chemical formulas. Using the formulas for molecular hydrogen, molecular oxygen and water leads to the following equation:

$$H_2 + O_2 \rightarrow H_2O$$

A quick look at this equation will show you that this is not a balanced equation. Do you see why not? While there are two atoms of hydrogen on both sides of the equation, there are two atoms of oxygen on the left side and only one atom on the right side. This means that one atom of oxygen is unaccounted for. Since matter is always conserved, this is an unacceptable situation. Fortunately, however, a method has been developed to reconcile this, and balance the equation.

Scene 19

Perhaps it has occurred to you that the equation can be balanced if the subscript is removed from the oxygen molecule. This may be tempting, but it is not an acceptable way to balance equations because changing the subscripts of a substance changes the nature of the substance. For example, removing one oxygen atom from the relatively nontoxic carbon dioxide molecule leads to the highly toxic carbon monoxide molecule. In a way it would be analogous to replacing a bicycle with a unicycle. Though a unicycle has half the number of wheels a bicycle has, that does not make it half a bicycle. Each has its own unique character. Molecular oxygen consists of two atoms of oxygen, and must be treated that way in the equation.

Scene 20

Instead of changing the subscript, how about multiplying the amount of products or reactants? This is an acceptable way to manipulate an equation, because only the amount of the substance changes, not its essential nature. In the example of water formation, two atoms of oxygen are needed on the right to balance the two atoms of oxygen on the left. This increase in the number of oxygen atoms can be achieved by doubling the number of water molecules. A whole number that precedes a chemical formula and tells how many units of the substance are present is called a **coefficient**. Therefore the coefficient two is placed in front of H_2O. When there are two molecules of water on the right, this means there are two atoms of oxygen on the right side because there is one atom of oxygen in each water molecule. This gives the equation:

$$H_2 + O_2 \rightarrow 2H_2O$$

This equation is currently balanced with respect to oxygen atoms, but not for hydrogen atoms. The next scene continues the process of balancing this equation.

Scene 21

Take another look at the equation from the last scene. Does this represent a balanced equation? There are two atoms of hydrogen in each water molecule, and there are two water molecules, so there are four hydrogen atoms on the right side. Since there are only two atoms of hydrogen on the left side, the equation is not yet balanced. Do you see a way to get four atoms of hydrogen on the left side? If you said placing the coefficient two in front of the hydrogen molecule could do it, you are correct. That gives the equation:

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

This is a balanced equation. There are four hydrogen atoms and two oxygen atoms on each side of the equation.

Scene 22

In the last few scenes, you have learned techniques for balancing equations. The following rules summarize these techniques and add some refinements and strategies. The first step in balancing equations is to write a preliminary, unbalanced equation using the correct chemical formulas. The second step is to adjust the coefficients of the reactants and products until the equation balances. A polyatomic ion, such as the sulfite ion or the nitrate ion, frequently goes through reactions unchanged, and can be treated as a unit when balancing equations. It is often easiest to begin balancing with elements or polyatomic ions found in only one reactant and one product. If the number of atoms of an element on the reactant side does not evenly divide the number of atoms of that element on the product side, it is often possible to use a variation of the crisscross rule. In this case, use the subscript of the element in the product as a coefficient for the reactant, and vice versa, then finish balancing as you normally would. Learning to balance equations requires a certain amount of trial and error, and becomes easier with practice. The third step in balancing equations is to confirm the number of atoms of each element balances. Finally, make sure the coefficients are in their smallest whole number ratio. In the example on the screen, the coefficients are not in their lowest whole number ratio, because they are all evenly divisible by two.

Scene 23

In addition to atomic symbols, subscripts, and coefficients, other symbols are frequently added to chemical equations. These symbols are used to provide more information about the reaction. For example, the physical states of the reactants and products are often noted. Placing the first letter of the name of the state, *s* for solid, *l* for liquid or *g* for gas, in parentheses after the chemical formula denotes the physical state of the substance. If the compound is in a solution of water, an aq, for aqueous solution, is placed in parentheses. Here are examples using the equations shown earlier. Arrows pointing in both directions indicate that the reaction is reversible, that is, that it will proceed in both directions, from reactants to products and back to reactants. An upper case Greek delta symbol above the arrow indicates that heat is being supplied to the reaction. An example is sodium bicarbonate being heated to form sodium carbonate, water, and carbon dioxide. If a chemical symbol appears above the arrow, it indicates that compound or element acts as a **catalyst**, which is a substance that speeds up a reaction and is present in the same form before and after the reaction.

Scenes 24-46
Types of Chemical Reactions

Scene 24

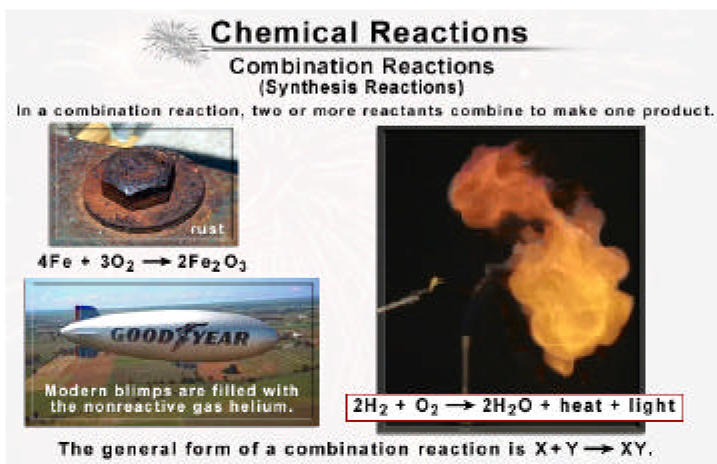
Millions of different chemical reactions are constantly going on all around you. Does this mean that to understand chemistry you have to memorize millions of reactions? Thankfully, the answer is “no.” By studying the way reactions occur, chemists have been able to classify many of them. In the remainder of this program you will learn five common reaction types. Not every chemical reaction fits into one of these five patterns, and some of them fit in more than one. However, most of the reactions you encounter in your chemistry studies will fit into one of the patterns. The five reaction types are: **combination, decomposition, single-replacement, double-replacement, and combustion**. Each type will be presented separately, starting with the combination reaction.

Scene 25

You have already seen that iron combines with oxygen to produce rust, or iron oxide. In a **combination, or synthesis, reaction**, two or more reactants combine to produce one product. The general form of a combination reaction is:

$$X + Y \rightarrow XY$$

The reactants in a combination reaction can be either elements or compounds. Because the product of a combination reaction is always more complex than the reactants, it will always be a compound. Earlier in the program you saw a combination reaction in which both reactants were molecules. Recall that hydrogen and oxygen combine to form water. In 1937 this reaction took place with frightening force when the airship Hindenberg, which was filled with hydrogen gas, exploded over New Jersey. The hydrogen gas in the blimp reacted with atmospheric oxygen to form water, and a great deal of energy. To avoid such tragedies modern blimps are filled with the nonreactive gas helium.



Scene 26

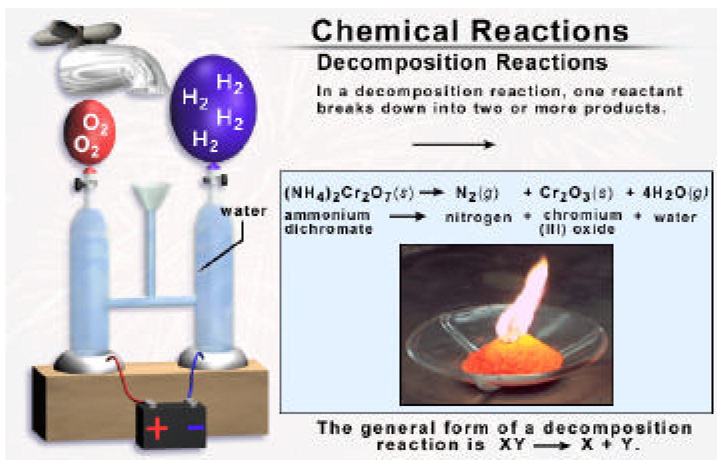
There are many common combination reactions. When a Group A metal cation reacts with a nonmetal the product is an ionic compound. An example is the reaction that produces common table salt. Sodium metal reacts with chlorine gas, producing sodium chloride. Here are some more examples of nonmetals reacting with Group A metals. When transition metals, such as iron, combine with nonmetals, or when two nonmetals combine with each other, there is often more than one possible product. For example, iron and oxygen can form iron(II) oxide or iron(III) oxide. Compounds of nonmetals and oxygen, nonmetal oxides, often combine with water to produce acids, which have a low pH. For example, carbon dioxide combines with water to produce carbonic acid. This reaction occurs in carbonated beverages, such as soda pop. Metallic oxides combine with water to form bases, which have a high pH, as when calcium oxide combines with water to yield calcium hydroxide. On the screen are some other examples of acid and base formation through combination reactions.

Scene 27

A **decomposition reaction** is essentially the reverse of a combination reaction. In a decomposition reaction, one reactant breaks down into two or more products. The general form for a decomposition reaction is:

$$XY \rightarrow X + Y$$

Electricity can be used to break water molecules apart. Notice that the word electricity is placed above the arrow to indicate current drives the reaction. This reaction is the reverse of the combination reaction studied earlier. Liquid water decomposes into hydrogen gas and oxygen gas. Ammonium dichromate decomposes into nitrogen gas, chromium(III) oxide, and water when ignited. In general, a source of energy must be provided for decomposition reactions to occur because the reactants are usually stable.



Scene 28

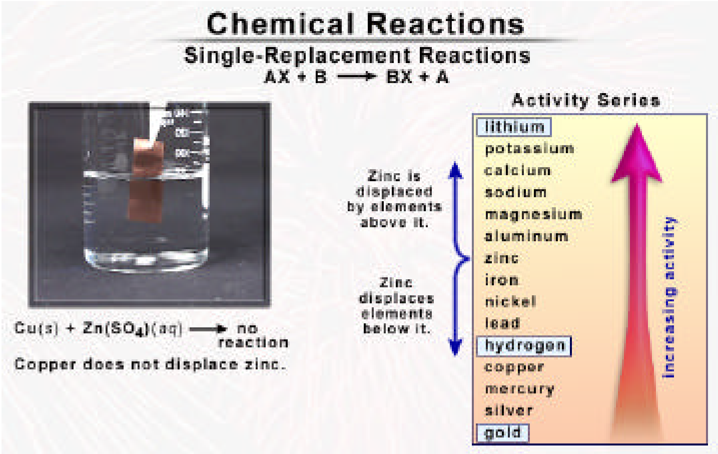
A third kind of chemical reaction is called a **single-replacement reaction**. These reactions are also known as single-displacement reactions. In a single-replacement reaction, one element takes the place of another element in a compound. Single-replacement reactions have the general form:

$$AX + B \rightarrow BX + A$$

When a piece of metallic potassium is placed in a dish of water, a violent reaction occurs. Potassium displaces one of the hydrogen atoms in a water molecule producing hydrogen gas and aqueous potassium hydroxide. In this case, potassium takes the place of one of the hydrogen atoms in a water molecule. A less dramatic single-replacement reaction takes place when a strip of zinc metal is placed in a solution of copper sulfate. The zinc replaces the copper ion in the solution and forms zinc sulfate. The copper that is displaced is deposited on the zinc strip.

Scene 29

What happens if the situation in the previous scene is reversed and a copper strip is placed in a solution of zinc sulfate? The answer is nothing will happen. There will be no reaction in this case, because zinc can displace copper from a compound, but copper cannot displace zinc. In fact, chemists have experimentally determined which metals displace other metals. The results can be displayed on a chart, showing the hierarchy of displacements. Any element in the chart displaces the elements below it, and is displaced by the elements above it. This arrangement of metal elements is known as the **activity series**, and it shows the relative reactivity of each metal. Thus, you can see that lithium will displace any metal on the chart, and any metal will displace gold. You may have noticed that the element hydrogen is on the activity chart with the metals, even though hydrogen is not a metal. It is placed there because in this type of reaction, it is useful to consider whether a metal can displace hydrogen from water.



Scene 30

The activity series can be used to predict the outcomes of reactions. For example, in the reaction demonstrated earlier, the displacement of copper and the formation of zinc sulfate could have been predicted, because zinc is higher on the chart than copper and thus you know it is more reactive. If you were to place a copper wire into a solution of silver nitrate, would the copper displace the silver? Looking at the activity series, you can see that it would. Silver would leave solution, plating on the wire, and aqueous copper(II) nitrate would form, giving the solution a bluish tint:

$$2AgNO_3\,(aq) + Cu(s) \rightarrow Cu(NO_3)_2(aq) + 2Ag(s)$$

What would happen if you placed silver into copper(II) nitrate solution? In this case, a look at the activity series tells you nothing would happen.

Scene 31

Single-replacement reactions also occur when nonmetal elements displace other nonmetal elements, just as some metals can displace other metals. For example, when chlorine gas is bubbled through a solution of sodium iodide, the chlorine displaces the iodine, yielding aqueous sodium chloride and solid iodine. Nonmetals also show trends in displacement. With the exception of the nonreactive noble gases, nonmetal elements on the right of the periodic table or higher on the chart tend to displace those that are lower or on the left. Knowing this, would you expect sulfur to displace oxygen from zinc oxide? This reaction does not happen, which can be predicted by the fact sulfur is lower on the periodic table than oxygen.

Scene 32

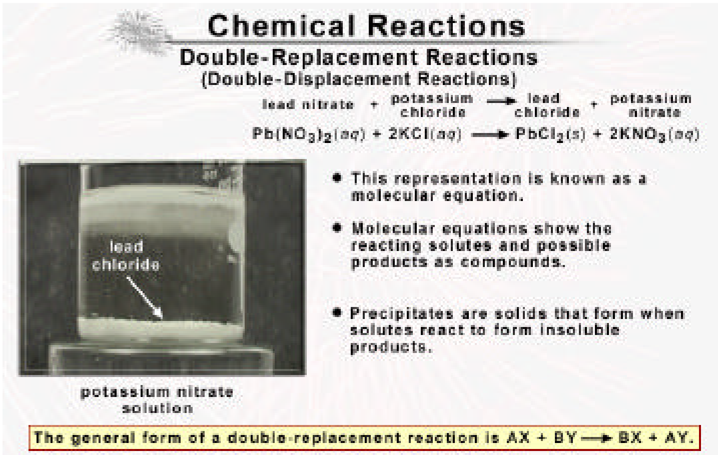
A fourth type of reaction is known as a double-replacement reaction. Double-replacement reactions have the general form:

$$AX + BY \rightarrow BX + AY$$

For example, if solutions of lead nitrate and potassium chloride are mixed, a white solid forms that settles to the bottom. The solid is lead chloride, and it is referred to as a precipitate. **Precipitates** are solids that form when solutes react and form insoluble products. The reaction in this case is a **double-replacement, or double-displacement, reaction** because an exchange of atoms or ions occurs between compounds. In this case, lead cations bond to chloride anions and precipitate out, and potassium cations and nitrate anions stay in solution. The reaction can be written like this:

$$Pb(NO_3)_2(aq) + 2KCl(aq) \rightarrow PbCl_2(s) + 2KNO_3(aq)$$

This way of representing a double-replacement reaction is known as a molecular equation, although this is a bit of a misnomer, since these equations represent not only molecular compounds, but also ionic compounds, as in the example. In a molecular equation, the formulas of the reacting solutes and the possible products are listed as compounds.



Scene 33

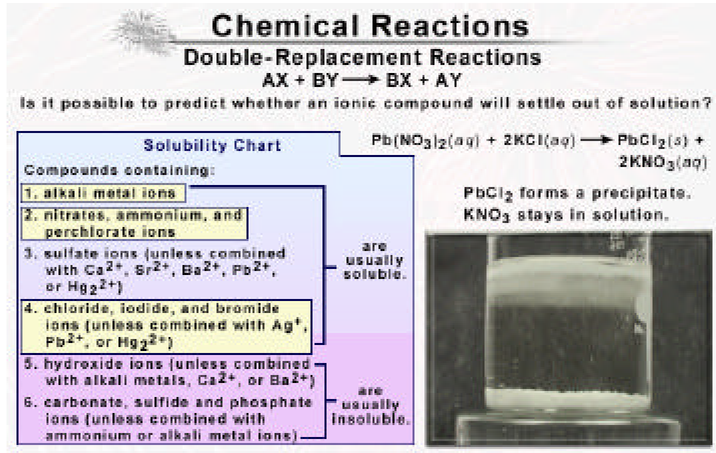
In some cases, the product of a double-replacement reaction is a gas, as when hydrochloric acid reacts with sodium sulfide. In this case, hydrogen sulfide gas is produced and bubbles out of solution while sodium chloride remains in solution. Hydrogen sulfide gas has a characteristic rotten egg smell, and is emitted by fumaroles, which are openings in volcanic areas. Sometimes the two solutions form a liquid, often water. This is the case in the reaction of sulfuric acid with aluminum hydroxide, which produces aluminum sulfate and water. This reaction is an example of an acid-base neutralization reaction, which you will learn more about as you continue studying chemistry. The water produced mixes with the solvent, which is also water, and the aluminum ions and sulfate ions stay in solution as indicated by the notation *aq*. The ions that stay in solution are called **spectator ions**, because they do not participate in the reaction. In the reaction that produced hydrogen sulfide, the sodium and chloride ions are spectator ions, since they remain separated in the solution. In the other reaction, the aqueous aluminum sulfate exists as spectator ions, because the ions remain separated in solution.

Scene 34

Sometimes when solutions are mixed, no precipitate forms, no gas bubbles off, and no water or other liquid forms. If none of these things happens, then no reaction is considered to have occurred. This is because all of the cations and anions stay in solution. For example when barium chloride and ammonium nitrate solutions are mixed, there is no net reaction and all the ions are spectator ions. The outcome of double-replacement reactions can be predicted by looking at the possible combinations the ions in solution can make if they switch partners. If a product forms a gas, like hydrogen sulfide, that is not very soluble, it will tend to leave the solution. If water is formed, it can join the solvent. If a precipitate such as lead chloride forms, it will settle out of solution. If none of these events occurs, there is no driving force for a reaction, and no reaction occurs.

Scene 35

While it is easy to predict if a gas, water, or another molecular compound is formed, is it possible to predict whether an ionic compound will settle out of solution? Chemists have developed a set of solubility rules that answers this question. Take another look at the reaction in which lead chloride precipitates out of a mixture of lead nitrate and potassium chloride solutions. Rule four on the solubility chart states that most chloride salts are soluble, with the exceptions of silver chloride, lead chloride and mercury(I) chloride. Since lead chloride is one of the exceptions to the rule that chloride compounds are soluble, it will form a precipitate. The other possible product is potassium nitrate. As can be seen from rule one and rule two on the solubility chart, both nitrate salts and salts of Group IA metals are usually soluble, so these ions stay in solution as spectator ions.



Scene 36

The solubility chart can be used to predict whether precipitates will form when solutions are mixed. If ammonium perchlorate and copper(II) nitrate solutions are mixed, what happens? The four ions that are in solution are the ammonium ion, the perchlorate ion, the copper(II) ion, and the nitrate ion. Since we already know that the reactants are in solution to start the reaction, we only have to check the solubility of the products. The possible products are ammonium nitrate and copper(II) perchlorate. Rule two on the solubility chart indicates that ammonium and nitrate ions will stay in solution and be spectator ions. Perchlorate ions are always soluble, so the copper(II) ions and perchlorate ions are also spectator ions, thus there are no precipitates formed.

Scene 37

The reaction of lead nitrate and potassium chloride solutions was shown earlier in a **molecular equation,** which shows the possible recombination of ions, whether they are spectator ions or not**.** A reaction can be shown in an equation with the individual ions dissociated, which more accurately represents what happens in a double replacement reaction. This type of reaction is called a **complete ionic equation**. The reaction of lead nitrate and potassium chloride can be rewritten in complete ionic form as shown on the screen:

$$Pb^{2+}(aq) + 2NO_3^-(aq) + 2K^+(aq) + 2Cl^-(aq) \rightarrow PbCl_2(s) + 2K^+(aq) + 2NO_3^-(aq)$$

Spectator ions are represented as separate ions. Notice that lead chloride is not represented as separate ions. This is because the ions form a precipitate and are no longer separated in solution. The complete ionic equation allows one to see all the ions involved in the reaction and any other products formed, such as precipitates or gases. When writing a complete ionic equation, make sure that you use the coefficients that accurately indicate the numbers of every ion involved. This can be done by multiplying the subscript of the ion by the coefficient of the substance from which it dissociated. For example, to determine the number of nitrate ions formed in solution by lead nitrate, multiply the coefficient of lead nitrate, which is one, by the subscript of the nitrate ion, in this case two. This yields two nitrate ions in the complete ionic equation.

Scene 38

Sometimes one is interested in portraying only the reaction that actually occurs in the mixed solutions. In this case, a **net ionic equation** is used. A net ionic equation is a complete ionic equation with the spectator ions removed. Sticking with our previous example, the mixing of lead nitrate and potassium sulfate solutions, the net ionic equation is:

$$Pb^{2+}(aq) + 2Cl^-(aq) \rightarrow PbCl_2(s)$$

As with the complete ionic equation, it is important to make sure that the ions have the correct coefficients. How about the net ionic equation for the mixing of ammonium perchlorate and copper(II) nitrate solutions? If all of the ions in this mixture remain in solution as spectator ions, how is a net ionic equation written? All of the spectator ions in a net equation are omitted, so in a case like this, it is indicated that no reaction occurs by simply writing “no reaction.”

Scene 39

The following scenes give an example of how to write the molecular, complete ionic, and net ionic equations of a double-replacement reaction. Solutions of cadmium chloride and sodium sulfide are mixed. First write the balanced molecular equation by exchanging the cations and anions to form new compounds:

$$CdCl_2 + Na_2S \rightarrow CdS + 2NaCl$$

What are the physical states of the reactants and products? By definition, the reactants are in aqueous solution, but what happens to the products? According to rule four on the solubility table, most chlorides are soluble, so the sodium ion and the chloride ion are spectator ions and sodium chloride is also in aqueous solution. By rule six of the solubility chart, cadmium sulfide, which is used to color glass, is insoluble, and it will form a precipitate, as you see in the video.

Scene 40

The next step is to construct a complete ionic equation for the reaction of cadmium chloride and sodium sulfide. Separating the ions, indicating the correct coefficients, and denoting the physical states gives the equation:

$$Cd^{2+}(aq) + 2Cl^{-}(aq) + 2Na^{+}(aq) + S^{2-}(aq) \rightarrow CdS(s) + 2Na^{+}(aq) + 2Cl^{-}(aq)$$

Are the charges on both sides balanced as well? On the left side of the reaction there are four positive charges and four negative charges, adding up to zero. On the right side there are two positive charges and two negative charges, which also add up to zero; thus the complete ionic equation is balanced for charge.

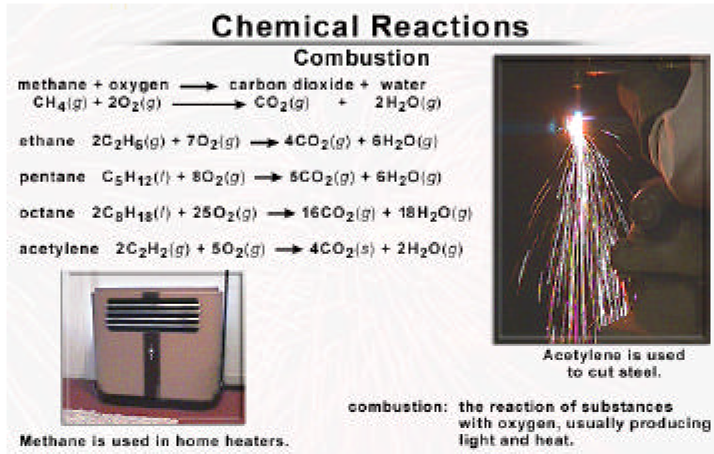
Scene 41

To construct the net ionic equation for the double replacement reaction of cadmium chloride and sodium sulfide, simply cancel out the spectator ions in the complete ionic equation. Doing this results in the equation:

$$Cd^{2+}(aq) + S^{2-}(aq) \rightarrow CdS(s)$$

Again, only the ions that participate in a reaction and are no longer dissociated in the solvent are listed in the net ionic equation. Notice that the overall charge on the left side of the equation is zero, because the two positive charges cancel the two negative charges. The charge on the right side is also zero, because the product, cadmium sulfide, is a compound and therefore uncharged. The equation is balanced and the charges on each side of the equation are equal. This gives you the molecular, complete ionic, and net ionic equations for the reaction of cadmium chloride and sodium sulfide.

Scene 42



The fifth type of reaction covered in this program is the combustion reaction. Much of the energy used in your everyday life comes from the reaction of molecules with oxygen. Gasoline reacts with oxygen, and when burned, generates enough energy to power a car. Propane in a camp stove combines with oxygen to generate heat for cooking. The combining of a substance with oxygen, usually in a way that produces heat and light, is called **combustion**. Many important combustion reactions, such as those just mentioned, occur with organic molecules called **hydrocarbons,** which are made up of carbon and hydrogen. A simple combustion reaction occurs when methane is burned. Methane is the major component in natural gas, which is commonly used to heat homes. In the presence of abundant oxygen and a source of ignition, methane will react with oxygen and produce carbon dioxide and water:

$$CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(g)$$

Similar reactions occur with more complex hydrocarbon compounds, such as ethane, pentane and octane. The combustion of the hydrocarbon acetylene and oxygen generates enough heat that it is used for cutting and welding steel.

Scene 43

If hydrocarbon compounds burn in insufficient amounts of oxygen, carbon monoxide is formed instead of carbon dioxide. While carbon dioxide is relatively nontoxic, and is generated by animals and used by plants, carbon monoxide is a poisonous gas, even at very low concentrations. For this reason, combustion reactions should always take place in a well-ventilated area. If, for example, wood, which reacts with oxygen like a hydrocarbon, is burned in a fireplace with a closed flue, the results could be tragic, because the high concentration of carbon monoxide in the room could be fatal. When even less oxygen is present, the reaction produces elemental carbon, usually called soot. In the typical campfire, there are regions in which oxygen is abundant, restricted, or scarce, thus carbon dioxide, carbon monoxide and soot are all produced.

Scene 44

Carbohydrates are molecules associated with living organisms. In contrast to hydrocarbons, which contain only carbon and hydrogen atoms, carbohydrates contain carbon, hydrogen, and oxygen. Glucose and other sugars are carbohydrates, as are many more complex molecules. Carbohydrates react with plentiful oxygen in organisms to produce carbon dioxide and water, but the reaction occurs much more slowly than the burning of hydrocarbons. The reaction of carbohydrates with oxygen in organisms is called metabolism instead of combustion, although the products are the same. Fats and proteins are also metabolized in organisms, producing carbon dioxide and water, and nitrogen compounds in the case of proteins. The metabolism of these compounds provides the energy necessary for the functioning, growth and reproduction of most living organisms. If there is a reduced amount of oxygen available to the organism, less energy, along with potentially toxic products, such as ethanol and lactic acid, are produced. This runner is feeling the effects of lactic acid buildup.

Scene 45

Metals can also undergo a reaction with molecular oxygen. Magnesium metal reacts quickly with oxygen, as you can see in this demonstration. Pure magnesium metal is reacting with the oxygen in air, producing heat, light and magnesium oxide. In most cases, the reactions of oxygen and metals are slower than this, do not generate light and heat, and are referred to as **corrosion**. The fact that corrosion and combustion reactions differ only in speed has led some people to refer to corrosion as a slow burn. Some products of slower combustion reactions are aluminum oxide and iron(III) oxide, or rust. Notice that these are also combination reactions. They are examples of reactions that can be classified in more than one way.

Scene 46

This completes your introduction to chemical reactions. You have learned how to balance equations, and write equations in the molecular, complete ionic, and net ionic forms. You have also learned about five types of reactions: combination, decomposition, single-replacement, double-replacement and combustion. In addition, you have developed methods of predicting the outcomes of reactions by using the activity series or by determining the products of a double-replacement reaction from the solubility chart. Understanding the various types of reactions and how to balance equations will be invaluable throughout your study of chemistry.

Quiz One
Introduction and Review

1. Which of the following is an example of a chemical reaction?
    A. The rusting of a ship at sea.
    B. Hydrogen and oxygen combining to form water.
    C. The breakdown of sugar as a source of energy in an organism.
    D. All of the above.

2. In a nonreversible chemical reaction, reactants are created from products.
    A. True
    B. False

3. Molecules _____.
    A. result from the formation of covalent bonds
    B. act as discrete units
    C. are formed by the attraction of cations and anions
    D. both A and B

4. In a molecular formula _____.
    A. subscripts indicate the number of atoms of each element in the molecule
    B. the elements are represented in their lowest whole number ratio
    C. all of the atoms in a molecule are represented
    D. both A and C

5. An ion is _____.
    A. a charged atom or group of atoms due to the gain or loss of protons
    B. a charged atom or group of atoms due to the gain or loss of electrons
    C. always necessary to have a combination reaction
    D. both A and C

6. Which is the best modern representation of the barium ion, which is formed when a barium atom loses two electrons?
    A. ^{+2}Ba
    B. ^{++}Ba
    C. Ba_{2+}
    D. Ba^{2+}

7. The metal elements ______.
   A. are found on the left side of the periodic table, tend to lose electrons and form cations
   B. are found on the right side of the periodic table, tend to gain electrons and form anions
   C. show no trend in distribution on the periodic table, and do not form ions
   D. are found on the left side of the periodic table and always form molecules

8. In a polyatomic ion _____.
   A. the individual atoms are held together by ionic bonds
   B. the individual atoms are held together by covalent bonds
   C. there is a tendency for the polyatomic ion to dissociate in water
   D. the positive and negative charges within the polyatomic ion add up to zero

9. The formula unit for strontium chloride, $SrCl_2$, indicates ______.
   A. that in a large sample each atom of strontium is bonded to two specific chorine atoms
   B. that in a sample of strontium chloride there are twice as many chlorine atoms as strontium atoms.
   C. that the charge on the strontium cation is twice the magnitude of the charge on the chloride cation.
   D. both B and C.

10. What is the proper formula unit for the combination of copper(II) ions and chloride ions (Cl^-)?
   A. Cu_2Cl
   B. Cu_2Cl_2
   C. Cu^2Cl
   D. $CuCl_2$

Quiz Two
Solutions

1. When a mixture of olive oil and vinegar is allowed to sit for a period of time, the olive oil floats atop the vinegar. Which of the following is the most likely explanation?
   A. Oil and vinegar have formed a homogeneous mixture.
   B. A double-replacement reaction has taken place.
   C. Oil is not soluble in vinegar.
   D. Both A and B are correct.

2. When the ionic compound sodium chloride dissolves in water _____.
   A. intact units of NaCl are distributed throughout the water
   B. dissociation of the sodium cations and chlorine anions leads to separated ions throughout the solution
   C. the ions separate and form an electrolyte solution
   D. both B and C

3. Molecular substances _____.
   A. never go into solution in water
   B. go into solution in water, but never dissociate
   C. may or may not dissociate in water
   D. form a complex with water molecules and precipitate out of solution

4. An unknown molecular substance is stirred into pure water. Prior to adding this substance, the water did not conduct an electric charge. After the molecular substance is added, a charge is conducted. Which of the following is an accurate conclusion?
   A. The molecular substance did not enter solution.
   B. The molecular substance separated into ions when it entered solution.
   C. The molecular substance did not separate into ions when it entered solution, and remained intact.
   D. The molecular substance and water underwent a combination reaction, leading to the formation of a more complex molecule.

5. A solution is _____.
   A. homogeneous
   B. a type of mixture
   C. uniform throughout
   D. all of the above

6. Sodium chloride is stirred into water to form a solution. In this case, sodium chloride is the _____ and water is the _____.

A. solution; solvent
B. solvent; solute
C. solute; solvent
D. solvent; soluble

7. The term for the amount of a substance that will go into solution at a given temperature and pressure is _____.

A. solvent
B. solubility
C. insoluble
D. solvency

8. Which of the following compounds is always part of an aqueous solution?

A. water
B. carbon tetrachloride
C. sodium chloride
D. acetic acid

9. Two different aqueous solutions are mixed and a white powder falls out of the mixed solution. You can infer that the white powder is _____ in water.

A. soluble
B. dissociated
C. insoluble
D. heterogeneous

10. Solutions are frequently used in chemistry experiments because they can increase how quickly the reaction occurs.

A. True
B. False

Quiz Three
Chemical Equations

1. Which statement is true of word equations for chemical reactions?
    - A. They provide the most accurate way of describing reactions.
    - B. They are recognizable by speakers of all languages.
    - C. At best, they provide a qualitative, but not quantitative, description of a reaction.
    - D. They are just as useful as reactions described by chemical nomenclature.

2. When balancing equations _____.
    - A. there must be as many atoms of each element on the products side as the reactants side
    - B. coefficients indicate the number of each reactant and product
    - C. atoms that leave solution as a gas can be ignored
    - D. both A and B

3. A reasonable next step toward balancing the equation for the reaction $N_2 + O_2 \rightarrow NO_2$ would be to _____.
    - A. place the coefficient three in front of the oxygen molecule
    - B. change the subscript of the nitrogen molecule to a one
    - C. place the coefficient two in front of the nitrogen dioxide molecule
    - D. relax, the equation is already balanced

4. Placing the coefficient two in front of the product tetraiodine nonaoxide (I_4O_9) means that how many atoms of each element must be accounted for on the other side of the equation?
    - A. Four iodine atoms and nine oxygen atoms.
    - B. Eight iodine atoms and nine oxygen atoms.
    - C. Nine iodine atoms and four oxygen atoms.
    - D. Eight iodine atoms and eighteen oxygen atoms.

5. Given the word equation "methane (CH_4) burns in oxygen to produce carbon dioxide and water," the first step in balancing would be to write a preliminary, unbalanced equation with the correct chemical formulas. Which of the following is the correct form?
    - A. $CH_4 + CO_2 \rightarrow O_2 + H_2O$
    - B. $CO_2 + H_2O \rightarrow CH_4 + O_2$
    - C. $CH_4 + O_2 \rightarrow CO_2 + H_2O$
    - D. $CH_4 \rightarrow O_2 + CO_2 + H_2O$

6. Is the equation $4NH_3 \rightarrow 2N_2 + 6H_2$ a completed, balanced equation?
   A. Yes, because there are equal amounts of atoms of each element on both sides.
   B. Yes, because the coefficients are in their lowest whole number ratio.
   C. No, because the coefficients could be reduced to 2, 2, and 4.
   D. No, because the coefficients could be reduced to 2,1, and 3.

7. A reasonable next step toward balancing the equation $I_2 + O_2 \rightarrow I_4O_9$ would be to _____.
   A. experiment with coefficient on the reactant side
   B. determine the charges of the ions formed by iodine and oxygen
   C. crisscross the subscript nine in the product to be the coefficient of molecular oxygen, and the subscript two from molecular oxygen to be the coefficient of the product
   D. crisscross the subscript nine in the product to be the coefficient of molecular iodine, and the subscript two from molecular iodine to be the coefficient of the product

8. Is the reaction $2C_8H_{18} + 25O_2 \rightarrow 8CO_2 + 18H_2O$ a completed, balanced equation?
   A. No, because the number of oxygen atoms on the product side does not equal the number of oxygen atoms on the reactant side.
   B. Yes, because all of the coefficients are in their lowest whole number ratio.
   C. No, because the number of carbon atoms on the product side does not equal the number of carbon atoms on the reactant side.
   D. Both A and C are correct.

9. A logical next step in balancing the equation $CS_2(l) + Cl_2(g) \rightarrow CCl_4(l) + S_2Cl_2(l)$ is to ______.
   A. place the coefficient 2 in front of sulfur dichloride
   B. place the coefficient 3 in front of the chlorine molecule
   C. leave it alone, as it is already balanced
   D. place the coefficient 4 in front of carbon disulfide

10. A logical next step to continue balancing the equation $3CO(g) + Fe_2O_3(s) \rightarrow Fe(s) + 3CO_2(g)$ is to ______.
   A. place the coefficient 2 in front of iron(III) oxide
   B. leave it alone, as it is already balanced
   C. place the coefficient 2 in front of elemental iron
   D. crisscross the subscript 2 from the oxygen in carbon dioxide as the coefficient of iron(III) oxide, and the subscript 3 from the oxygen in iron(III) oxide as the coefficient of carbon dioxide.

Quiz Four
Types of Chemical Reactions

1. The reaction $4I_2 + 9O_2 \rightarrow 2I_4O_9$ is an example of a _______ reaction.
    A. combination
    B. decomposition
    C. single-replacement
    D. double-replacement

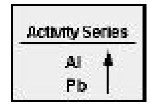
2. If chlorine gas is bubbled through an aqueous solution of sodium iodide, the result is elemental iodine and aqueous sodium chloride solution. What kind of reaction took place?
    A. Combination
    B. Combustion
    C. Double-replacement
    D. Single-replacement

3. A hockey player has the puck in the corner of the rink. An opposing player muscles him aside and emerges with the puck. This situation is most analogous to which kind of reaction?
    A. Double-replacement
    B. Combustion
    C. Nuclear
    D. Single-replacement

4. When blood passes through the lungs, carbon dioxide and water are formed from carbonic acid dissolved in the blood ($H_2CO_3(aq) \rightarrow H_2O(l) + CO_2(g)$) The carbon dioxide formed passes into the lungs and is exhaled. What kind of reaction has occurred?
    A. Decomposition
    B. Combination
    C. Chain
    D. Single-replacement

5. Aluminum metal can react with oxygen gas to produce aluminum oxide (Al_2O_3). What type of reaction is this?
    A. Combination
    B. Single-replacement
    C. Corrosion
    D. Both A and C are correct.

6. Use the activity chart to answer the following question. When a piece of aluminum is placed in a lead(II) nitrate solution, what will happen?



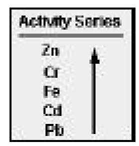
A. $Al(s) + Pb(NO_3)_2(aq) \rightarrow Al(NO_3)_3(aq) + Pb(s)$
B. No reaction occurs.
C. $2Al(s) + 3Pb(NO_3)_2(aq) \rightarrow 2Al(NO_3)_3(aq) + 3Pb(s)$
D. The answer cannot be determined from the information given.

7. When solutions of sodium nitrate ($NaNO_3$) and calcium hydroxide ($Ca(OH)_2$) are mixed, all of the ions are spectator ions. What is the net ionic equation?

A. $Ca^{2+} + 2NO_3^- \rightarrow Ca(NO_3)_2$
B. $Na^+ + OH^- \rightarrow NaOH$
C. $Ca^{2+} + 2OH^- + 2Na^+ + 2NO_3^- \rightarrow Ca(NO_3)_2 + 2NaOH$
D. No reaction

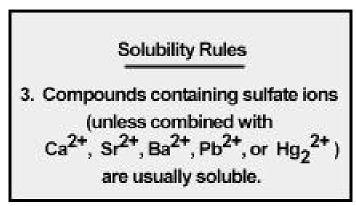
8. An unknown metal displaces cadmium from solution, but does not displace chromium. Based on the activity series, this metal is most likely _____.

A. lead
B. sodium
C. iron
D. zinc



9. Based on the solubility chart, calcium sulfate ($CaSO_4$) will precipitate in water.

A. True
B. False



10. Potassium sulfide and zinc chloride solutions are mixed. The equation $2K^+(aq) + S^{2-}(aq) + Zn^{2+}(aq) + 2Cl^-(aq) \rightarrow ZnS(s) + 2K^+(aq) + 2Cl^-(aq)$ represents what kind of equation?

A. Net ionic
B. Complete ionic
C. Molecular
D. Unbalanced

Multiple Choice Exam

1. Which of the following is an example of a chemical reaction?
   A. The rusting of a ship at sea.
   B. Hydrogen and oxygen combining to form water.
   C. The breakdown of sugar as a source of energy in an organism.
   D. All of the above.

2. In a nonreversible chemical reaction, reactants are created from products.
   A. True
   B. False

3. Molecules _____.
   A. result from the formation of covalent bonds
   B. act as discrete units
   C. are formed by the attraction of cations and anions
   D. both A and B

4. In a molecular formula _____.
   A. subscripts indicate the number of atoms of each element in the molecule
   B. the elements are represented in their lowest whole number ratio
   C. all of the atoms in a molecule are represented
   D. both A and C

5. An ion is _____.
   A. a charged atom or group of atoms due to the gain or loss of protons
   B. a charged atom or group of atoms due to the gain or loss of electrons
   C. always necessary to have a combination reaction
   D. both A and C

6. Which is the best modern representation of the barium ion, which is formed when a barium atom loses two electrons?
   A. ^{+2}Ba
   B. ^{++}Ba
   C. Ba_{2+}
   D. Ba^{2+}

7. The metal elements ______.
   A. are found on the left side of the periodic table, tend to lose electrons and form cations
   B. are found on the right side of the periodic table, tend to gain electrons and form anions
   C. show no trend in distribution on the periodic table, and do not form ions
   D. are found on the left side of the periodic table and always form molecules

8. In a polyatomic ion _____.
   A. the individual atoms are held together by ionic bonds
   B. the individual atoms are held together by covalent bonds
   C. there is a tendency for the polyatomic ion to dissociate in water
   D. the positive and negative charges within the polyatomic ion add up to zero

9. The formula unit for strontium chloride, $SrCl_2$, indicates ______.
   A. that in a large sample each atom of strontium is bonded to two specific chorine atoms
   B. that in a sample of strontium chloride there are twice as many chlorine atoms as strontium atoms
   C. that the charge on the strontium cation is twice the magnitude of the charge on the chloride cation
   D. both B and C.

10. When a mixture of olive oil and vinegar is allowed to sit for a period of time, the olive oil floats atop the vinegar. Which of the following is the most likely explanation?
   A. Oil and vinegar have formed a homogeneous mixture.
   B. A double-replacement reaction has taken place.
   C. Oil is not soluble in vinegar.
   D. Both A and B are correct.

11. What is the proper formula unit for the combination of copper(II) ions and chloride ions (Cl^-)?
   A. Cu_2Cl
   B. Cu_2Cl_2
   C. Cu^2Cl
   D. $CuCl_2$

12. When the ionic compound sodium chloride dissolves in water _____.
   A. intact units of NaCl are distributed throughout the water
   B. dissociation of the sodium cations and chlorine anions leads to separated ions throughout the solution
   C. the ions separate and form an electrolyte solution
   D. both B and C

13. Molecular substances _____.
   A. never go into solution in water
   B. go into solution in water, but never dissociate
   C. may or may not dissociate in water
   D. form a complex with water molecules and precipitate out of solution

14. An unknown molecular substance is stirred into pure water. Prior to adding this substance, the water did not conduct an electric charge. After the molecular substance is added, a charge is conducted. Which of the following is an accurate conclusion?

A. The molecular substance did not enter solution.
B. The molecular substance separated into ions when it entered solution.
C. The molecular substance did not separate into ions when it entered solution, and remained intact.
D. The molecular substance and water underwent a combination reaction, leading to the formation of a more complex molecule.

15. Which statement is true of word equations for chemical reactions?

A. They provide the most accurate way of describing reactions.
B. They are recognizable by speakers of all languages.
C. At best, they provide a qualitative, but not quantitative, description of a reaction.
D. They are just as useful as reactions described by chemical nomenclature.

16. When balancing equations _____.

A. there must be as many atoms of each element on the products side as the reactants side
B. coefficients indicate the number of each reactant and product
C. atoms that leave solution as a gas can be ignored
D. both A and B

17. A reasonable next step toward balancing the equation for the reaction $N_2 + O_2 \rightarrow NO_2$ would be to _____.

A. place the coefficient three in front of the oxygen molecule
B. change the subscript of the nitrogen molecule to a one
C. place the coefficient two in front of the nitrogen dioxide molecule
D. relax, the equation is already balanced

18. Placing the coefficient two in front of the product tetraiodine nonaoxide (I_4O_9) means that how many atoms of each element must be accounted for on the other side of the equation?

A. Four iodine atoms and nine oxygen atoms.
B. Eight iodine atoms and nine oxygen atoms.
C. Nine iodine atoms and four oxygen atoms.
D. Eight iodine atoms and eighteen oxygen atoms.

19. Given the word equation “methane (CH_4) burns in oxygen to produce carbon dioxide and water,” the first step in balancing would be to write a preliminary, unbalanced equation with the correct chemical formulas. Which of the following is the correct form?

A. $CH_4 + CO_2 \rightarrow O_2 + H_2O$
B. $CO_2 + H_2O \rightarrow CH_4 + O_2$
C. $CH_4 + O_2 \rightarrow CO_2 + H_2O$
D. $CH_4 \rightarrow O_2 + CO_2 + H_2O$

20. Is the equation $4NH_3 \rightarrow 2N_2 + 6H_2$ a completed, balanced equation?

A. Yes, because there are equal amounts of atoms of each element on both sides.
B. Yes, because the coefficients are in their lowest whole number ratio.
C. No, because the coefficients could be reduced to 2, 2, and 4.
D. No, because the coefficients could be reduced to 2,1, and 3.

21. A reasonable next step toward balancing the equation $I_2 + O_2 \rightarrow I_4O_9$ would be to _____.

A. experiment with coefficient on the reactant side
B. determine the charges of the ions formed by iodine and oxygen
C. crisscross the subscript nine in the product to be the coefficient of molecular oxygen, and the subscript two from molecular oxygen to be the coefficient of the product
D. crisscross the subscript nine in the product to be the coefficient of molecular iodine, and the subscript two from molecular iodine to be the coefficient of the product

22. The reaction $4I_2 + 9O_2 \rightarrow 2I_4O_9$ is an example of a _______ reaction.

A. combination
B. decomposition
C. single-replacement
D. double-replacement

23. Is the reaction $2C_8H_{18} + 25O_2 \rightarrow 8CO_2 + 18H_2O$ a completed, balanced equation?

A. No, because the number of oxygen atoms on the product side does not equal the number of oxygen atoms on the reactant side.
B. Yes, because all of the coefficients are in their lowest whole number ratio.
C. No, because the number of carbon atoms on the product side does not equal the number of carbon atoms on the reactant side.
D. Both A and C are correct.

24. A logical next step in balancing the equation $CS_2(l) + Cl_2(g) \rightarrow CCl_4(l) + S_2Cl_2(l)$ is to ______.

A. place the coefficient 2 in front of sulfur dichloride
B. place the coefficient 3 in front of the chlorine molecule
C. leave it alone, as it is already balanced
D. place the coefficient 4 in front of carbon disulfide

25. A logical next step to continue balancing the equation $3CO(g) + Fe_2O_3(s) \rightarrow Fe(s) + 3CO_2(g)$ is to ______.

A. place the coefficient 2 in front of iron(III) oxide
B. leave it alone, as it is already balanced
C. place the coefficient 2 in front of elemental iron
D. crisscross the subscript 2 from the oxygen in carbon dioxide as the coefficient of iron(III) oxide, and the subscript 3 from the oxygen in iron(III) oxide as the coefficient of carbon dioxide.

26. If chlorine gas is bubbled through an aqueous solution of sodium iodide, the result is elemental iodine and aqueous sodium chloride solution. What kind of reaction took place?

A. Combination
B. Combustion
C. Double-replacement
D. Single-replacement

27. In a car's exhaust system, carbon monoxide is converted to carbon dioxide by the reaction $2CO + O_2 \xrightarrow{Pt} 2CO_2$. What is the role of platinum in this reaction?

A. It provides energy for the reaction.
B. It makes up the container in which the reaction takes place.
C. It is converted into carbon atoms to balance the reaction.
D. It acts as a catalyst.

28. Two pairs of dancers encounter each other on the dance floor. The couples switch partners, with each woman now dancing with the other man. This situation is analogous to which kind of reaction?

A. Double-replacement
B. Combustion
C. Nuclear
D. Single-replacement

29. A hockey player has the puck in the corner of the rink. An opposing player muscles him aside and emerges with the puck. This situation is most analogous to which kind of reaction?
   A. Double-replacement
   B. Combustion
   C. Nuclear
   D. Single-replacement

30. The corrosion of metal can be seen as a type of combustion reaction, and is sometimes referred to as a slow burn.
   A. True
   B. False

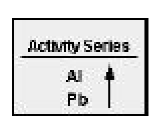
31. What kind of reaction is depicted by the equation $2CO + O_2 \xrightarrow{Pt} 2CO_2$?
   A. Double-replacement
   B. Decomposition
   C. Combination
   D. Single-replacement

32. When blood passes through the lungs, carbon dioxide and water are formed from carbonic acid dissolved in the blood ($H_2CO_3(aq) \rightarrow H_2O(l) + CO_2(g)$) The carbon dioxide formed passes into the lungs and is exhaled. What kind of reaction has occurred?
   A. Decomposition
   B. Combination
   C. Chain
   D. Single-replacement

33. In single-replacement reactions, metals lower on the activity chart replace metals higher on the activity chart.
   A. True
   B. False

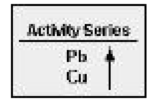
34. Aluminum metal can react with oxygen gas to produce aluminum oxide (Al_2O_3). What type of reaction is this?
   A. Combination
   B. Single-replacement
   C. Corrosion
   D. Both A and C are correct.

35. Use the activity chart to answer the following question. When a piece of aluminum is placed in a lead(II) nitrate solution, what will happen?



   A. $Al(s) + Pb(NO_3)_2(aq) \rightarrow Al(NO_3)_3(aq) + Pb(s)$
   B. No reaction occurs.
   C. $2Al(s) + 3Pb(NO_3)_2(aq) \rightarrow 2Al(NO_3)_3(aq) + 3Pb(s)$
   D. The answer cannot be determined from the information given.

36. Use the activity chart to answer the following question. When a piece of copper is placed in a lead nitrate solution, what will happen?



A. $Cu + Pb(NO_3)_2(aq) \rightarrow Cu(NO_3)_2(aq) + Pb(s)$
B. No reaction occurs.
C. $2Cu(s) + 3Pb(NO_3)_2(aq) \rightarrow 2Cu(NO_3)_2(aq) + 3Pb(s)$
D. The answer cannot be determined from the information given.

37. How many carbon dioxide molecules are generated by the combustion of one molecule of hexane (C_7H_{14}) in ample oxygen?
A. Fourteen
B. Four
C. Seven
D. Eight

38. Which of the following most accurately describes spectator ions?
A. They are brightly colored ions that allow a chemist to view the progress of a reaction in a solution.
B. They are ions that are present in solution on both the product and reactant sides of a complete ionic equation, but do not participate in a reaction.
C. They are a necessary component of all combustion reactions.
D. They are written on the products side of a complete ionic reaction, but not the reactants side.

39. When solutions of hydrochloric acid (HCl) and calcium hydroxide ($Ca(OH)_2$) are mixed, the products are calcium and chloride ions in solution and water. What is the net ionic reaction?
A. $Ca^{2+} + 2Cl^- \rightarrow CaCl_2$
B. $Ca^{2+} + 2OH^- + 2H^+ + 2Cl^- \rightarrow CaCl_2 + 2H_2O$
C. $H^+ + OH^- \rightarrow H_2O$
D. No reaction.

40. When solutions of sodium nitrate ($NaNO_3$) and calcium hydroxide ($Ca(OH)_2$) are mixed, all of the ions are spectator ions. What is the net ionic equation?
A. $Ca^{2+} + 2NO_3^- \rightarrow Ca(NO_3)_2$
B. $Na^+ + OH^- \rightarrow NaOH$
C. $Ca^{2+} + 2OH^- + 2Na^+ + 2NO_3^- \rightarrow Ca(NO_3)_2 + 2NaOH$
D. No reaction.

41. In the equation $NH_4NO_3 \xrightarrow{\Delta} N_2O + 2H_2O$, what does the delta symbol above the arrow indicate?

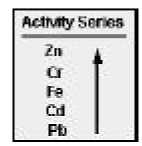
A. The reaction was carried out at high altitude.
B. The reaction happens extremely quickly.
C. The reaction is a decomposition reaction.
D. Heat is supplied to drive the reaction.

42. Based on their positions on the periodic table, would bromine displace chlorine from a compound?

A. Yes
B. No

43. An unknown metal displaces cadmium from solution, but does not displace chromium. Based on the activity series, this metal is most likely _____.

A. lead
B. sodium
C. iron
D. zinc



44. Based on the solubility chart, calcium sulfate ($CaSO_4$) will precipitate in water.

A. True
B. False

Solubility Rules

3. Compounds containing sulfate ions (unless combined with Ca^{2+}, Sr^{2+}, Ba^{2+}, Pb^{2+}, or Hg_2^{2+}) are usually soluble.

45. Based on the solubility chart, sodium hydroxide (NaOH) will precipitate in water.

A. True
B. False

Solubility Rules

5. Compounds containing hydroxide ions (unless combined with alkali metals, Ca^{2+}, or Ba^{2+}) are usually insoluble.

46. When a person exercises extremely vigorously, the products of the metabolism of glucose are lactic acid and water. At a less vigorous level of exercise, glucose is completely metabolized into carbon dioxide and water. Which of the following statements best explains why lactic acid is produced in one reaction and carbon dioxide is produced in the other?
   A. In vigorous exercise, enzymes are unable to keep up with the reaction.
   B. In vigorous exercise, water collects in the cells.
   C. In vigorous exercise, there is insufficient oxygen for complete combustion of glucose.
   D. Lactic acid is a more useful by-product.

47. Potassium sulfide and zinc chloride solutions are mixed. The equation $2K^+(aq) + S^{2-}(aq) + Zn^{2+}(aq) + 2Cl^-(aq) \rightarrow ZnS(s) + 2K^+(aq) + 2Cl^-(aq)$ represents what kind of equation?
   A. Net ionic
   B. Complete ionic
   C. Molecular
   D. Unbalanced

48. What is wrong with the equation $2K^+(aq) + S^{2-}(aq) + Zn^+(aq) + 2Cl^-(aq) \rightarrow ZnS(s) + 2K^+(aq) + 2Cl^-(aq)$?
   A. The number of each atom on the product side does not equal the number of each atom on the reactant side.
   B. The potassium ion is never found in aqueous solution.
   C. The overall charge on the product side of the reaction does not equal the overall charge on the reactant side.
   D. There is nothing wrong with this equation.

49. Iron(II) sulfate and sodium phosphate solutions are mixed. The complete ionic form of the reactant side of the equation is $3Fe^{2+} + 3SO_4^{2-} + 6Na^+ + 2PO_4^{3-}$. What is the overall charge for the reactants?
   A. Negative one
   B. Zero
   C. One
   D. Two

50. The metabolism of organic compounds in living organisms provides the energy necessary for growth, reproduction, and other functions.
   A. True
   B. False

Key to Quizzes

Quiz 1 Key	Quiz 2 Key	Quiz 3 Key	Quiz 4 Key
1. D	1. C	1. C	1. A
2. B	2. D	2. D	2. D
3. D	3. C	3. C	3. D
4. D	4. B	4. D	4. A
5. B	5. D	5. C	5. D
6. D	6. C	6. D	6. C
7. A	7. B	7. C	7. D
8. B	8. A	8. A	8. C
9. D	9. C	9. B	9. A
10. D	10. A	10. C	10. B

Multiple Choice Exam Key

1. D	11. D	21. C	31. C	41. D
2. B	12. D	22. A	32. A	42. B
3. D	13. C	23. A	33. B	43. C
4. D	14. B	24. B	34. D	44. A
5. B	15. C	25. C	35. C	45. B
6. D	16. D	26. D	36. B	46. C
7. A	17. C	27. D	37. C	47. B
8. B	18. D	28. A	38. B	48. C
9. D	19. C	29. D	39. C	49. B
10. C	20. D	30. A	40. D	50. A

Glossary

acid: a substance that produces hydronium ions when dissolved in water.

activity series: a table of elements listed in order of chemical reactivity.

anion: a negatively charged atom or group of atoms resulting from the gain of one or more electrons. An anion has more electrons than protons.

atom: the smallest unit of an element that retains the chemical identity of that element. Atoms are composed of electrons, protons, and neutrons.

atomic theory of matter: postulates presented by John Dalton in 1803 regarding the composition of matter. The theory states: 1) elements are composed of atoms that are similar to one another and different from atoms of other elements, 2) that these atoms can neither be created nor destroyed, and 3) that compounds are composed of combinations of atoms in fixed ratios.

carbohydrate: a type of organic molecule that contains carbon, hydrogen and oxygen atoms.

catalyst: a substance that increases the rate of a chemical reaction, but is not chemically changed as a result of the reaction.

cation: any positively charged atom or group of atoms resulting from the loss of one or more electrons. A cation has more protons than electrons.

chemical bond: the electrical forces which hold together atoms or groups of atoms.

chemical equation: a system for using chemical formulas and coefficients to indicate the types and ratios of products and reactants in a chemical reaction.

chemical formula: a system of using element symbols and subscripted numbers to describe the ratios of elements in compounds.

chemical reaction: the conversion of substances into different substances that have different chemical properties.

coefficient: in chemical equations, a numerical prefix indicating the number of each reactant or product in a chemical equation.

combination reaction: the chemical combining of two or more reactants to form one product. The general form of a combination reaction is $X + Y \rightarrow XY$.

combustion reaction: the chemical reaction of a substance with oxygen, usually producing light and heat.

compound: a substance of more than one element bonded together in a set ratio.

corrosion: the chemical reaction of metals with oxygen, this process is generally slower than combustion reactions, and therefore does not usually produce light and heat.

covalent bond: the sharing of electrons between atoms, resulting in electrical attraction.

decomposition reaction: the chemical breakdown of a reactant into two or more products. The general form of a decomposition reaction is $XY \rightarrow X + Y$.

dissociation: a process in which a compound splits into its component molecules or ions.

dissolution: a process in which a compound dissolves in a solvent to make a solution.

double-replacement reaction: the mutual exchange of ions or atoms in two compounds. The general form of a double replacement reaction is $AX + BY \rightarrow BX + AY$.

electron: an atomic particle that is negatively charged.

electronic structure: the organization of the electrons in an atom, accounting for the various levels, sublevels, orbitals, and spins of the electrons.

element: the most fundamental form of matter; elements can not be further simplified by chemical means.

gas: a state of matter with no set shape or volume.

homogeneous mixture: a mixture that is uniform throughout, in that a sample taken in one place is chemically identical to a sample taken anywhere else in the mixture.

hydrocarbon: a type of organic molecule that is composed of only carbon and hydrogen atoms.

insoluble: the incapability of a substance (solute) to dissolve in a given solvent.

ion: any atom or group of atoms that carries a positive or negative charge.

ionic bond: the attractive force that occurs between a metal cation and a nonmetal anion, resulting in an ionic compound.

liquid: : the state of matter that assumes the shape of its container and occupies a definite volume.

metal: an element that occupies the center or the left side of the periodic table. Metallic elements tend to lose electrons, typically have high melting points, can be formed into shapes, and are good conductors of heat and electricity.

mixture: a combination of two or more substances that do not react when mixed.

molecular formula: a chemical formula used to show the number and types of atoms present in a molecule.

molecule: a collection of two or more covalently bonded atoms.

noble gas: an element that occupies Group 8A of the periodic table(Group 18 in the IUPAC system). The term noble refers to the fact that they are nonreactive due to their closed shell electronic structure.

nonmetal: an element found at the far right of the periodic table. The nonmetals tend to accept electrons, typically have a low melting point, cannot be formed into shapes, and are poor conductors of heat and electricity.

octet rule: the tendency of an atom to form compounds that result in eight electrons occupying its valence shell.

periodic table: a chart illustrating factual information and predictable relationships, or trends, among the elements. The periodic table shows chemical elements, arranged in the order of their atomic numbers as groups displaying similar physical and chemical properties.

polyatomic ion: a group of covalently bonded atoms that charge.

precipitate: an insoluble ionic solid formed by mixing solutions of ionic compounds.

precipitation: the formation of insoluble ionic solids when solutions containing ionic compounds are mixed.

product: a substance resulting from a chemical reaction.

reactant: a substance that enters a chemical reaction.

single-replacement reaction: a chemical reaction resulting in the substitution of an uncombined element (B) for an element in a compound and the formation of an uncombined element (A). The general form for a single-replacement reaction is $AX + B \rightarrow BX + A$.

solid: a state of matter having a definite shape and volume.

solubility: the quantity of a solute that will dissolve into a given amount of solvent at a specified temperature and pressure.

solute: a substance dissolved in a solution.

solution: a homogeneous mixture of more than one substance combined in the same physical state.

solvent: the medium in which a substance (a solute) is dissolved in a solution.

spectator ion: an ion present in solution before and after a reaction because it does not participate in the reaction.

Stock system: a system of characterizing ions by using Roman numerals to indicate ionic charge. For example, Fe^{+3} would be the iron(III) ion in this system.

valence electrons: the outer shell electrons that are available for and capable of forming bonds with other atoms. Valence electrons are electrons occupying the outermost energy level.