Chapter 10

Chemical Reactions

When some people think of *chemistry*, they often think of things that suddenly give off smelly odors, or explode. The process that makes the "stink" in a "stink bomb" and an explosion are examples of *chemical reactions*. Chemical reactions occur everywhere around you every day. Chemical reactions happen in the engines of automobiles to make them go. Chemical reactions happen in plants that release oxygen into the atmosphere.

Would you be surprised to learn that chemical strong enough to dissolve metal is in your stomach all the time? The chemical is hydrochloric acid and it is a necessary part of the chemical process of breaking food down into nutrients that can be used by your body. In fact, chemical reactions are responsible for most of the food digestion that occurs in your body each day, as well as many other body processes. In this chapter you will learn what chemical reactions are and how they occur.

Key Questions

1. ***Why are baking soda and vinegar such good ingredients for making a volcano model?***

2. ***What does it mean to balance a chemical reaction equation?***

3. ***When something burns, is there a chemical reaction taking place?***

10.1 Understanding Chemical Reactions

If you leave a tarnished copper penny in acid for a few minutes the penny becomes shiny again. The copper oxide that tarnished the penny was removed by a chemical reaction with the acid. Chemical reactions are the process through which chemical changes happen.

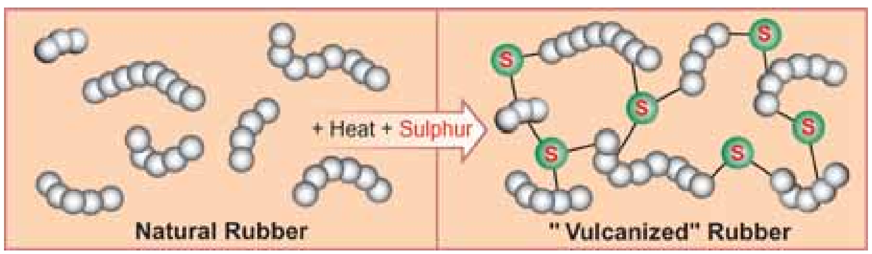
VOCABULARY

chemical reaction - a process that rearranges chemical bonds to create new substances.

Chemical changes rearrange chemical bonds

Chemical change Ice melting is an example of a *physical change*. During a physical change, a substance changes its form but remains the same substance. A *chemical change* turns one or more substances into different substances that usually have different properties. An example of chemical change is burning wood into ashes.

Using chemical changes We use chemical changes to create useful materials. The rubber in car tires is an example of a material that has been modified by chemical changes. A chemical change called *vulcanization* inserts pairs of sulfur atoms into the long chain molecules of natural rubber. The sulfur ties adjacent molecules together like rungs on a ladder and makes vulcanized rubber much harder and more durable.



Recognizing chemical change A **chemical reaction** is a system of chemical changes that involves the breaking and reforming of chemical bonds to create new substances. A chemical reaction occurs when you mix baking soda with vinegar. The mixture bubbles violently as carbon dioxide gas, a new substance, is formed. The temperature of the mixture also gets noticeably colder. Bubbling, new substances, and temperature change can all be evidence of chemical change (Figure 10.1).

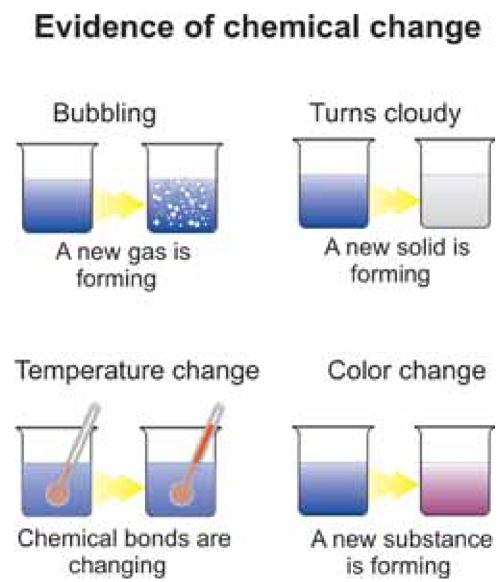


Figure 10.1: *Four observations that may be evidence of chemical change.*

Products and reactants

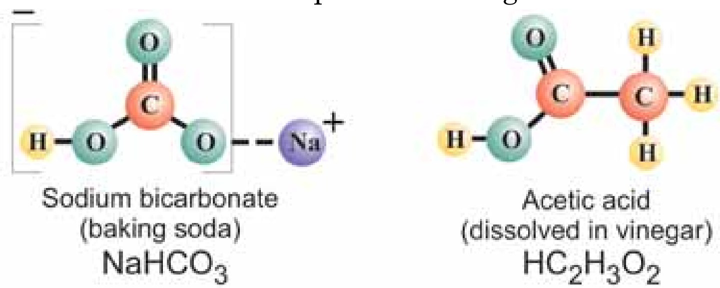
Products and reactants How do we show the chemical reaction between baking soda and vinegar (Figure 10.2)? In cooking, you start with *ingredients* that are combined to make different *foods*. In chemical reactions, you start with **reactants** that are combined to make **products**. The reactants are substances which are combined and changed in the chemical reaction (baking soda and vinegar). The products are the new substances which result from the chemical reaction. The reactants and products may include atoms, compounds, and energy.

VOCABULARY

reactants - the substances which are combined and changed in the chemical reaction.

products - the new substances which result from a chemical reaction.

Products may change phase in a reaction The substances in a chemical reaction may be in different phases. In this reaction the reactants are a solid (baking soda) and a liquid solution (vinegar). What are the products? The bubbling that goes on is a clue that at least one of the products is a gas.



Start by counting the atoms in the products Chemically, the components that react are sodium bicarbonate ($NaHCO_3$) in the baking soda and acetic acid ($HC_2H_3O_2$) in the vinegar. The first step in understanding the reaction is to see what atoms are in the reactants. If you count them you see there are four elements: carbon, oxygen, sodium, and hydrogen. *The reaction must rearrange these same atoms into the products.*

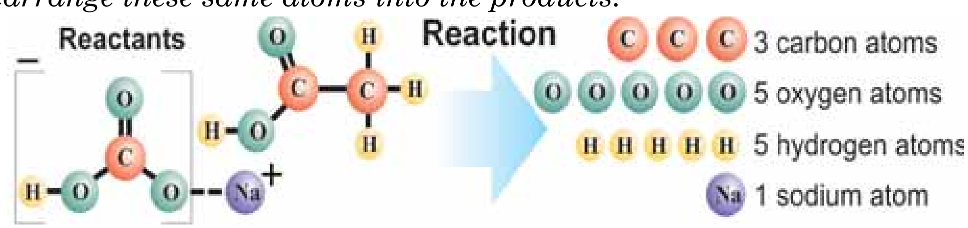
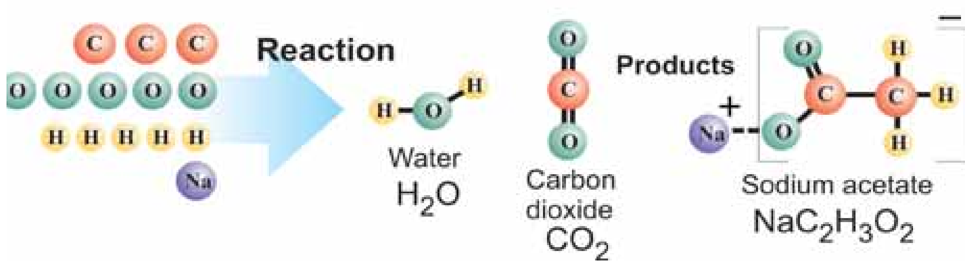


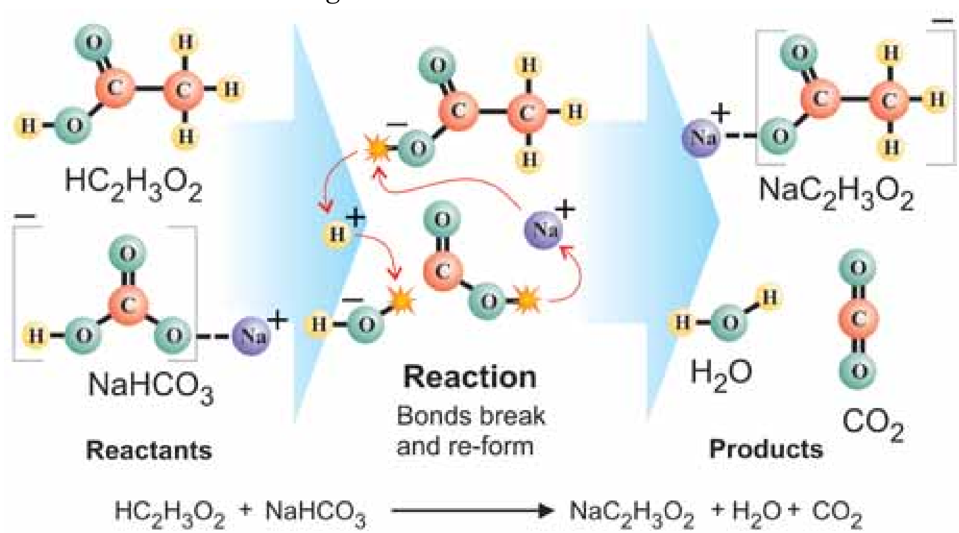
Figure 10.2: *The chemical reaction between baking soda and and vinegar.*

The products of the reaction

Figuring out the products The chemical reaction rearranges the same atoms in the reactants to become new compounds in the products. In this case, the 3 carbon, 5 oxygen, 5 hydrogen, and 1 sodium atoms are rearranged to become sodium acetate ($NaC_2H_3O_2$), water (H_2O) and carbon dioxide (CO_2). Note that *the same exact atoms in the reactants are rearranged to make the products*. No new atoms are created!



The whole reaction We can now see the whole reaction clearly. Only three chemical bonds actually change. The sodium ion jumps to the acetic acid to make sodium acetate. The rest of the bicarbonate breaks up into water and carbon dioxide. Since carbon dioxide is a gas, that explains the bubbles observed during the reaction.



A chemical reaction rearranges the atoms of the reactants to form the new compounds of the products

No new atoms are created!

CHALLENGE

A similar reaction occurs when an effervescent tablet is dropped into water. The tablet contains sodium bicarbonate and citric acid. The reactants are:

$NaHCO_3$ + H^+ (from citric acid) + H_2O

Can you figure out what the products are? Hint: This reaction creates a bubbling gas, too.

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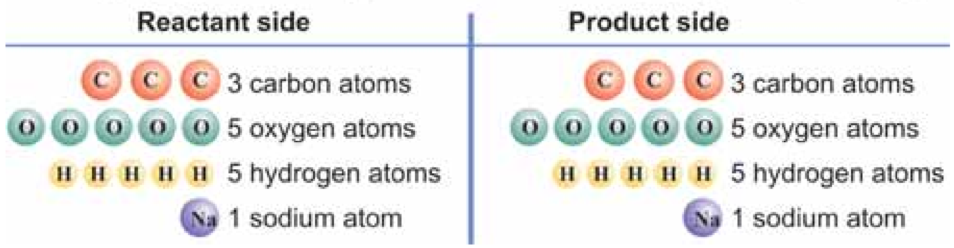
Chemical equations

Understanding a chemical equation

A **chemical equation** is an abbreviated way to show the exact numbers of atoms and compounds in a chemical reaction. Without drawing elaborate diagrams, we can write the baking soda and vinegar reaction as a chemical equation. The arrow shows the direction the reaction goes, from reactants to products.

Chemical equation

$$HC_2H_3O_2 + NaHCO_3 \longrightarrow NaC_2H_3O_2 + H_2O + CO_2$$



Conservation of mass

Notice that there are the exact same number of each type of atom on the reactant side of the equation as there are on the product side. There are three carbon atoms in the reactants and three carbon atoms in the products. This demonstrates that *chemical reactions conserve mass*. The total mass of the reactants is equal to the total mass of the products because they are the same atoms! They have just been rearranged into new compounds.

Demonstrating conservation of mass

Once you understand atoms and reactions, conservation of mass is a perfectly obvious result. The mass is the same because *the atoms are the same atoms*. Of course, demonstrating the conservation of mass in this reaction is tricky because one of the products is a gas! It took a long time before people realized that mass is conserved because they were fooled by their own measurements. If you compared the mass of the reactants and products as shown in Figure 10.3, what do you think you will find? Can you think of a way to do the experiment so that no mass escapes being measured?

VOCABULARY

chemical equation - an equation of chemical formulas that shows the exact numbers of atoms and compounds in a chemical reaction. For example:

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

Conservation of mass

The mass of the reactants equals the mass of the products

Would doing the reaction this way demonstrate the conservation of mass?

Figure 10.3: *If you tried to demonstrate conservation of mass this way, what would you find? Would the mass of the reactants equal the mass of the products?*

Balancing chemical equations

Multiple compound reactions

The baking soda and vinegar reaction was a good one to learn about chemical equations because only one kind of each compound appeared. However, many reactions involve more than one compound of each type. A good example is the reaction that combines hydrogen and oxygen to produce water.

Start with the un-balanced reaction

The reaction combines hydrogen and oxygen molecules as shown.

Count the atoms on each side

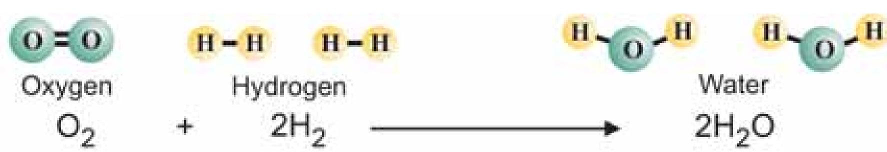
Next we count the atoms to see if there are the same number of each type of atom on the reactant and product sides of the equation.

Reactant side	Product side
2 oxygen atoms	1 oxygen atom
2 hydrogen atoms	2 hydrogen atoms

There is one more oxygen atom on the reactant side than there is on the product side. This means the reaction equation is not *balanced*. A balanced chemical equation has the same number of each type of atom on the product side and the reactant side.

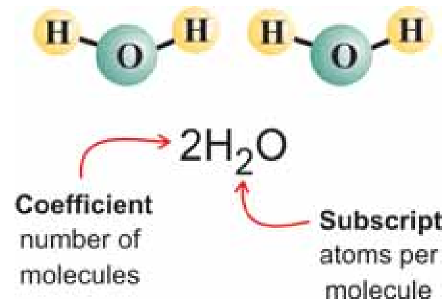
The balanced chemical equation

To balance the equation, we add another water molecule to the product side. Now there are equal numbers of oxygen atoms on both sides. However, there aren't equal numbers of hydrogen atoms, so another hydrogen molecule is added to the reactant side.



Reactant side	Product side
2 oxygen atoms	2 oxygen atoms
4 hydrogen atoms	4 hydrogen atoms

Understanding the numbers in a chemical equation



The large number 2 in "$2H_2O$" tells you there are *two molecules* of H_2O in the reaction. The large number is called a *coefficient*. If a coefficient is not written it is understood to be "1."

The little numbers (subscripts) tell you how many atoms of each element there are in *one molecule*. For example, the subscript 2 in H_2O means there are two hydrogen atoms in a single water molecule.

CHALLENGE

The hydrogen-oxygen reaction releases a lot of energy and many people hope hydrogen will replace gasoline as a fuel for cars.

10.1 Section Review

1. What is the difference between a physical change in matter and a chemical change in matter?
2. In the following list, decide whether each item is a physical or a chemical change:
   a. liquid water freezes into solid ice
   b. wood burns to ashes
   c. a window shatters when hit with a rock
   d. an old car sits in a junkyard and rusts
   e. a cup of hot chocolate gives off steam
3. Answer the following questions about this chemical equation:

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

   a. How many carbon atoms are on the reactant side of the equation? How many hydrogen? How many oxygen?
   b. How many carbon atoms are on the product side of the equation? How many hydrogen? How many oxygen?
   c. Is this equation balanced? How do you know?
   d. What does the coefficent “2” in front of the H_20 mean?
4. Which of the following reactions is balanced?
   a. $CS_2 + 3O_2 \rightarrow CO_2 + SO_2$
   b. $2N_2O_5 + NO \rightarrow 4NO_2$
   c. $P_4 + 5O_2 \rightarrow P_2O_5$
   d. $Cl_2 + 2Br \rightarrow 2Cl + Br_2$
5. What does “mass is conserved in a chemical reaction” mean?
6. It has been said that chemical equations are sentences in the language of chemistry. List three things that chemical equations can tell you about a chemical reaction.

Balancing chemical equations

(1) Start with the correct chemical formula for each compound that appears as a reactant or product.

(2) Write down the equation for the reaction (un-balanced).

(3) Count the number of atoms of each element in the reactants and the products.

(4) Adjust the coefficient of each reactant or product until the total number of each type of atom is the same on both sides of the equation. This is done by trial and error.

Important reminder: You can NOT change subscripts in order to balance an equation. For example, calcium chloride has the chemical formula, $CaCl_2$. You can NOT change the subscript on Cl from 2 to 3 and make $CaCl_3$ to get an extra chlorine atom. $CaCl_3$ is a totally different compound than $CaCl_2$. *You can only change coefficients to balance equations.*

10.2 Energy and chemical reactions

If you have ever felt the heat from a campfire or fireplace, you have experienced the energy from a chemical reaction. *Burning* is a chemical reaction that *gives off* energy in the form of heat and light. In plants, photosynthesis is a reaction that *uses* energy from sunlight (Figure 10.4). In fact, *all chemical reactions involve energy*.

The two types of reactions

Energy is involved in two ways

Energy is involved in chemical reactions in two ways. (1) At the start of a chemical reaction, some (or all) bonds between atoms in the reactants must be broken so that the atoms are available to form new bonds. (2) Energy is released when new bonds form as the atoms recombine into the new compounds of the products. We classify chemical reactions based on how energy used in (1) compares to energy released in (2).

Exothermic reactions

If forming new bonds releases *more* energy than it takes to break the old bonds, the reaction is **exothermic.** Once started, exothermic reactions tend to keep going because each reaction releases enough energy to start the reaction in neighboring molecules. A good example is the burning of hydrogen in oxygen. If we include energy, the balanced reaction looks like this.

$$\underset{\text{Oxygen}}{O_2} + \underset{\text{Hydrogen}}{2H_2} \longrightarrow \underset{\text{Water}}{2H_2O} + \text{Energy}$$

Endothermic reactions

If forming new bonds in the products releases *less* energy than it took to break the original bonds in the reactants, the reaction is **endothermic**. *Endothermic reactions absorb energy*. These reactions need energy to keep going. An example of an important endothermic reaction is *photosynthesis*. In photosynthesis, plants use energy in sunlight to make glucose and oxygen from carbon dioxide and water.

$$\underset{\text{Carbon dioxide}}{6\,CO_2} + \underset{\text{Water}}{6\,H_2O} + \text{Energy} \longrightarrow \underset{\text{Glucose}}{C_6H_{12}O_6} + \underset{\text{Oxygen}}{6\,O_2}$$

VOCABULARY

exothermic - a reaction is exothermic if it releases more energy than it uses.

endothermic - A reaction is endothermic if it uses more energy than it releases.

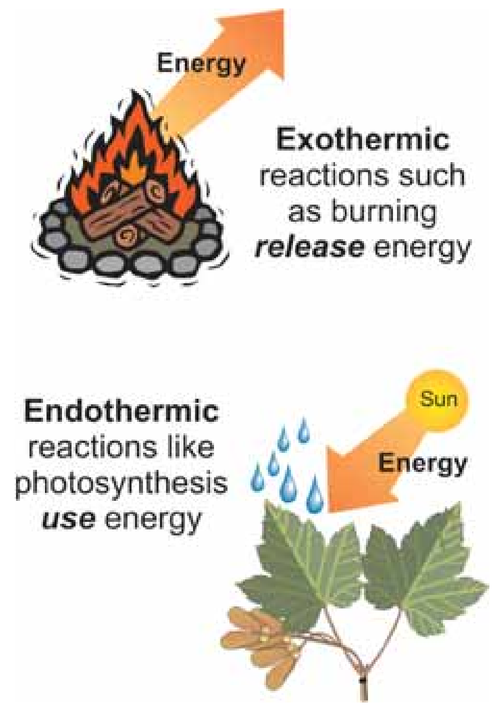
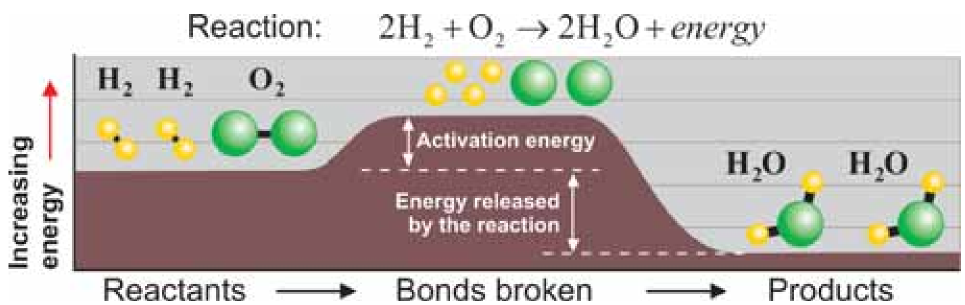


Figure 10.4: *Exothermic and endothermic reactions.*

Activation energy

An interesting question Exothermic reactions occur because the atoms arranged as compounds of the products have lower energy then they had when arranged as compounds of the reactants. Since this is true, why don't all of the elements immediately combine into the molecules that have the lowest possible energy?

Activation energy The answer has to do with **activation energy**. Activation energy is the energy needed to start a reaction and break chemical bonds in the reactants. Without enough activation energy, a reaction will not happen even if it releases energy when it does happen. That is why a flammable material, like gasoline, does not burn without a spark or flame. The spark supplies the activation energy to start the reaction.



An example reaction The diagram above shows how the energy flows in the reaction of hydrogen and oxygen. The activation energy must be supplied to break the molecules of hydrogen and oxygen apart. Combining 4 free hydrogen and oxygen atoms into 2 water molecules releases energy. The reaction is exothermic because the energy released by forming water is greater than the activation energy. Once the reaction starts, it supplies its own activation energy and quickly grows (Figure 10.5).

Thermal energy A reaction starts by itself when thermal energy is greater than the activation energy. Any reaction which could start by itself, probably already has! The compounds and molecules that we see around us are ones that need more activation energy to change into anything else.

VOCABULARY

activation energy - energy needed to break chemical bonds in the reactants to start a reaction.

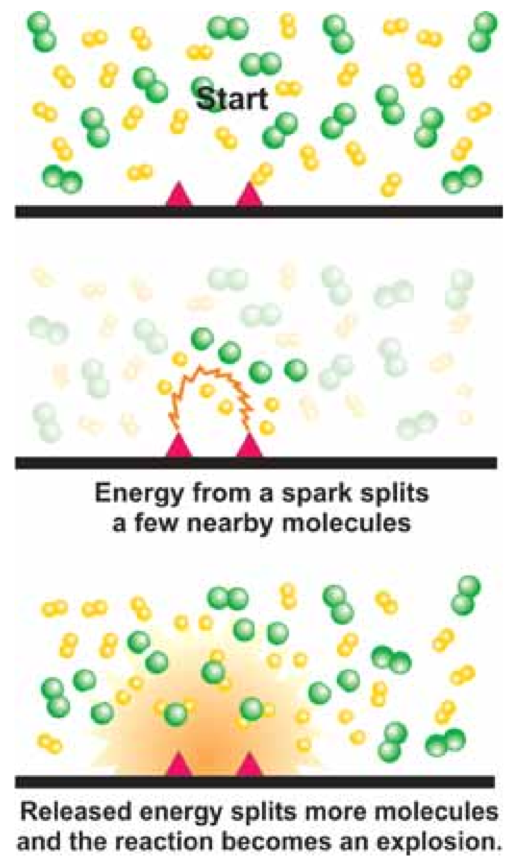
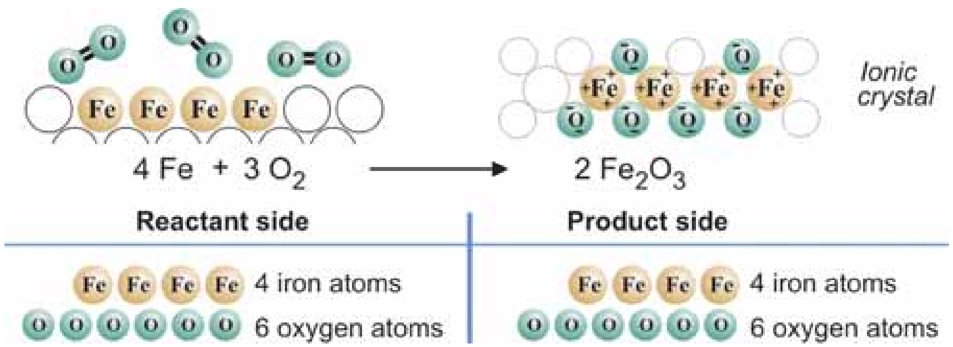


Figure 10.5: *Because energy released by one reaction supplies activation energy for new reactions, exothermic reactions can grow quickly once activation energy has been supplied.*

Addition reactions

Compounds are made in addition reactions

In an **addition reaction**, two or more substances combine to form a new compound. A good example of an addition reaction is the formation of rust (iron oxide, Fe_2O_3) from pure iron and dissolved oxygen in water. Iron oxide is an ionic crystal because the bonds between iron and oxygen are ionic bonds. Ionic crystals do not have structure diagrams like molecules however, they do have the specific ratio of atoms given by the chemical formula (2 Fe to every 3 O).



Polymerization is an addition reaction

As you saw earlier in this chapter, polymers are large molecules made up of repeating segments. The process of creating these molecules is called **polymerization**. Polymerization is a series of addition reactions that join small molecules into very long chain molecules. Polymers are made by joining smaller molecules called monomers.

Acid rain

Some fossil fuels, like coal, contain sulfur. When these fuels are burned, the sulfur reacts with oxygen in the air to form sulfur dioxide in an addition reaction. In air polluted with sulfur dioxide, sulfur trioxide is create when sulfur dioxide reacts with oxygen. Finally, *sulfuric acid* is produced by a third addtion reaction of sulfur trioxide with water.

VOCABULARY

addition reaction - two or more substances chemically combine to form a new compound.

polymerization - a series of addition reactions that join small molecules into large chain molecules.

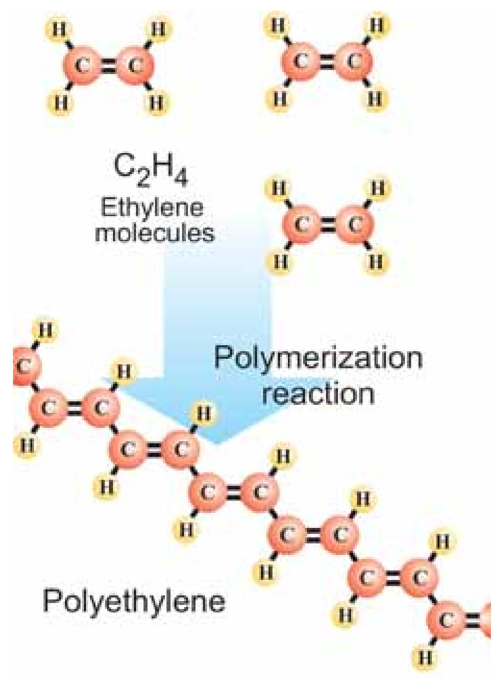


Figure 10.6: *Polymerization is a series of successive addition reactions that combine small molecules into large chain molecules.*

Decomposition reactions

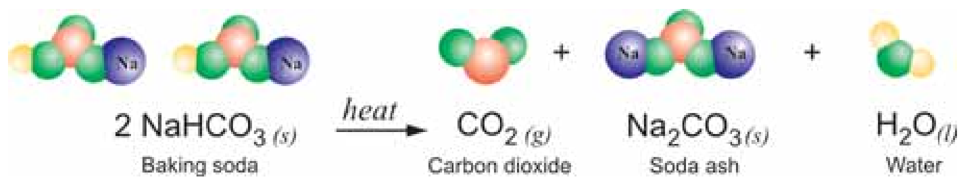
Describing the phase of a product or reactant

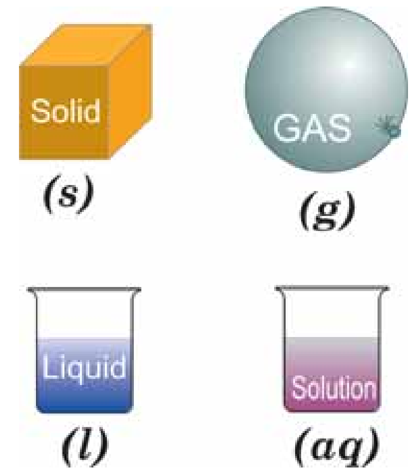
In many cases, you wish to know the form of the products and reactant in a reaction. Are they solid, liquid or gas? Are they dissolved in water? The small symbols in the parentheses (*s, l, g, aq*) next to each chemical formula indicate the phase of each component in the reaction (Figure 10.7).

Decomposition reactions

A chemical reaction in which a single compound is broken down to produce two or more smaller compounds is called a **decomposition reaction**. The simplest kind of decomposition is the breakdown of a binary compound into its elements, as in the decomposition of water into hydrogen and oxygen with electricity:

Larger compounds can also decompose to produce other compounds, as in the decomposition of baking soda with heat:





symbol	meaning
(s)	substance is a solid
(l)	substance is a liquid
(g)	substance is a gas
(aq)	substance is dissolved in solution (aqueous)

Figure 10.7: *What do the symbols shown in parentheses mean?*

Write a balanced decomposition reaction

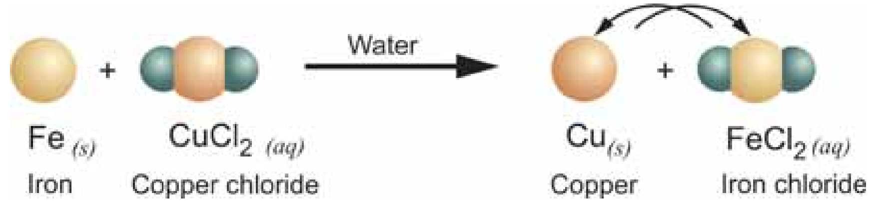
Write a balanced chemical equation for the decomposition reaction of potassium chlorate ($KClO_3$) into potassium chloride (KCl) a salt substitute in food, and oxygen (O_2).

1. Looking for: The balanced chemical equation
2. Given: Products ($KClO_3$) and reactants (KCl, O_2)
3. Relationships: The total number of each type of atom must be the same on both sides of the equation.
4. Solution: The unbalanced equation is: $KClO_3 \rightarrow KCl + O_2$
   The oxygen atoms are not balanced so we need to add molecules of $KClO_3$ and O_2
   The balanced equation is: $2KClO_3 \rightarrow 2KCl + 3O_2$

Displacement and precipitation reactions

In single displacement, one element replaces another

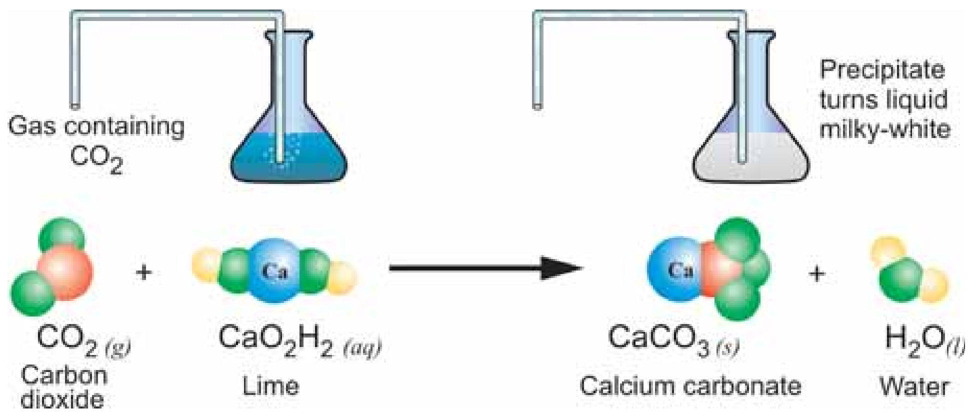
In single-displacement reactions, one element replaces a similar element in a compound. For example, if you place an iron nail into a beaker of copper (II) chloride solution, you will begin to see reddish copper forming on the iron nail. In this reaction, iron *replaces* copper in the solution and the copper *falls out* of the solution as a metal:



Precipitation occurs when one product is insoluble

In many reactions dissolved substances react to form substances that are no longer soluble. The insoluble product drops out of solution, forming a **precipitate**. A precipitate is a solid product that comes out of solution in a chemical reaction. Precipitates usually form many small particles which cause a cloudy appearance in a solution (Figure 10.8).

The limewater test for carbon dioxide is a precipitation reaction. In this test, a gas suspected of containing carbon dioxide is bubbled through a solution of CaO_2H_2 (limewater). Any carbon dioxide in the gas reacts to form a precipitate, turning the solution milky-white.



VOCABULARY

precipitate - a solid product that comes out of solution in a chemical reaction.

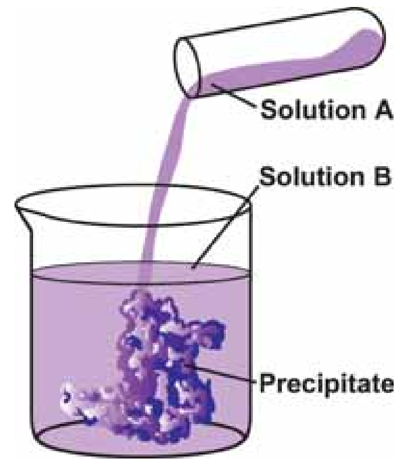


Figure 10.8: *The formation of a cloudy precipitate is evidence that a double-displacement reaction has occurred.*

Combustion reactions

Petroleum is a mixture of hydrocarbons

Almost 40 percent of all the energy we use comes from petroleum (oil) and 2/3 of that is gasoline and diesel fuel. Petroleum is not a single substance but a complex mixture of many substances created over millions of years by the decay of plants and animals. The major elements in petroleum are hydrogen and carbon, with smaller amounts of oxygen, nitrogen, and sulfur.

Refining

The *refining* process separates petroleum into molecules with different numbers of carbon atoms. The smaller molecules are used in gasoline. Heavier molecules become kerosene and heating oil. The heaviest molecules become tar and asphalt used for roads (Figure 10.9).

Range of molecule sizes	End use
C_1 - C_{12}	Gasoline and light fuels, such as aviation fuel
C_{12} - C_{18}	Kerosene and heating oil
C_{19} - C_{30}	Grease, motor oil, wax
C_{31} - C_{36+}	Tar and asphalt

The reactions of burning gasoline

In a perfect reaction, all the hydrocarbon molecules are completely burned to into carbon dioxide and water. Unfortunately, in an engine not all the fuel burns completely and pollutants such as carbon monoxide are also formed. Impurities in fuel, such as sulfur and nitrogen in the air, also have reactions that form pollutants such as oxides of nitrogen and sulfuric acid.

Perfect combustion reaction

$$\underset{\text{Iso-octane}}{2\,C_8H_{18}} + \underset{\text{Oxygen}}{25\,O_2} \xrightarrow{\text{spark}} \underset{\text{Carbon dioxide}}{16\,CO_2} + \underset{\text{Water}}{18\,H_2O}$$

Actual combustion reaction

$$\underset{\text{Iso-octane}}{2\,C_8H_{18}} + \underset{\text{Oxygen}}{27\,O_2} + \underset{\text{Nitrogen}}{N_2} + \underset{\text{Sulfur}}{S} \longrightarrow \underset{\text{Carbon dioxide}}{15\,CO_2} + \underset{\text{Carbon monoxide}}{CO} + \underset{\text{Water}}{17\,H_2O} + \underset{\text{Nitrogen oxides}}{2\,NO} + \underset{\text{Sulfuric acid}}{H_2SO_4}$$

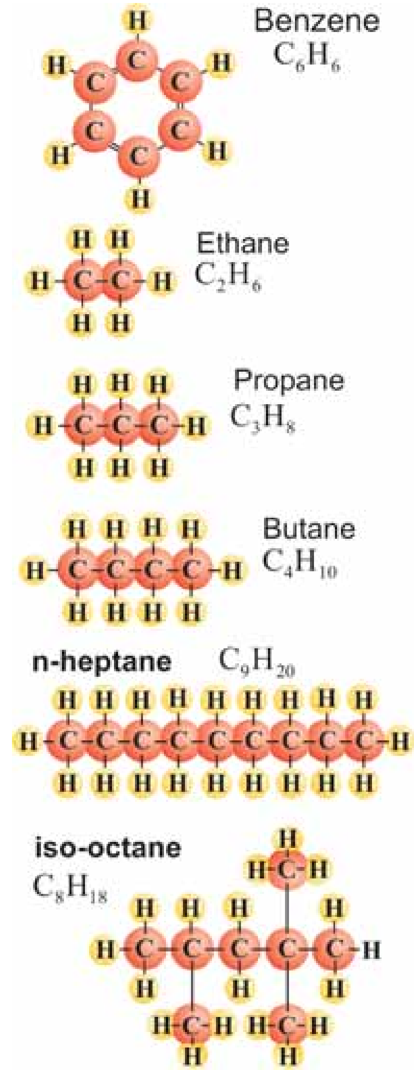


Figure 10.9: *Some of the many molecules found in gasoline. These are examples of hydrocarbons, molecules made with only hydrogen and carbon.*

Nuclear reactions

What is a nuclear reaction?

Nuclear reactions change the nucleus of an atom. Until just 100 years ago people looked for a way to turn lead into gold. With today's understanding of nuclear reactions, it is now possible. However, we don't do it very often because the process is much more expensive than gold itself!

Nuclear versus chemical

Because they affect the nucleus itself, nuclear reactions can change one element into a different element. Nuclear reactions can also change an isotope into a different isotope of the same element. Remember, isotopes of the same element have the same number of protons but different numbers of neutrons in the nucleus. By comparison, chemical reactions do *not* change the types of atoms. Chemical reactions only rearrange atoms into different compounds.

Nuclear reactions involve more energy than chemical reactions

Nuclear reactions involve much more energy than chemical reactions. The energy in a nuclear reaction is much greater because nuclear reactions involve the strong nuclear force, the strongest force in the universe. Chemical reactions involve electrical forces. The electrical force acting on an electron far from the nucleus is much smaller than the strong force acting on a proton or neutron *inside* the nucleus. The difference in strength between the forces involved is the reason nuclear reactions are so much more energetic than chemical reactions (Figure 10.10).

Mass and energy in nuclear reactions

Mass and energy are conserved together but *not* separately in nuclear reactions. This is because nuclear reactions can convert mass into energy. If you could take apart a nucleus and separate all of its protons and neutrons, the separated protons and neutrons would have more mass than the nucleus does all together. This bizarre fact is explained by Einstein's formula ($E = mc^2$), which tells us that mass (m) can be converted to energy (E), when multiplied by the speed of light (c) squared. The mass of a nucleus is reduced by the energy that is released when the nucleus comes together.

VOCABULARY

nuclear reaction - a process that changes the nucleus of an atom and may turn one element into a completely different element.

Chemical reactions	Nuclear reactions
What part of the atom is involved?	
Outer electrons	Nucleus (protons and neutrons)
What changes?	
Atoms are rearranged into new molecules but the atoms stay the same	Atoms may change into atoms of a different element
How much energy is involved?	
A small amount	A huge amount

Figure 10.10: *Comparing nuclear and chemical reactions.*

10.2 Section Review

1. What two ways is energy involved in chemical reactions?
2. Explain the difference between an exothermic and an endothermic reaction.
3. This is the chemical equation for the formation of rust:

$$4Fe_{(s)} + 3O_{2(g)} \rightarrow 2Fe_2O_{3(s)} + \text{energy}$$

   a. What do the symbols "(s)" and "(g)" mean?
   b. Is this reaction endothermic or exothermic?
   c. Is this a decomposition, addition, or displacement reaction?
4. Explain what *activation energy* is, and give an example that proves you understand its meaning.
5. What is a *polymer*, and what type of chemical reaction produces a polymer?
6. Identify the following reactions as: addition, decomposition, displacement, or combustion reactions.
   a. $2KCLO_3 \rightarrow 2KCl + 3O_2$
   b. $Mg + 2AgNO_3 \rightarrow Mg(NO_3)_2 + 2Ag$
   c. $6Li + N_2 \rightarrow 2Li_3N$
   d. $2C_3H_7OH + 9O_2 \rightarrow 6CO_2 + 8H_2O$
7. List three ways that nuclear reactions are different from chemical reactions.
8. Petroleum refineries can be found throughout the United States. What does it mean to *refine* petroleum, and why must this process be performed?

CHALLENGE

Propane - a common fuel

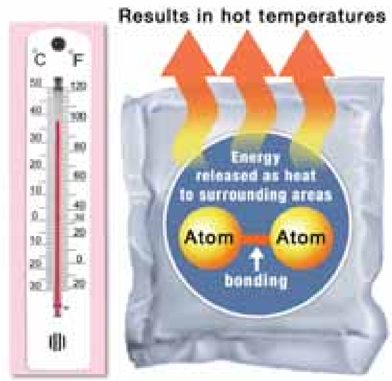
Propane, C_3H_8, is a fuel that is used by cooks and campers every day. It is burned in oxygen to make a flame that can cook food, provide heat and light, and even run refrigerators. Write the complete, balanced chemical equation for the combustion of propane.

CHEMISTRY CONNECTION: The Science of Hot and Cold Packs

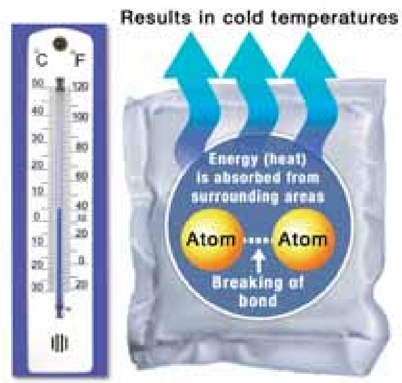
Have you ever had an injury, such as to you knee or back? If so, chances are you have used a cold or hot pack to treat the injury and provide pain relief. Cold and hot packs can be made ready in an instant without refrigeration or a microwave. Although it seems that these packs magically work, it's really a mini chemistry lab that lies within the plastic wrap.

Endothermic and exothermic reactions

Thermochemistry is the study of the heat given off or absorbed during a chemical reaction. A chemical reaction refers to when substances are mixed and new substances are formed. In chemical reactions, bonds between atoms are broken or formed, and heat may be given off or taken up during the process.



With many chemical reactions, energy may be released in the form of heat. This is called an exothermic reaction. When an exothermic reaction occurs, bonds are made between atoms. During this bond making, energy is lost to the surroundings. As a result, exothermic reactions produce hot temperatures or may even be explosive.



Some chemical reactions can only be completed if they absorb energy. When a chemical reaction absorbs heat from the environment, it is called an endothermic reaction. In endothermic reactions, bonds are broken between atoms. Here, the energy required for bond breaking is absorbed from the surroundings. As a result, endothermic reactions produce cold temperatures.

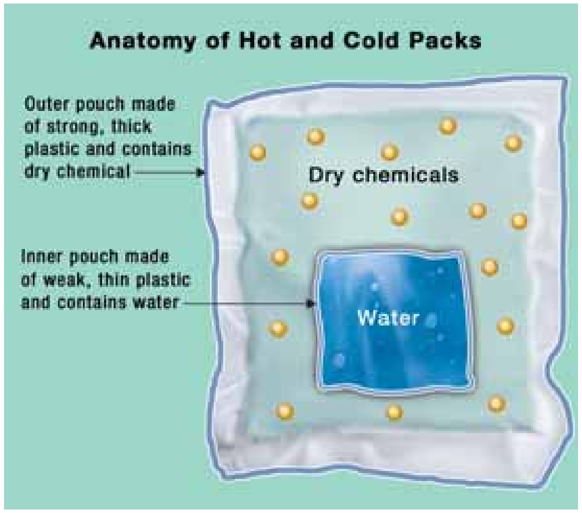
How hot and cold packs work

Let's look at the so-called "magic" inside a common hot and cold packs. Usually these packs are pouches made of thick, strong plastic. The pouches contain a dry chemical in the form of a powder. Within the large pouch of hot and cold packs is an inner pouch made of thin, weak plastic. This inner pouch contains water. The packs are make active when the seal of the inner water pouch is broken and the contents are vigorously shaken. Water is released and mixes with the chemical in the outer pouch to create either an exothermic or endothermic reaction.

Sounds simple, but let's look at the chemicals involved. Hot packs are made of chemicals that produce an exothermic reaction when mixed with water. Usually, hot packs contain calcium chloride or magnesium sulfate. These chemicals release heat energy when mixed with water and raise the temperature of the pack.

Cold packs work much the same way as hot packs, except different chemicals are used. Cold packs are made of chemicals that produce an endothermic reaction when mixed with water. Often, the chemical used in cold packs is ammonium nitrate. It absorbs heat energy and lowers the temperature of the pack.

The concentrations of the water and chemicals determine how hot or cold a pack gets. Commercial hot and cold packs typically last for about twenty minutes.



Hot and cold therapy

Physical therapists and sports trainers often use hot packs and cold packs to treat patients and athletes with injuries. However, the type of pack that should be used depends on the nature of injury.

Applying heat to your body can improve the flexibility of your tendons and ligaments. Tendons are bands of cordlike tissue that connect bone to muscle, while ligaments are cordlike tissues that connect bone to bone. Heat therapy can also reduce muscle spasms, reduce pain, and increase blood flow. The exact way in which heat relieves pain is not known. However, researchers think that heat inactivates nerves fibers that can force muscles to spasm. Heat may also induce the release of endorphins. Endorphins are chemicals in our body that block the transmission of pain by our nerves. Heat applied to body parts also relaxes the walls of blood vessels, resulting in increased blood flow. Health care professionals recommend using heat to untighten muscles and increase overall flexibility. However, it is best to avoid heating up already inflamed joints.

Like heat therapy, cold therapy may also be used to reduce muscle spasms. Muscle spasms are reduced with cold therapy because muscles fibers become less sensitive to being stretched. Cold is also useful for reducing pain and swelling. Cold therapy slows pain by reducing the speed of nerve impulses. Most tissue swelling is drastically decreased when cold and compression are applied to an injured area. The cold temperature constricts the walls of blood vessels, while the compression reduces the blood flow to the injured body part. Cold therapy is best used to reduce inflammation and swelling caused by sprains, strains, and bruises.

A variety of inexpensive, disposable hot and cold packs can be purchased at pharmacy stores. So next time you experience a minor injury, just reach for the magic pack that fits your needs.

Questions:

1. What are the differences between endothermic and exothermic reactions?
2. What are the structural components of hot packs and cold packs?
3. What are the differences between hot packs and cold packs?
4. How do physical therapists and sports trainers use hot packs and cold packs to treat patients and athletes with injuries?

CHAPTER ACTIVITY

Explore Hot and Cold Packs

All chemical reactions are either exothermic (release energy) or endothermic (absorb energy). In addition, some physical processes such as dissolution (dissolving) can also release or absorb energy. This is the basis for commercially available hot packs and cold packs. Most hot and cold packs work by breaking a membrane that separates a solid and water. Once the membrane is broken the solid dissolves in the water. Depending on the nature of the compound, heat is either released (hot pack) or removed from the environment (cold pack) during the process.

Materials:

Thermometer, Styrofoam cups, hot pack, cold pack, safety goggles, scissors, goggles, apron

What you will do

For the Hot Pack

1. Cut apart the outer pouch of hot pack and pour the solid into a styrofoam cup.

SAFETY NOTE: Do not touch the chemicals from the hot pack with your hands. Wear goggles and an apron!

1. Carefully cut the corner of the inner pouch and pour the water into another cup.
2. Meaure and record the temperature of the water in the cup.
3. Pour the water into the cup containing the solid and quickly transfer the thermometer to the mixture.
4. Stir the mixture until it dissolves and record its final temperature.

For the Cold Pack

1. Repeat the above procedure with the cold pack.

SAFETY NOTE: Do not touch the chemicals from the cold pack with your hands. Wear goggles and an apron!

Experiment	Starting Temperature (°C)	Final Temperature (°C)
Part A: Hot Pack		
Part B: Cold Pack		

Questions:

a. What is the change in temperature for for the hot pack? What is the change in temperature for the cold pack?
b. What compounds are used in commercial hot packs and cold packs?
c. Why does your skin feel cool when a cold pack is applied?

Vocabulary

Select the correct term to complete the sentences.

reactant	chemical equation	endothermic
exothermic	addition reaction	chemical reaction
products	polymerization	activation energy
nuclear reaction		decomposition reaction

Section 10.1

1. A(n) ____ occurs when you mix baking soda and vinegar.
2. The new substances that are created in chemical reactions are called ____.
3. A substance that changes during a chemical reaction is a(n) ____.
4. A(n) ____ is a short hand description of a chemical reaction using chemical formulas and symbols.

Section 10.2

5. A reaction is ____ if it releases more energy than it uses.
6. ____ is needed to start a reaction and break chemical bonds in the reactants.
7. In a(n) ____, the nucleus of an atom is changed, and one element may become a completely different element.
8. A series of addition reactions that join small molecules into large chain molecules is known as ____.
9. A reaction is ____ if it uses more energy than it releases.
10. Combining iron and oxygen to form rust is an example of a chemical reaction called a(n) ____.
11. The reaction that breaks down water into hydrogen and oxygen using electricity is known as a(n) ____.

Concepts

Section 10.1

1. Is tearing a piece of paper a physical change or a chemical change?
2. What happens to chemical bonds during chemical reactions?
3. The substance produced when iron is oxidized is:
   a. water.
   b. oxygen.
   c. iron precipitate.
   d. rust.
4. The reactants in the equation $2H_2 + O_2 \rightarrow 2H_2O$ + energy are:
   a. hydrogen and energy.
   b. hydrogen and oxygen.
   c. water and energy.
   d. oxygen and water.
5. The number of atoms of each element on both sides of a chemical equation must always be:
   a. greater than one.
   b. less than two.
   c. different.
   d. equal.
6. The chemical formula $3H_2O$ means
   a. three atoms of hydrogen and three atoms of oxygen.
   b. six atoms of hydrogen and three atoms of oxygen.
   c. three atoms of water.
   d. three atoms of hydrogen and two atoms of oxygen.
7. How do balanced chemical equations illustrate the law of conservation of mass?

8. Which is an example of the use of activation energy?
   a. Plugging in an iron
   b. Playing basketball
   c. Holding a match to paper
   d. Eating
9. What physical and chemical changes occur when a wax candle burns?

Section 10.2

10. What conditions must be met in order for a reaction to be considered exothermic?
11. A “instant cold pack” is a plastic bag with a packet of water surrounded by crystals of ammonium nitrate. To activate the cold pack, you squeeze the plastic bag to release the water. When the water contacts the ammonium nuitrate crystals, a reaction occurs and the pack becomes icy cold. Is the reaction inside the cold pack an endothermic or an exothermic reaction?
12. List two or more combustion reactions that are a part of your everyday life.
13. Calcium chloride and silver nitrate react to form a *precipitate* of silver chloride in a solution of calcium nitrate. This is an example of:
    a. a combustion reaction.
    b. a dispacement reaction.
    c. polymerization.
14. Explain why *mass* is not necessarily conserved in a nuclear reaction.
15. Write the balanced chemical equation for the decomposition of lithium carbonate (Li_2CO_3) into lithium oxide (Li_2O) and carbon dioxide (CO_2).

Problems

Section 10.1

1. Calculate the number of atoms of each element shown in each of the following
   a. $CaSO_4$
   b. $4NaOCl$
   c. $Fe(NO_3)_2$
   d. $2Al_2(CO_3)_3$
2. Is this chemical equation balanced?
   $2C_4H_{10}\ (g) + 13O_2\ (g) = 8CO_2\ (g) \rightarrow 10H_2O\ (l)$
3. The mass of an iron bolt was 5.4 grams when it was manufactured. After being bolted to an outdoor structure for several months, the mass of the bolt was found to have increased by 0.2 grams. Given the following balanced equation for the reaction, does this example support the law of conservation of mass? Why or why not?
   $4Fe\ (s) + 3O_2\ (g) \rightarrow 2Fe_2O_3\ (s)$

Section 10.2

4. Many drain cleaners are a mixture of sodium hydroxide and aluminum filings. When these two substances mix in water, they react to produce enough heat to melt the fat in a clogged drain. The bubbles produced are hydrogen gas. The complete reaction occurs in two steps:
   step 1: $Al(s) + NaOH(aq) \rightarrow Al(OH)_3(s) + Na^+(aq)$
   step 2: $Na^+(aq) + H_2O \rightarrow Na_2O(s) + H_2(g)$
   a. Classify step 1 of the reaction as: addition, displacement, or decomposition.
   b. Is this an endothermic or an exothermic reaction?
   c. Balance each equation for each step of the reaction.