All living things are made of the same basic materials: carbon, hydrogen, oxygen, and nitrogen. Living things, such as this jellyfish, *Pseudorhiza haeckeli*, are made of cells that are composed primarily of water. The chemical reactions of life occur in the aqueous environment of the cell.

**SECTION 1  Composition of Matter**
**SECTION 2  Energy**
**SECTION 3  Water and Solutions**
COMPOSITION OF MATTER

Earth supports an enormous variety of organisms. The structure and function of all living things are governed by the laws of chemistry. An understanding of the basic principles of chemistry will give you a better understanding of living things and how they function.

MATTER

Everything in the universe is made of matter. Matter is anything that occupies space and has mass. Mass is the quantity of matter an object has. Mass and weight are not the same; weight is defined as the force produced by gravity acting on mass. The same mass would have less weight on the moon than it would on Earth because the moon exerts less force on the object than the Earth does.

Chemical changes in matter are essential to all life processes. Biologists study chemistry because all living things are made of the same kinds of matter that make up nonliving things. By learning how changes in matter occur, you will gain an understanding of the life processes of the organisms you will study.

ELEMENTS AND ATOMS

Elements are substances that cannot be broken down chemically into simpler kinds of matter. More than 100 elements have been identified, though fewer than 30 are important to living things. In fact, more than 90 percent of the mass of all kinds of living things is composed of combinations of just four elements: oxygen, carbon, hydrogen, and nitrogen.

Information about the elements is summarized on a chart known as the periodic table, which appears in the Appendix. Each element has a different chemical symbol. A chemical symbol consists of one, two, or three letters, as shown in Figure 2-1. In most cases, the symbol derives from the first letter or other letters in the name of the element, such as Cl for chlorine. Most of the other symbols are derived from the Latin names of elements. One example is sodium’s symbol, Na, from the Latin word natrium.

SECTION 1

OBJECTIVES

● Define the term matter.
● Explain the relationship between elements and atoms.
● Draw and label a model of the structure of an atom.
● Explain how compounds affect an atom’s stability.
● Contrast covalent and ionic bonds.

VOCABULARY

matter
mass
element
atom
nucleus
proton
neutron
atomic number
mass number
electron
orbital
isotope
compound
chemical bond
covalent bond
molecule
ion
ionic bond

FIGURE 2-1

The periodic table lists information about the elements, including the atomic number, the chemical symbol, and the atomic mass for each element. A complete periodic table can be found in the Appendix.

Atomic number
Chemical symbol
Atomic mass

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The simplest particle of an element that retains all of the properties of that element is an **atom**. The properties of different kinds of atoms determine the structure and properties of the matter they compose. Atoms are so small that their structure cannot be directly observed. However, scientists have developed models that describe the structure of the atom. One model is shown in Figure 2-2.

**The Nucleus**

The central region, or **nucleus**, makes up the bulk of the mass of the atom and consists of two kinds of subatomic particles, a **proton** and a neutron. The proton is positively charged and the neutron has no charge. The number of protons in an atom is called the **atomic number** of the element. In the periodic table of elements, the atomic number generally appears directly above the chemical symbol, as shown in Figure 2-1. The atomic number of fluorine is 9, which indicates that each atom of the element fluorine has nine protons. The **mass number** of an atom is equal to the total number of protons and neutrons of the atom. The mass number of fluorine is 19, which indicates that each atom of fluorine has 10 neutrons.

**Electrons**

In an atom, the number of positively charged protons is balanced by an equal number of small, negatively charged particles called **electrons**. The net electrical charge of an atom is zero. Electrons are high-energy particles that have very little mass. They move about the nucleus at very high speeds and are located in orbitals. An **orbital** is a three-dimensional region around a nucleus that indicates the probable location of an electron. Electrons in orbitals that are farther away from the nucleus have greater energy than electrons that are in orbitals closer to the nucleus. When all orbitals are combined, there is a cloud of electrons surrounding the nucleus, as shown in Figure 2-2.

Orbitals correspond to specific energy levels. Each energy level corresponds to a group of orbitals that can hold only a certain, total number of electrons. For example, the orbital that corresponds to the first energy level can hold only two electrons. The first energy level is the highest energy level for the elements hydrogen and helium. There are four orbitals in the second energy level, and that energy level can hold up to eight total electrons, with a maximum of two electrons in each orbital.

**Isotopes**

All atoms of an element have the same number of protons. However, all atoms of an element do not necessarily have the same number of neutrons. Atoms of the same element that have a different number of neutrons are called **isotopes**. Additional neutrons change the mass of the element. Most elements are made up of a mixture of isotopes, as shown in Figure 2-2. The **average atomic mass** of an element takes into account the relative amounts of each isotope in the element, and this average is the mass found in the periodic table.
Under natural conditions, most elements do not exist alone; atoms of most elements can readily combine with the same or different atoms or elements to make compounds. **Compounds** are made up of atoms of two or more elements in fixed proportions. A chemical formula shows the kinds and proportions of atoms of each element that forms a particular compound. For example, water’s chemical formula, $\text{H}_2\text{O}$, shows that the atoms always combine in a proportion of two hydrogen (H) atoms to one oxygen (O) atom.

The physical and chemical properties differ between the compounds and elements that compose them. In nature, the elements oxygen and hydrogen are usually found as gases with the formulas $\text{O}_2$ and $\text{H}_2$. However, when oxygen gas and hydrogen gas combine at room temperature, they form liquid $\text{H}_2\text{O}$. How elements combine and form compounds depends on the number and arrangement of electrons in their orbitals. An atom is chemically stable when the orbitals that correspond to its highest energy level are filled with the maximum number of electrons. Some elements, such as helium and neon, consist of atoms that have the maximum number of electrons in the orbitals of their highest energy levels. These elements, also called noble or inert elements, do not react with other elements under normal conditions.

Most atoms are not stable in their natural state, so they tend to react with other atoms in different ways to become more stable. Carbon, nitrogen, and oxygen atoms have unfilled orbitals that correspond to their highest energy levels. Similar to these elements, most elements tend to interact with other atoms to form chemical bonds. **Chemical bonds** are the attractive forces that hold atoms together.

**Covalent Bonds**

A **covalent bond** forms when two atoms share one or more pairs of electrons. For example, water is made up of one oxygen atom and two hydrogen atoms held together by covalent bonds. In Figure 2-3, step 1, an atom of hydrogen needs a second electron to achieve stability. Having two electrons in the orbital that corresponds to hydrogen’s highest energy level allows the atom to be more stable. The oxygen atom needs two more electrons to give it a stable arrangement of eight electrons, which fill oxygen’s orbitals to its highest energy level. Thus, hydrogen atoms and oxygen atoms share pairs of electrons in a ratio of two atoms of hydrogen to one atom of oxygen. The resulting stable compound, $\text{H}_2\text{O}$ (water), is shown in step 2.

A **molecule** is the simplest part of a substance that retains all of the properties of that substance and can exist in a free state. For example, one molecule of the compound water is $\text{H}_2\text{O}$, and one molecule of oxygen gas is $\text{O}_2$. Some molecules that biologists study are large and complex.
CHAPTER 2

1. What is matter?

2. What is the relationship between elements and atoms?

3. Describe the arrangement within energy levels of the six electrons of an atom of carbon.

4. How are isotopes of the same element alike?

5. How can we predict which elements are reactive under normal conditions and which are unreactive?

6. Distinguish between covalent and ionic bonds.

7. Distinguishing Differences Explain why the terms mass and weight should not be used interchangeably.

8. Applying Information Classify each of the following as an element or a compound: HCl, CO₂, Cl, Li, and H₂O.

9. Applying Information Given that elements are pure substances, how many types of atoms make up the structure of a single element? Explain your answer.
All living things use energy. The amount of energy in the universe remains the same over time, but energy can change from one form to another. It is the transfer of energy—from the sun to and through almost every organism on Earth—that biologists seek to understand when they study the chemistry of living things.

ENERGY AND MATTER

Scientists define energy as the ability to do work. Energy can occur in various forms, and one form of energy can be converted to another form. In a light bulb’s filament, electrical energy is converted to radiant energy (light) and thermal energy (heat). Some forms of energy important to biological systems include chemical energy, thermal energy, electrical energy, and mechanical energy. Inside any single organism, energy may be converted from one form to another. For example, after you eat a meal, your body changes the chemical energy found in food into thermal and mechanical energy, among other things.

States of Matter

Although it is not apparent when we observe matter, all the atoms and molecules in any substance are in constant motion. The motion of and spacing between atoms or molecules of a substance determine the substance’s state: solid, liquid, or gas, as shown in Figure 2-5. In general, the atoms or molecules of a solid are more closely linked together than in a liquid or gas. Water is an exception to this, as will be described later. Solids move less rapidly than the particles that make up a liquid or a gas. A solid maintains a fixed volume and shape. A liquid maintains a fixed volume, but its particles move more freely than those of a solid, which gives a liquid its ability to flow and to conform to the shape of any container. Particles of a gas move the most rapidly. Gas particles have little or no attraction to each other, and they fill the volume of the container they occupy. Thermal energy must be added to the substance to cause a substance to change states.

OBJECTIVES

● Describe the physical properties of each state of matter.
● Describe the role of reactants and products in chemical reactions.
● Explain the relationship between enzymes and activation energy.
● Explain how oxidation and reduction reactions are linked.

VOCABULARY

energy
chemical reaction
reactant
product
metabolism
activation energy
catalyst
enzyme
redox reaction
oxidation reaction
reduction reaction
ENERGY AND CHEMICAL REACTIONS

In a chemical reaction, one or more substances change to produce one or more different substances. Energy is absorbed or released when chemical bonds are broken and new ones are formed. Living things undergo many thousands of chemical reactions every day. Reactions can vary from highly complex to very simple. The chemical reaction in Figure 2-6 takes place in your blood. Carbon dioxide is taken up from body cells and into the blood when it crosses the thin capillary walls. The carbon dioxide reacts with water in the blood to form carbonic acid. Carbon dioxide is then released into the lung’s alveoli and exhaled when the carbonic acid breaks down to carbon dioxide and water.

If the reaction proceeds in only one direction, the reactants are shown on the left side of the equation. In the reaction in Figure 2-6, the reactants are carbon dioxide (CO$_2$) and water (H$_2$O). In a chemical reaction, bonds present in the reactants are broken, the elements are rearranged, and new compounds are formed as the products. The products of this reaction are shown on the right side. In this reaction, the product is carbonic acid (H$_2$CO$_3$). Notice that the number of each kind of atom must be the same on either side of the arrow. Some chemical reactions can proceed in either direction and a two-direction arrow (⇌) is used. For example, the equation in Figure 2-6 is reversible and can be written as CO$_2$ + H$_2$O ⇌ H$_2$CO$_3$.

The energy your body needs is provided by the sugars, proteins, and fats found in foods. Your body continuously undergoes a series of chemical reactions in which these energy-supplying substances are broken down into carbon dioxide, water, and other products. In this process, energy is released for use by your body to build and maintain body cells, tissues, and organs. Metabolism (MUH-TAB-uh-LIZ-uhm) is the term used to describe all of the chemical reactions that occur in an organism.

Activation Energy

For most chemical reactions to begin, energy must be added to the reactants. In many chemical reactions, the amount of energy needed to start the reaction, called activation energy, is large. Figure 2-7 shows the activation energy for a hypothetical chemical reaction.

Certain chemical substances, known as catalysts (KAT-uh-LISTS), reduce the amount of activation energy that is needed for a reaction to take place, as shown in Figure 2-7. A reaction in the presence of the correct catalyst will proceed spontaneously or with the addition of a small amount of energy. In living things enzymes act as catalysts. An enzyme is a protein or RNA molecule that speeds up metabolic reactions without being permanently changed or destroyed.
Oxidation Reduction Reactions

You know that there is a constant transfer of energy into and throughout living things. Many of the chemical reactions that help transfer energy in living things involve the transfer of electrons. These reactions in which electrons are transferred between atoms are known as oxidation-reduction reactions, or redox reactions. In an oxidation (ah-KS-i-DAY-shuhn) reaction, a reactant loses one or more electrons, thus becoming more positive in charge. For example, remember that a sodium atom loses an electron to achieve stability when it forms an ionic bond, as shown in Figure 2-4. Thus, the sodium atom undergoes oxidation to form a Na⁺ ion. In a reduction reaction, a reactant gains one or more electrons, thus becoming more negative in charge. When a chlorine atom gains an electron to form a Cl⁻ ion, the atom undergoes reduction. Redox reactions always occur together. An oxidation reaction occurs, and the electron given up by one substance is then accepted by another substance in a reduction reaction.

SECTION 2 REVIEW

1. Name and describe the physical properties of the three states of matter.
2. Explain the roles of reactants and products in a chemical reaction.
3. Describe the effect of an enzyme on the activation energy in a chemical reaction.
4. Enzymes are biological catalysts. Explain what they do in living systems.
5. Why does a reduction reaction always accompany an oxidation reaction?

CRITICAL THINKING

6. Analyzing Concepts Living things need a constant supply of energy. Explain why.
7. Analyzing Graphics Carbonic anhydrase is the enzyme that catalyzes the chemical reaction illustrated in Figure 2-6. What effect might a molecule that interferes with the action of carbonic anhydrase have on your body?
8. Analyzing Information In a reduction reaction, the reduced atom gains one or more electrons. Why is this reaction called a reduction?
HYPOTHESIS: Water Exists on Mars
Scientists at the National Aeronautics and Space Administration (NASA) have sent orbiters, (reusable spacecraft designed to transport people and cargo) between Earth and Mars. Recent orbiters to be sent to Mars include NASA’s Mars Global Surveyor (MGS) and Mars Odyssey. These missions revealed boulders, dust, canyons, and tall volcanic peaks. Some of the most exciting images revealed gullies carved into the Martian landscape. The appearance of these gullies led geologists to hypothesize that the gullies had been carved by running water within the past few million years.

Why is the presence of water on Mars so intriguing? On our planet, where there is water, there is life. For now, scientists are assuming that life-forms on Mars would have the same dependence on water.

METHODS: Image and Analyze Martian Rock Samples
In the summer of 2003, NASA scientists launched Spirit and Opportunity, two Mars exploration rovers. The job of these two rovers was to take small-scale geologic surveys of surrounding rocks and soil and to search for ancient traces of water. These rovers landed in regions near the Martian equator that may have held water at one time.

RESULTS: Water and Minerals That Can Form in Water Are Present on Mars
The images sent back by the Odyssey and MGS orbiters reveal that water covers large areas of Mars’ polar regions as well as some large areas at its equator. The water is almost certainly frozen in the form of dusty snowpacks, which may occur largely as an icy soil layer. These icewax may resemble the permafrost of Earth’s polar regions.

In addition, Opportunity detected the presence of hematite at its landing site, the Meridiani Planum, an area on Mars that was thought to have been a shallow lake at one time. Hematite is a mineral that often forms in pools of standing water on Earth but can also form as a result of volcanic activity.

Opportunity also found strong evidence that the rocks at Meridii Planum were once sediments that were laid down by liquid water. This discovery also gives greater weight to the hypothesis that Mars was once a habitat for microbial life.

CONCLUSION: Mars Once Had Water
Chances are that the current mission to Mars will not determine whether life ever started on the planet, but scientists are hopeful that they will have an answer someday. Human exploration of Mars is already being planned. Astronauts would be able to carry out many experiments that robots cannot do.
WATER AND SOLUTIONS

Compare the body of a jellyfish with your own body. A jellyfish would die if it was removed from its watery environment. Yet you can live on the driest parts of Earth. Jellyfish and humans seem unlike each other, yet the bodies of both are made of cells that consist mostly of water. The chemical reactions of all living things take place in the aqueous environment of the cell. Water has several unique properties that make it one of the most important compounds found in living things.

POLARITY

Many of water’s biological functions stem from its chemical structure. Recall that in the water molecule, \( \text{H}_2\text{O} \), the hydrogen and oxygen atoms share electrons to form covalent bonds. However, these atoms do not share the electrons equally. The oxygen atom has a greater ability to attract electrons to it because it pulls hydrogen’s electrons towards its nucleus. As a result, as shown in Figure 2-8, the region of the molecule where the oxygen atom is located has a partial negative charge, denoted with a \( \delta^- \), while the regions of the molecule where each of the two hydrogen atoms are located have partial positive charges, each of which are denoted with a \( \delta^+ \). Thus, even though the total charge on a water molecule is neutral, the charge is unevenly distributed across the water molecule. Because of this uneven distribution of charge, water is called a polar compound.

Notice also in Figure 2-8 that the three atoms in a water molecule are not arranged in a straight line as you might expect. Rather, the two hydrogen atoms bond with the single oxygen atom at an angle.

FIGURE 2-8

The oxygen region of the water molecule is weakly negative, and the hydrogen regions are weakly positive. Notice the different ways to represent water, \( \text{H}_2\text{O} \). You are familiar with the electron cloud model (a). The space-filling model (b) shows the three-dimensional structure of a molecule.
The dotted lines in this figure represent hydrogen bonds. A hydrogen bond is a force of attraction between a hydrogen atom in one molecule and a negatively charged region or atom in a second molecule.

**FIGURE 2-10**

The polar nature of water also causes water molecules to be attracted to one another. As is shown in Figure 2-10, the positively charged region of one water molecule is attracted to the negatively charged region of another water molecule. This attraction is called a hydrogen bond. A hydrogen bond is the force of attraction between a hydrogen molecule with a partial positive charge and another atom or molecule with a partial or full negative charge. Hydrogen bonds in water exert an attractive force strong enough so that water “clings” to itself and some other substances.

Hydrogen bonds form, break, and reform with great frequency. However, at any one time, a great number of water molecules are bonded together. The number of hydrogen bonds that exist depends on the state that water is in. If water is in its solid state all its water molecules are hydrogen bonded and do not break. As water liquifies, more hydrogen bonds are broken than are formed, until an equal number of bonds are formed and broken. Hydrogen bonding accounts for the unique properties of water, some of which we will examine further. These properties include cohesion and adhesion, the ability of water to absorb a relatively large amount of energy as heat, the ability of water to cool surfaces through evaporation, the density of ice, and the ability of water to dissolve many substances.

**HYDROGEN BONDING**

The dotted lines in this figure represent hydrogen bonds. A hydrogen bond is a force of attraction between a hydrogen atom in one molecule and a negatively charged region or atom in a second molecule.
Cohesion and Adhesion

Water molecules stick to each other as a result of hydrogen bonding. An attractive force that holds molecules of a single substance together is known as cohesion. Cohesion due to hydrogen bonding between water molecules contributes to the upward movement of water from plant roots to their leaves.

Related to cohesion is the surface tension of water. The cohesive forces in water resulting from hydrogen bonds cause the molecules at the surface of water to be pulled downward into the liquid. As a result, water acts as if it has a thin “skin” on its surface. You can observe water’s surface tension by slightly overfilling a drinking glass with water. The water will appear to bulge above the rim of the glass. Surface tension also enables small creatures such as spiders and water-striders to run on water without breaking the surface.

Adhesion is the attractive force between two particles of different substances, such as water molecules and glass molecules. A related property is capillarity (KAP-uh-LER-i-tee), which is the attraction between molecules that results in the rise of the surface of a liquid when in contact with a solid. Together, the forces of adhesion, cohesion, and capillarity help water rise through narrow tubes against the force of gravity. Figure 2-11 shows cohesion and adhesion in the water-conducting tubes in the stem of a flower.

Temperature Moderation

Water has a high heat capacity, which means that water can absorb or release relatively large amounts of energy in the form of heat with only a slight change in temperature. This property of water is related to hydrogen bonding. Energy must be absorbed to break hydrogen bonds, and energy is released as heat when hydrogen bonds form. The energy that water initially absorbs breaks hydrogen bonds between molecules. Only after these hydrogen bonds are broken does the energy begin to increase the motion of the water molecules, which raises the temperature of the water. When the temperature of water drops, hydrogen bonds reform, which releases a large amount of energy in the form of heat.

Therefore, during a hot summer day, water can absorb a large quantity of energy from the sun and can cool the air without a large increase in the water’s temperature. At night, the gradually cooling water warms the air. In this way, the Earth’s oceans stabilize global temperatures enough to allow life to exist. Water’s high heat capacity also allows organisms to keep cells at an even temperature despite temperature changes in the environment.

As a liquid evaporates, the surface of the liquid that remains behind cools down. A relatively large amount of energy is absorbed by water during evaporation, which significantly cools the surface of the remaining liquid. Evaporative cooling prevents organisms that live on land from overheating. For example, the evaporation of sweat from a person’s skin releases body heat and prevents overheating on a hot day or during strenuous activity.
Density of Ice

Unlike most solids, which are denser than their liquids, solid water is less dense than liquid water. This property is due to the shape of the water molecule and hydrogen bonding. The angle between the hydrogen atoms is quite wide. So, when water forms solid ice, the angles in the molecules cause ice crystals to have large amounts of open space, as shown in Figure 2-12. This open space lattice structure causes ice to have a low density.

Because ice floats on water, bodies of water such as ponds and lakes freeze from the top down and not the bottom up. Ice insulates the water below from the cold air, which allows fish and other aquatic creatures to survive under the icy surface.

**SOLUTIONS**

A solution is a mixture in which one or more substances are uniformly distributed in another substance. Solutions can be mixtures of liquids, solids, or gases. For example, plasma, the liquid part of blood, is a very complex solution. It is composed of many types of ions and large molecules, as well as gases, that are dissolved in water. A solute (SAHL-yoot) is a substance dissolved in the solvent. The particles that compose a solute may be ions, atoms, or molecules. The solvent is the substance in which the solute is dissolved. For example, when sugar, a solute, and water, a solvent, are mixed, a solution of sugar water results. Though the sugar dissolves in the water, neither the sugar molecules nor the water molecules are altered chemically. If the water is boiled away, the sugar molecules remain and are unchanged.

Solutions can be composed of various proportions of a given solute in a given solvent. Thus, solutions can vary in concentration. The concentration of a solution is the amount of solute dissolved in a fixed amount of the solution. For example, a 2 percent saltwater solution contains 2 g of salt dissolved in enough water to make 100 mL of solution. The more solute dissolved, the greater is the concentration of the solution. A saturated solution is one in which no more solute can dissolve.

Aqueous (AY-kwee-uhks) solutions—solutions in which water is the solvent—are universally important to living things. Marine microorganisms spend their lives immersed in the sea, an aqueous solution. Most nutrients that plants need are in aqueous solutions in moist soil. Body cells exist in an aqueous solution of intercellular fluid and are themselves filled with fluid; in fact, most chemical reactions that occur in the body occur in aqueous solutions.
ACIDS AND BASES

One of the most important aspects of a living system is the degree of its acidity or alkalinity. What do we mean when we use the terms acid and base?

Ionization of Water

As water molecules move about, they bump into one another. Some of these collisions are strong enough to result in a chemical change: one water molecule loses a proton (a hydrogen nucleus), and the other gains this proton. This reaction really occurs in two steps. First, one molecule of water pulls apart another water molecule, or dissociates, into two ions of opposite charge:

\[ \text{H}_2\text{O} \rightleftharpoons \text{H}^+ + \text{OH}^- \]

The \( \text{OH}^- \) ion is known as the hydroxide ion. The free \( \text{H}^+ \) ion can react with another water molecule, as shown in the equation below.

\[ \text{H}^+ + \text{H}_2\text{O} \rightleftharpoons \text{H}_3\text{O}^+ \]

The \( \text{H}_3\text{O}^+ \) ion is known as the hydronium ion. Acidity or alkalinity is a measure of the relative amounts of hydronium ions and hydroxide ions dissolved in a solution. If the number of hydronium ions in a solution equals the number of hydroxide ions, the solution is said to be neutral. Pure water contains equal numbers of hydronium ions and hydroxide ions and is therefore a neutral solution.

Acids

If the number of hydronium ions in a solution is greater than the number of hydroxide ions, the solution is an acid. For example, when hydrogen chloride gas, HCl, is dissolved in water, its molecules dissociate to form hydrogen ions, \( \text{H}^+ \), and chloride ions, \( \text{Cl}^- \), as is shown in the equation below.

\[ \text{HCl} \rightleftharpoons \text{H}^+ + \text{Cl}^- \]

These free hydrogen ions combine with water molecules to form hydronium ions, \( \text{H}_3\text{O}^+ \). This aqueous solution contains many more hydronium ions than it does hydroxide ions, making it an acidic solution. Acids tend to have a sour taste; however, never taste a substance to test it for acidity. In concentrated forms, they are highly corrosive to some materials, as you can see in Figure 2-13.

Bases

If sodium hydroxide, NaOH, a solid, is dissolved in water, it dissociates to form sodium ions, \( \text{Na}^+ \), and hydroxide ions, \( \text{OH}^- \), as shown in the equation below.

\[ \text{NaOH} \rightleftharpoons \text{Na}^+ + \text{OH}^- \]

Acid Precipitation

Acid precipitation, more commonly called acid rain, describes rain, snow, sleet, or fog that contains high levels of sulfuric and nitric acids. These acids form when sulfur dioxide gas, \( \text{SO}_2 \), and nitrogen oxide gas, \( \text{NO} \), react with water in the atmosphere to produce sulfuric acid, \( \text{H}_2\text{SO}_4 \), and nitric acid, \( \text{HNO}_3 \).

Acid precipitation makes soils and bodies of water, such as lakes, more acidic than normal. These high acid levels can harm plant and animal life directly. A high level of acid in a lake may kill mollusks, fish, and amphibians. Even in a lake that does not have a very elevated level of acid, acid precipitation may leach aluminum and magnesium from soils, poisoning water-dwelling species.

Reducing fossil-fuel consumption, such as occurs in gasoline engines and coal-burning power plants, should reduce high acid levels in precipitation.

FIGURE 2-13

Sulfur dioxide, \( \text{SO}_2 \), which is produced when fossil fuels are burned, reacts with water in the atmosphere to produce acid precipitation. Acid precipitation, or acid rain, can make lakes and rivers too acidic to support life and can even corrode stone, such as the face of this statue.
This solution then contains more hydroxide ions than hydronium ions and is therefore defined as a base. The adjective alkaline refers to bases. Bases have a bitter taste; however, never taste a substance to test for alkalinity. They tend to feel slippery because the OH\(^{-}\) ions react with the oil on our skin to form a soap. In fact, commercial soap is the product of a reaction between a base and a fat.

**pH**

Scientists have developed a scale for comparing the relative concentrations of hydronium ions and hydroxide ions in a solution. This scale is called the pH scale, and it ranges from 0 to 14, as shown in Figure 2-14. A solution with a pH of 0 is very acidic, a solution with a pH of 7 is neutral, and a solution with a pH of 14 is very basic. A solution’s pH is measured on a logarithmic scale. That is, the change of one pH unit reflects a 10-fold change in the acidity or alkalinity. For example, urine has 10 times the H\(_3\)O\(^+\) ions at a pH of 6 than water does at a pH of 7. Vinegar, has 1,000 times more H\(_3\)O\(^+\) ions at a pH of 3 than urine at a pH of 6, and 10,000 times more H\(_3\)O\(^+\) ions than water at a pH of 7. The pH of a solution can be measured with litmus paper or with some other chemical indicator that changes color at various pH levels.

**Buffers**

The control of pH is important for living systems. Enzymes can function only within a very narrow pH range. The control of pH in organisms is often accomplished with buffers. Buffers are chemical substances that neutralize small amounts of either an acid or a base added to a solution. As Figure 2-14 shows, the composition of your internal environment—in terms of acidity and alkalinity—varies greatly. Some of your body fluids, such as stomach acid and urine, are acidic. Others, such as intestinal fluid and blood, are basic or alkaline. Complex buffering systems maintain the pH values in a normal healthy body.

**SECTION 3 REVIEW**

1. Illustrate the structure of a water molecule by drawing a space-filling model.
2. Why is water called a polar molecule?
3. Identify the properties of water that are important for life to be able to exist.
4. Identify the solute and solvent in a hot chocolate solution that is made of chocolate syrup and warm milk.
5. Why does pure water have a neutral pH?
6. Outline a reason why the control of pH is important in living systems.

**CRITICAL THINKING**

7. **Recognizing Relationships** What is the relationship among hydrogen bonds and the forces of cohesion, adhesion, and capillarity?
8. **Applying Information** The active ingredient in aspirin is acetylsalicylic acid. Why would doctors recommend buffered aspirin, especially for those with a “sensitive” stomach?
9. **Analyzing Graphics** All units on the pH scale in Figure 2-14 look equivalent, but they are not. Why is the scale drawn as though they are?
SECTION 1 Composition of Matter

- Matter is anything that occupies space and has mass.
- Elements are made of a single kind of atom and cannot be broken down by chemical means into simpler substances.
- Atoms are composed of protons, neutrons, and electrons. Protons and neutrons make up the nucleus of the atom. Electrons move about the nucleus in orbitals.
- Compounds consist of atoms of two or more elements that are joined by chemical bonds in a fixed proportion.

Vocabulary

- matter (p. 31)
- mass (p. 31)
- element (p. 31)
- atom (p. 32)
- nucleus (p. 32)
- proton (p. 32)
- neutron (p. 32)
- atomic number (p. 32)
- mass number (p. 32)
- orbital (p. 32)
- isotope (p. 32)
- compound (p. 33)
- chemical bond (p. 33)
- covalent bond (p. 33)

SECTION 2 Energy

- Addition of energy to a substance can cause its state to change from a solid to a liquid and from a liquid to a gas.
- Reactants are substances that enter chemical reactions. Products are substances produced by chemical reactions.

Vocabulary

- energy (p. 35)
- chemical reaction (p. 36)
- reactant (p. 36)
- product (p. 36)
- metabolism (p. 36)
- activation energy (p. 36)
- catalyst (p. 36)
- enzyme (p. 36)
- redox reaction (p. 37)
- oxidation reaction (p. 37)
- reduction reaction (p. 37)

SECTION 3 Water and Solutions

- The two hydrogen atoms and one oxygen atom that make up a water molecule are arranged at an angle to one another.
- Water is a polar molecule. The electrons in the molecule are shared unevenly between hydrogen and oxygen. This polarity makes water effective at dissolving other polar substances.
- Hydrogen bonding accounts for most of the unique properties of water.
- The unique properties of water include the ability to absorb a relatively large amount of energy as heat, the ability to cool surfaces through evaporation, and the low density of ice.

Vocabulary

- polar (p. 39)
- hydrogen bond (p. 40)
- cohesion (p. 41)
- adhesion (p. 41)
- capillarity (p. 41)
- solution (p. 42)
- solute (p. 42)
- solvent (p. 42)
- concentration (p. 42)
- saturated solution (p. 42)
- aqueous solution (p. 42)
- hydroxide ion (p. 43)
- hydronium ion (p. 43)
- acid (p. 43)
- base (p. 44)

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CHAPTER REVIEW

USING VOCABULARY

1. For each pair of terms, explain how the meanings of the terms differ.
   a. oxidation and reduction
   b. reactants and products
   c. acid and base

2. Explain the relationship between electrons, neutrons, and protons.

3. Choose the term that does not belong in the following group, and explain why it does not belong: element, compound, chemical bonds, and adhesion.

4. Word Roots and Origins The term catalyst comes from the Greek katalysis, meaning “dissolution.” Give reasons that this term is appropriate in describing the function of enzymes.

UNDERSTANDING KEY CONCEPTS

5. Differentiate between the mass and the weight of an object.

6. Name the subatomic particles that are found in the nucleus of an atom.

7. Describe the arrangement within energy levels of the seven electrons of an atom of nitrogen.

8. Describe how compounds affect an atom’s stability.


10. Compare the motion and spacing of the molecules in a solid to the motion and spacing of the molecules in a gas.

11. Identify the reactants and the products in the following chemical reaction.

   \[ A + B \rightarrow C + D \]

12. Explain the relationship between enzymes and activation energy.

13. Explain oxidation and reduction in terms of electron transfer and charge.

14. Describe the structure of a water molecule.

15. Outline what happens when water ionizes.

16. Describe how water behaves at its surface and the role hydrogen bonding plays in this behavior.

17. Identify the solute(s) and solvent(s) in a cup of instant coffee with sugar.

18. Name two ions that are the products of the dissociation of water.

19. Compare an acid to a base in terms of the hydroxide ion concentration.

20. CONCEPT MAPPING Use the following terms to create a concept map that shows how the properties of water help it rise in plants: water, hydrogen bonds, cohesion, adhesion, capillarity, and plants.

CRITICAL THINKING

21 Analyzing Concepts In nature, the elements oxygen and hydrogen are usually found as gases with the formulas \( \text{O}_2 \) and \( \text{H}_2 \). Why? Are they compounds? Are they molecules?

22. Analyzing Data The table below shows melting and boiling points at normal pressure for five different elements or compounds. Above the boiling point, a compound or element exists as a gas. Between the melting point and the boiling point, a compound or element exists as a liquid. Below the melting point, a compound or element exists as a solid. Use the table to answer the following questions:
   a. At 20°C and under normal pressure conditions, which substances exist as solids? as liquids? as gases?
   b. Which substance exists as a liquid over the broadest range of temperature?
   c. Which substance exists as a liquid over the narrowest range of temperature?
   d. Which one of the substances are you least likely to encounter as a gas?

<table>
<thead>
<tr>
<th>Substance</th>
<th>Melting point (°C)</th>
<th>Boiling point (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>658</td>
<td>2,330</td>
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<tr>
<td>Argon</td>
<td>-190</td>
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<tr>
<td>Chlorine</td>
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<td>Mercury</td>
<td>-39</td>
<td>357</td>
</tr>
<tr>
<td>Water</td>
<td>0</td>
<td>100</td>
</tr>
</tbody>
</table>

23. Recognizing Relationships Cells contain mostly water. What would happen to the stability of an organism’s internal temperature with respect to environmental temperature changes if cells contained mostly oil, which does not have extensive hydrogen bonding?
DIRECTIONS: Choose the letter of the answer choice that best answers the question.

1. The way in which elements bond to form compounds depends on which of the following?
   A. the model of the atom
   B. the structural formula of the compound
   C. the dissociation of the ions in the compound
   D. the number and arrangement of electrons in the atoms of the elements

2. If an atom is made up of 6 protons, 7 neutrons, and 6 electrons, what is its atomic number?
   F. 6
   G. 7
   H. 13
   J. 19

INTERPRETING GRAPHICS: The graph below shows the energy in a chemical reaction as the reaction progresses. Use the graph to answer the questions that follow.

3. The amount of energy needed for this chemical reaction to begin is shown by the line rising from the reactants. What is this energy called?
   A. chemical energy
   B. electrical energy
   C. activation energy
   D. mechanical energy

4. Suppose that this reaction needs a catalyst to proceed. In the absence of a catalyst, the activation energy would be which of the following?
   F. larger than what is shown
   G. the same as what is shown
   H. smaller than what is shown
   J. not much different from what is shown

5. What is an aqueous solution that contains more hydroxide ions than hydronium ions called?
   A. a gas
   B. a base
   C. a solid
   D. an acid

DIRECTIONS: Complete the following analogy.

6. Oxidation : loss :: reduction :
   F. win
   G. gain
   H. take
   J. forfeit

INTERPRETING GRAPHICS: The illustration below is a space-filling model of water. Use the model to answer the following question.

7. The water molecule above has partial positive charges on the hydrogen atoms and a partial negative charge on the oxygen atom. What can you conclude from this information and the diagram of the water molecule?
   A. Water is an ion.
   B. Water is a polar molecule.
   C. Water needs a proton and two electrons to be stable.
   D. Oxygen atoms and hydrogen atoms have opposite charges.

SHORT RESPONSE
Covalent bonding is a sharing of electrons between atoms. Why do some atoms share electrons?

EXTENDED RESPONSE
Pure water contains equal numbers of hydronium ions and hydroxide ions and is therefore a neutral solution.

Part A What is the initial cause of the dissociation of water molecules into hydrogen and hydroxide ions? Explain the process.

Part B After water dissociates, hydronium ions are formed. Explain this process.
CHAPTER 2

Measuring the Activity of Enzymes in Detergents

OBJECTIVES
- Recognize the function of enzymes in laundry detergents.
- Relate the factors of temperature and pH to the activity of enzymes.

PROCESS SKILLS
- designing an experiment
- making observations
- measuring volume, mass, and pH
- graphing
- analyzing data
- making conclusions

MATERIALS
- safety goggles
- lab apron
- balance
- graduated cylinder
- glass stirring rod
- 150 mL beaker
- 18 g regular instant gelatin or 1.8 g sugar-free instant gelatin
- 0.7 g Na₂CO₃, sodium carbonate
- tongs or a hot mitt
- 50 mL boiling water
- thermometer
- pH paper
- 6 test tubes
- test-tube rack
- pipet with bulb
- plastic wrap
- tape
- 50 mL beakers (6)
- 50 mL distilled water
- 1 g each of 5 brands of laundry detergent
- wax pencil
- metric ruler

Background
1. Write a definition for the term enzyme.
2. From what you know about enzymes, why might enzymes be added to detergents?

Procedure
PART A Making a Protein Substrate
1. **CAUTION** Always wear safety goggles and a lab apron to protect your eyes and clothing. Put on safety goggles and a lab apron.

2. **CAUTION** Use tongs or a hot mitt to handle heated glassware. Put 18 g of regular (1.8 g of sugar-free) instant gelatin in a 150 mL beaker. Slowly add 50 mL of boiling water to the beaker, and stir the mixture with a stirring rod. Test and record the pH of this solution.

3. **CAUTION** Do not touch or taste any chemicals. Very slowly add 0.7 g of Na₂CO₃ to the hot gelatin while stirring. Note any reaction. Test and record the pH of this solution.

4. **CAUTION** Glassware is fragile. Notify the teacher of broken glass or cuts. Do not clean up broken glass or spills with broken glass unless the teacher tells you to do so. Remember to use tongs or a hot mitt to handle heated glassware. Place 6 test tubes in a test-tube rack. Pour 5 mL of the gelatin-Na₂CO₃ mixture into each tube. Use a pipet to remove any bubbles from the surface of the mixture in each tube. Cover the tubes tightly with plastic wrap and tape. Cool the tubes, and store them at room temperature until you begin Part C. Complete step 11 in Part C.
PART B Designing Your Experiment

5. Based on the objectives for this lab, write a question you would like to explore about enzymes in detergents. To explore the question, design an experiment that uses the materials listed for this lab.

6. Write a procedure for your experiment. Make a list of all the safety precautions you will take. Have your teacher approve your procedure and safety precautions before you begin the experiment.

PART C Conducting Your Experiment

7. CAUTION Always wear safety goggles and a lab apron to protect your eyes and clothing. Put on safety goggles and a lab apron.

8. Make a 10 percent solution of each laundry detergent by dissolving 1 g of detergent in 9 mL of distilled water.

9. Set up your experiment. Repeat step 11.

10. Record your data after 24 hours in a data table similar to the one below.

CAUTION Know the location of the emergency shower and eyewash station and how to use them. If you get a chemical on your skin or clothing, wash it off at the sink while calling to the teacher. Notify the teacher of a spill. Spills should be cleaned up promptly, according to your teacher’s directions. Dispose of solutions, broken glass, and gelatin in the designated waste containers. Do not pour chemicals down the drain or put lab materials in the trash unless your teacher tells you to do so.

11. Clean up your work area and all lab equipment. Return lab equipment to its proper place. Wash your hands thoroughly before leaving the lab and after finishing all work.

Analysis and Conclusions

1. Suggest a reason for adding Na$_2$CO$_3$ to the gelatin solution.

2. Make a bar graph of your data. Plot the amount of gelatin broken down (change in the depth of the gelatin) on the y-axis and the type of detergent on the x-axis. Use a separate sheet of graph paper.

3. What conclusions did your group infer from the results? Explain.

Further Inquiry

Research other household products that contain enzymes, and find out their role in each of the products.

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**DATA TABLE**

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