Basic Chemistry

chapter 2

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Key Terms

acid (p. 23)
adenosine triphosphate (ATP) (p. 25)
atom (p. 16)
base (p. 23)
catalyst (p. 22)
compound (p. 21)
covalent bond (p. 18)
electrolyte (p. 20)
element (p. 15)
energy (p. 24)
enzyme (p. 22)
hydrogen bond (p. 18)
ionic bond (p. 18)
isotope (p. 17)
molecule (p. 20)
pH (p. 23)
solution (p. 26)
suspension (p. 26)

Objectives

1. Define the terms *matter*, *element*, and *atom*, and do the following:
   - List the four elements that comprise 96% of body weight.
   - Describe the three components of an atom.
   - Describe the role of electrons in the formation of chemical bonds.
2. Differentiate among ionic, covalent, and hydrogen bonds.
3. Explain ions, including the differences among electrolytes, cations, and anions.
4. Explain the difference between a molecule and a compound, and list five reasons why water is essential to life.
5. Explain the role of catalysts and enzymes.
6. Differentiate between an acid and a base, and define pH.
7. List the six forms of energy and describe the role of adenosine triphosphate (ATP) in energy transfer.
8. Differentiate among a mixture, solution, suspension, colloidal suspension, and precipitate.

Why a chapter on chemistry? Because our bodies are made of different chemicals. The food we eat, the water we drink, and the air we breathe are all chemical substances. We digest our food, move our bodies, experience emotions, and think great thoughts because of chemical reactions. To understand the body, we must understand some general chemical principles.

MATTER, ELEMENTS, AND ATOMS

MATTER

Chemistry is the study of matter. Matter is anything that occupies space and has weight. Anything that you see as you look around is matter.

Matter exists in three states: solid, liquid, and gas. Solid matter—such as skin, bones, and teeth—has a definite shape and volume. Liquid matter—such as blood, saliva, and digestive juices—takes the shape of the container that holds it. A gas, or gaseous matter—such as the air we breathe—has neither shape nor volume.

Matter can undergo both physical and chemical changes. The logs in a fireplace illustrate the difference between a physical and a chemical change (Figure 2-1). The logs can undergo a physical change by being chopped into smaller chips of wood with a hatchet. The wood chips are smaller than the log, but they are still wood. The matter (wood) has not essentially changed; only the physical appearance has changed. A chemical change occurs when the wood is burned. When burned, the wood ceases to be wood. The chemical composition of the ashes is essentially different from that of wood.

The body contains many examples of physical and chemical changes. For example, digestion involves physical and chemical changes. Chewing breaks the food into smaller pieces; this is a physical change. Potent chemicals digest or change the food into simpler substances; this is a chemical change.

ELEMENTS

All matter, living or dead, is composed of elements. An **element** is matter that is composed of atoms that have the same number of positive charges in their nuclei. Even a very small amount of an element such as sodium contains millions and millions of sodium atoms. The same name is used for both the

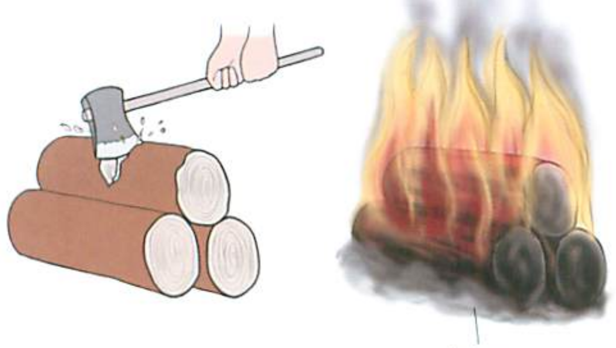


FIGURE 2-1 Changes in matter.

element and the atom. Although more than 100 elements exist, only about 25 elements are required by living organisms.

Do You Know...

Why Children Should Not Be Allowed to Play in Traffic and Chew on Old Paint?

Aside from the obvious safety issues, old paint and emissions from motor vehicles contain high amounts of lead. Exposure to high levels of lead causes lead poisoning, a serious condition that damages the major organs, including the brain, liver, kidney, and bone marrow. The old name for chronic lead poisoning is plumbism, from the Latin word for lead *(plumbum)*. The chemical symbol for lead is Pb. (By the way, a plumber is called a plumber because ancient water pipes were made of *plumbum*, or lead.) Why does plumbism have such a great history? Lead was used to make pipes that carried water and was used to make pottery, particularly drinking vessels. This practice killed many of the rich and famous—those wealthy enough to afford leaded wine goblets. Because of the toxic nature of lead, pipes and pottery in the United States are no longer made of lead, gasoline and paint are now lead-free by law, and the disposal of acid lead batteries is regulated. Is the lead problem a done deal? No! Children are still huffing lead fumes from car emissions, playing with toys laced with lead paint, and wearing clothing impregnated with lead. Go figure!

The most abundant elements found in the body are listed in Table 2-1. Four elements—carbon, hydrogen, oxygen, and nitrogen—make up 96% of the body weight. The trace elements are present in tiny amounts, but despite the small amounts required, the trace elements are essential for life. (Not all the trace elements appear in Table 2-1.)

Each of the elements included in Table 2-1 is represented by a symbol, and the first letter of the symbol is always capitalized. For example, the symbol O is for oxygen, N is for nitrogen, Na is for sodium, K is for potassium, and C is for carbon. These symbols are used frequently, so you should memorize the symbols of the major elements.

ATOMS

ATOMIC STRUCTURE

Elements are composed of atoms, the basic units of matter. An **atom** is the smallest unit of an element with that element's chemical characteristics. An atom is composed of three subatomic particles: protons, neutrons, and electrons. The arrangement of the subatomic particles resembles the sun and planets (Figure 2-2, *A*), with the sun in the center and the planets constantly moving around the sun in orbits, or circular paths. The atom is composed of a nucleus (the sun) and shells, or orbits, that surround the nucleus (see Figure 2-2, *B*).

Where are the subatomic particles located? The protons and the neutrons are located in the nucleus (see Figure 2-2, *C*). Protons carry a positive (+) electrical charge; neutrons carry no electrical charge. The electrons are located in the shells, or orbits, surrounding the nucleus like planets. Electrons carry a negative (−) electrical charge. In each atom, the number of protons (+) is equal to the number of electrons (−). The atom is therefore electrically neutral; it carries no net electrical charge.

All protons are alike, all neutrons are alike, and all electrons are alike. So what makes one atom different from another atom? The difference is primarily in the numbers of protons and electrons in each atom. For example, hydrogen is the simplest and smallest atom.

Table 2-1 Common Elements in the Human Body

ELEMENT	SYMBOL	PERCENTAGE OF BODY WEIGHT (%)
Oxygen	O	65.0
Carbon	C	18.5
Hydrogen	H	9.5
Nitrogen	N	3.2
Calcium	Ca	
Phosphorus	P	
Potassium	K	
Sulfur	S	
Sodium	Na	
Chlorine	Cl	
Magnesium	Mg	
Iron	Fe	
Iodine*	I	
Chromium*	Cr	
Cobalt*	Co	
Copper*	Cu	
Fluorine*	F	
Selenium*	Se	
Zinc*	Zn	

*Trace elements.

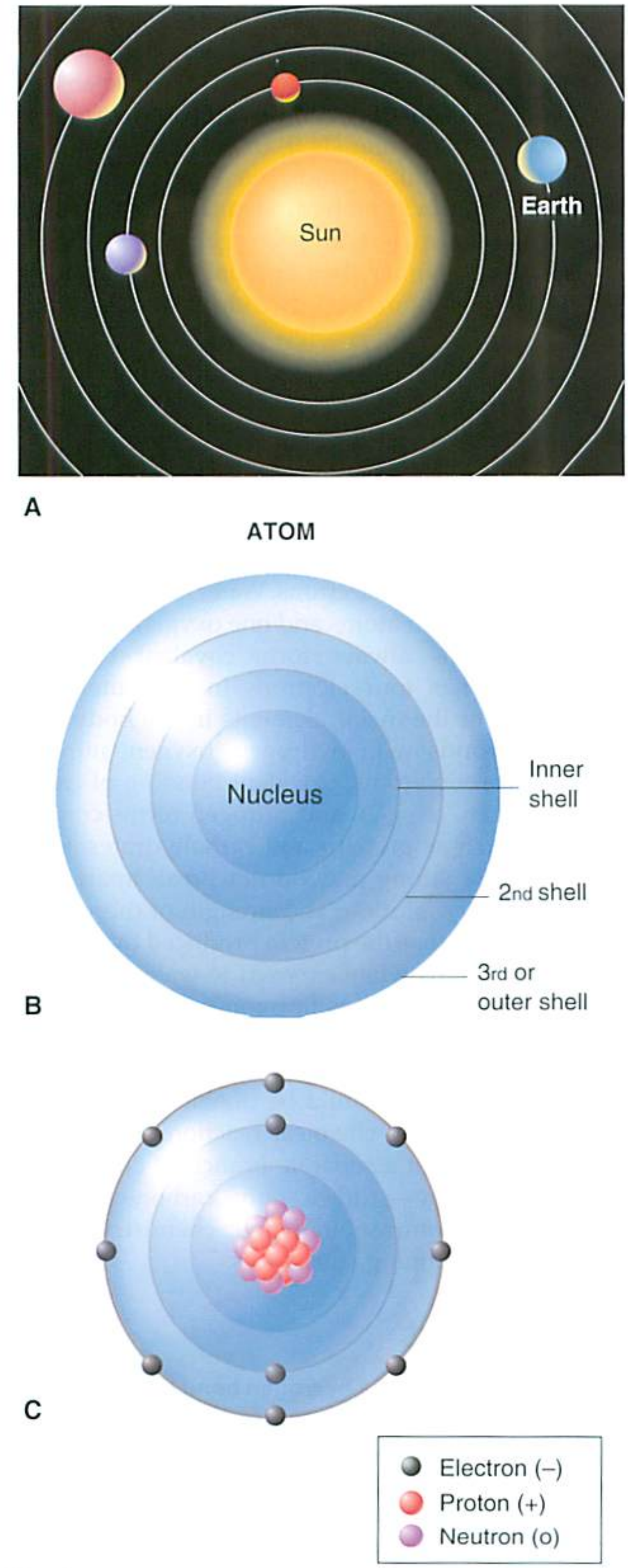


FIGURE 2-2 Structure of the atom. **A,** Subatomic particles arranged like the sun and the planets. **B,** Nucleus and electron shells. **C,** Protons and neutrons located in the nucleus and electrons encircling the nucleus in orbits.

It has one proton and one electron. Helium has two protons and two electrons. Lithium has three protons and three electrons. Hydrogen, helium, and lithium are different atoms because of the different numbers of protons and electrons.

? Re-Think

1. How does the structure of an atom resemble the solar system (sun and planets)?
2. What electrical charge is carried by the proton, electron, and neutron?
3. Identify the locations of the proton, neutron, and electron.

OTHER CHARACTERISTICS OF ATOMS

Two terms describe individual atoms. The atomic number is the number of protons in the nucleus. Thus, hydrogen has an atomic number of 1, helium has an atomic number of 2, and lithium has an atomic number of 3. The atomic mass of an atom is determined by adding the numbers of protons and neutrons in the nucleus. Thus, the atomic mass of hydrogen is also 1 because the hydrogen nucleus contains one proton and no neutrons. The atomic mass of helium is 4 because the nucleus contains two protons and two neutrons. (The atomic mass is roughly equivalent to the atomic weight.)

An **isotope** (EYE-so-tohp) is a different form of the same atom. For example, hydrogen has different forms. Hydrogen has an atomic number of 1 and an atomic mass of 1; it has one proton and no neutrons in the nucleus. A second and less common form of hydrogen is called *heavy hydrogen*. It has one proton and one neutron in its nucleus; thus, its atomic number is 1, but its atomic mass is 2. Because its atomic number is 1, it is still a hydrogen atom. The additional neutron in the nucleus, however, makes it heavy and changes its atomic mass. Heavy hydrogen is an isotope of hydrogen. Remember that an isotope has the same atomic number as an atom but a different atomic mass.

Isotopes are often unstable and their nuclei break down, or decay, giving off energy. In doing so, the unstable nuclei become more stable. Unstable isotopes are called *radioisotopes*. The process of spontaneous breakdown (decay) is called *radioactivity*. Radioisotopes are damaging to tissue and are used clinically to destroy cells. For example, radioactive iodine is used to destroy excess thyroid tissue. Other radioisotopes are used to destroy cancer cells, and radioisotopes can also be used diagnostically. For example, radioactive iodine (^{131}I) is normally taken up by the thyroid gland at a certain rate. Alterations in the rate of ^{131}I uptake can indicate thyroid dysfunction.

? Re-Think

1. What is the difference between the atomic number and atomic mass?
2. What is an isotope? A radioisotope?

ELECTRON SHELLS

Electrons surround the nucleus in orbits called *energy levels* or *electron shells* (see Figure 2-2, *C*). The number of shells varies from one atom to the next. Some atoms, like hydrogen, have only one shell; other atoms, like sodium, have three shells. Each shell can hold a specific number of electrons. The inner shell closest to the nucleus can hold only two electrons. The second and third shells can each hold eight electrons.

The only electrons that are important for chemical bonding are the electrons in the outermost shell. If it is not filled with its proper number of electrons, the outer shell becomes unstable. It then tries to give up electrons to empty the shell, acquire electrons to fill the shell, or share electrons so that each participating atom acquires the proper number of electrons in its outer shells. The tendency of the outer shell to want to become stable forms the basis of chemical bonding.

CHEMICAL BONDS

Atoms are attracted to each other because they want to achieve a stable outer electron shell. In other words, they want to fill or empty the outer electron shell. The force of attraction between the atoms is similar to the force of two magnets. When you try to separate the magnets, you can feel the pull. The electrical attraction between atoms is a chemical bond. The three types of chemical bonds are ionic bonds, covalent bonds, and hydrogen bonds.

IONIC BONDS

An **ionic** (eye-ON-ik) **bond** is caused by a transfer of electrons between atoms. The interaction of the sodium and chlorine atoms illustrates an ionic bond (Figure 2-3, *A*). The sodium atom has 11 protons in the nucleus and 11 electrons in the shells. Two electrons are in the inner shell, eight in the second shell, and only one in the outer shell. This single electron makes the outer shell unstable. To become more stable, the sodium atom would like to donate the single electron. Donating an electron forms a bond between the two atoms.

Sodium often bonds with chlorine. The chlorine (Cl) atom has 17 protons in the nucleus and 17 electrons orbiting in its shells. The electrons are positioned as follows: two electrons in the inner shell, eight in the second shell, and seven in the outer shell. The seven electrons make the outer shell unstable. The chlorine atom would like to add a single electron. The electrical attraction occurs between the outer shells of the sodium and chlorine atoms. The single electron in the outer shell of the sodium (Na) atom is attracted to the seven electrons in the outer shell of the chlorine atom. Thus, the sodium atom and chlorine atom bond ionically to form sodium chloride (NaCl), or table salt.

COVALENT BONDS

A second type of chemical bond is the **covalent** (ko-VAYL-ent) **bond**. Covalent bonding involves a sharing of electrons by the outer shells of the atoms. Covalent bonding is like joining hands (see Figure 2-3, *B*). The formation of water from hydrogen and oxygen atoms illustrates covalent bonding. Oxygen has eight electrons, two in the inner shell and only six in the outer shell. An oxygen atom needs two electrons to complete the outer shell. Hydrogen has only one electron and requires one electron to complete its inner shell.

Water is formed when two hydrogen atoms, each with one electron, share those electrons with one oxygen atom. By sharing the electrons of the oxygen, each of the two hydrogen atoms has completed the inner shells (capacity is two electrons). By sharing the electrons of two hydrogen atoms, the outer shell of the oxygen is completed, with eight electrons. Water is represented as H_2O (two hydrogen atoms and one oxygen atom).

Carbon atoms always form covalent bonds. A carbon atom has four electrons in the outer shell. Carbon, one of the major elements in the body, most commonly bonds with hydrogen, oxygen, nitrogen, and other carbon atoms. Covalent bonding of carbon with hydrogen, oxygen, and nitrogen forms complex molecules such as proteins and carbohydrates. Covalent bonds are strong and do not break apart in an aqueous (water) solution. The strength of these bonds is important because the protein produced by the body must not fall apart when exposed to water.

Many proteins, such as hormones, are transported around the body by blood, which is mostly water. If the covalent bonds of the protein broke apart in water, the hormones would be unable to accomplish their tasks. So many chemical reactions in the body involve carbon that a separate branch of chemistry—organic chemistry—studies only carbon-containing substances. In contrast, inorganic chemistry studies non–carbon-containing substances.

HYDROGEN BONDS

A third type of bond is a **hydrogen bond** (see Figure 2-3, *C*). It differs from the ionic and covalent bonds in that the hydrogen bond is not caused by the transfer or sharing of electrons of the outer shells of atoms. A hydrogen bond is best illustrated by the weak attraction between water molecules. Water is composed of hydrogen and oxygen. The weak positive charge around the hydrogen of one water molecule is attracted to the weak negative charge of the oxygen in a second water molecule. Because the bond occurs between two molecules it is called an *intermolecular bond*.

POLARITY

Water engages in hydrogen bonding because it is a polar molecule. What makes water a polar molecule?

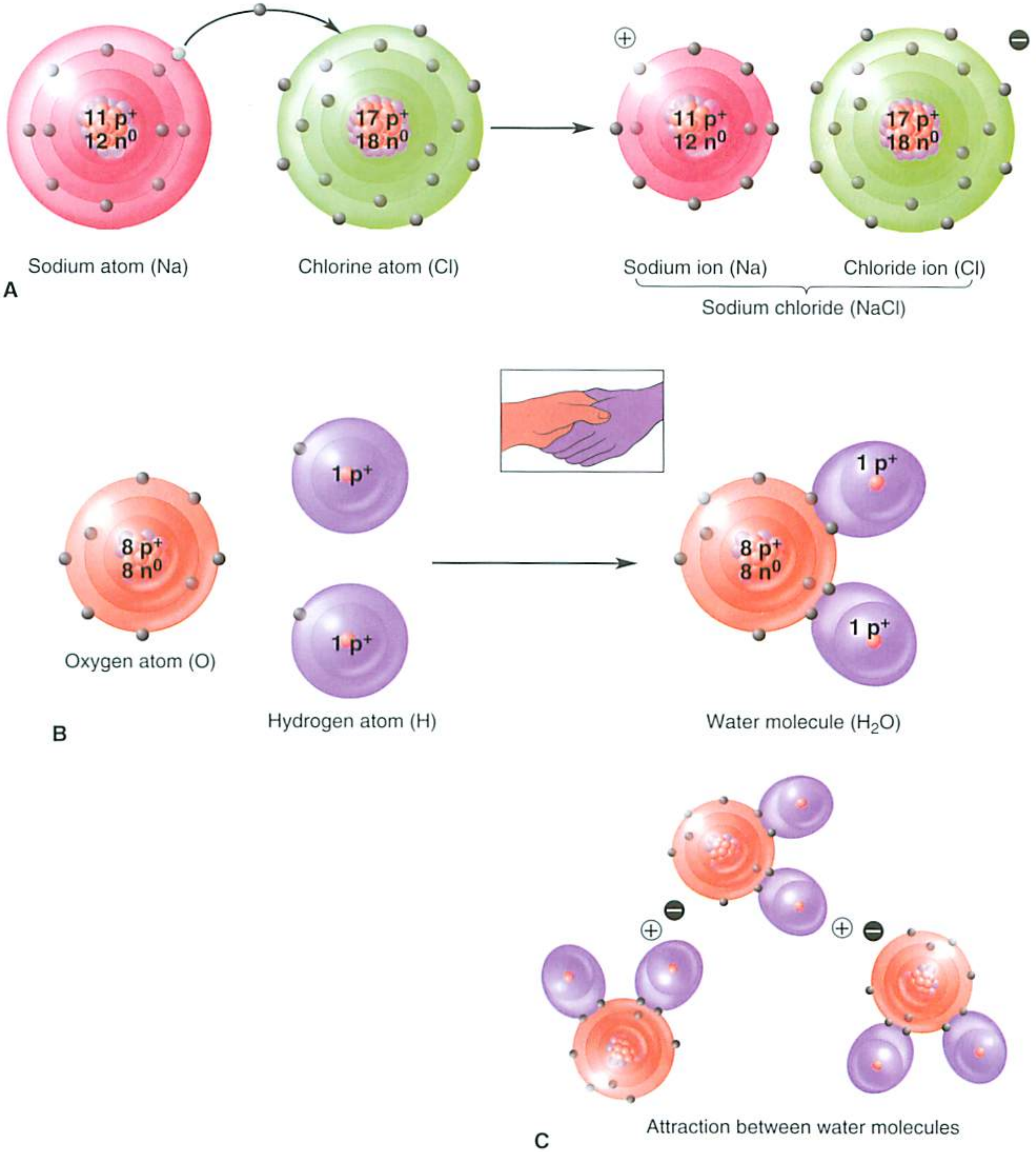


FIGURE 2-3 Chemical bonds. **A,** Ionic bond. **B,** Covalent bond. **C,** Hydrogen bond.

Because of the uneven sharing of electrons within a water molecule, there is a slight positive charge around the hydrogen end of the water and a slight negative charge around the oxygen end. Note how lopsided the water molecule appears in Figure 2-3, *C;* more importantly, the *charges* are lopsided. A polar molecule is defined as a molecule that has a lopsided charge—a positive end and a negative end. The lopsided charge means that the positive end—hydrogen—of one water molecule is attracted to the negative end—oxygen—of a second water molecule.

? Re-Think

1. Explain the role of the outer electron shell to ionic and covalent bonding.
2. Explain why water is described as a polar molecule.

IONS

CATIONS, ANIONS, AND ELECTROLYTES

Several other terms are related to the activity of the electrons in the outer shells of the atoms. If the negatively charged electrons are lost from or gained by the outer shell of an atom, the electrical charge of the atom changes. In other words, the electrical charge of the atom changes from a neutral charge (i.e., no charge) to a positive (+) charge or negative (–) charge. Atoms that carry an electrical charge are called *ions*. If the ion is positively charged (+), it is a cation. If the ion is negatively charged (–), it is an anion.

An **electrolyte** is a substance that forms ions when it is dissolved in water. Electrolytes, as the name implies, are capable of conducting an electrical current. For example, the electrocardiogram (ECG) and the electroencephalogram (EEG) record electrical events in the heart and brain.

ION FORMATION

Ions are formed when electrons in the outer shell are lost or gained. For example, the sodium atom has 11 protons (positive charge) and 11 electrons (negative charge). If a single electron is donated, the sodium is left with 11 positive (+) charges and only 10 negative (–) charges. Sodium is said to carry a net charge of +1. The sodium ion, represented as Na^+, is therefore a cation.

The chlorine atom has 17 protons (positive charge) and 17 electrons (negative charge). If an electron is gained, the chlorine then contains 17 (+) charges and 18 (–) charges. Chlorine is said to carry a net charge of –1 and is considered an anion. The chlorine anion is called *chloride* and is represented as Cl^-. Some atoms may give up more than one electron and have a stronger positive charge. Calcium, for example, gives up two electrons. It is represented as Ca^{2+}. Table 2-2 presents other important ions. Note that combinations of atoms, such as bicarbonate (HCO_3^-), carry an electrical charge and are therefore ions.

IONIZATION

When an electrolyte splits, or breaks apart in solution, the electrolyte is said to dissociate (Figure 2-4). For example, NaCl is an electrolyte. In the solid state, it appears as tiny white granules. When dissolved in water, however, the table salt dissociates. What is happening?

$$\underset{\text{salt}}{NaCl} \rightarrow \underset{\substack{\text{sodium ion}\\\text{(cation)}}}{Na^+} + \underset{\substack{\text{chloride ion}\\\text{(anion)}}}{Cl^-}$$

When the salt is placed in water, the ionic bonds holding the sodium and chlorine together weaken. The solid NaCl then splits into Na^+ (sodium ion) and Cl^- (chloride ion). In other words, the NaCl dissociates. Because the products of this dissociation are ions, this dissociation process is referred to as *ionization*. Only electrolytes ionize.

Table 2-2 Common Ions

NAME	SYMBOL	FUNCTION
Cations		
Sodium	Na^+	Fluid balance (chief extracellular cation), nerve and muscle function
Calcium	Ca^{2+}	Component of bones and teeth, blood clotting, muscle contraction
Iron	Fe^{2+}	Component of hemoglobin (oxygen transport)
Hydrogen	H^+	Important in acid-base balance. Its concentration determines the pH of a solution.
Potassium	K^+	Nerve and muscle function, chief intracellular cation
Ammonium	NH_4^+	Important in acid-base regulation
Anions		
Chloride	Cl^-	Chief extracellular anion
Bicarbonate	HCO_3^-	Important in acid-base regulation
Phosphate	PO_4^{3-}	Component of bones and teeth, component of ATP (energy)

ATP, Adenosine triphosphate.

Do You Know...

What the Patient's "Lytes" Are?

This is medical jargon for electrolytes. One of the most important clinical tools is the assessment of the patient's electrolytes. Actually, the "lytes" are really ions such as Na^+ (sodium), K^+ (potassium), Cl^- (chloride), Mg^{2+} (magnesium), and HCO_3^- (bicarbonate). The terms *electrolytes* and *ions* are used interchangeably in the clinical setting.

Re-Think

Using table salt (NaCl) as an example, explain the difference between an electrolyte, ion, cation, and anion.

MOLECULES AND COMPOUNDS

MOLECULES

When two or more atoms bond, they form a **molecule**. Two identical atoms may bond. For example, one atom of oxygen may bond with another atom of oxygen to

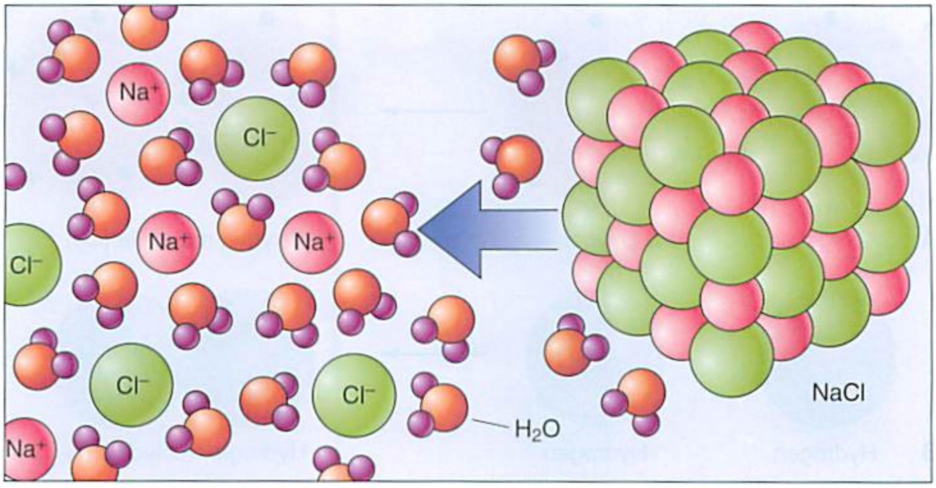


FIGURE 2-4 Ionization—dissociation of NaCl → Na^+ + Cl^- in water.

form a molecule of oxygen, which is designated O_2. The same bonding is true for nitrogen (N_2) and hydrogen (H_2) (Figure 2-5). A molecule can also be formed when atoms of different elements combine. For example, when two atoms of hydrogen combine with one atom of oxygen, a molecule of water (H_2O) is formed.

COMPOUNDS

A substance that contains molecules formed by two or more different atoms is called a **compound**. For example, if two atoms of hydrogen combine with one atom of oxygen, water is formed. Water is considered both a molecule and a compound.

SOME IMPORTANT COMPOUNDS AND MOLECULES

WATER

Water is the most abundant compound in the body. It constitutes approximately two thirds of an adult's body weight and even more of a child's body weight. Water is essential for life. Although we can last for many weeks without food, we can last only a few days without water. What makes water so special?

- *Water as the universal solvent.* Water is called the universal solvent because most substances dissolve in water. Its use as a solvent is one of the most important characteristics of water. The ability to dissolve substances is largely because of the polar structure of water (positive charge on one end, negative charge on the other end). For example, the plasma protein albumin carries a negative (–) charge. It is attracted to the positive (+) end of the water molecule. The attraction of the electrical charges allows albumin to dissolve in water. Many nutrients, waste products, and hormones dissolve in water for transport throughout the body.
- *Water as temperature regulator.* Water has the ability to absorb large amounts of heat without the temperature of the water itself increasing dramatically. This ability means that heat can be removed from heat-producing tissue, like exercising muscle, while the body maintains a normal temperature. Also, when water evaporates from the skin surface, it carries with it a considerable amount of heat. Water, therefore, plays an important role in the body's temperature regulation.
- *Water as an ideal lubricant.* Water is a major component of mucus and other lubricating fluids. Lubricating fluids decrease friction as two structures slide past each other, thereby minimizing wear and tear.
- *Water in chemical reactions.* Water plays a crucial role in many chemical reactions. For example, water is necessary to break down carbohydrates during digestion.
- *Water as a protective device.* Water may also be used to protect an important structure. For example, the cerebrospinal fluid surrounds and cushions the delicate brain and spinal cord. Similarly, amniotic fluid surrounds and cushions the developing infant in the mother's womb.

? Re-Think

1. Physiologically, why is water so important?
2. What characteristic of water allows it to transport solute throughout the body?

OXYGEN

Oxygen (O_2), a molecule composed of two oxygen atoms, exists in nature as a gas. The air we breathe contains 21% oxygen. Oxygen is essential for life; without a continuous supply, we would quickly die. The oxygen we inhale is used by cells to liberate the energy from the food we eat. This energy powers the body; like an engine, if the body has no energy, it stops running. The importance of oxygen accounts for the urgency associated with cardiopulmonary resuscitation (CPR). If the heart stops beating, the delivery of oxygen to the tissue ceases and the brain dies.

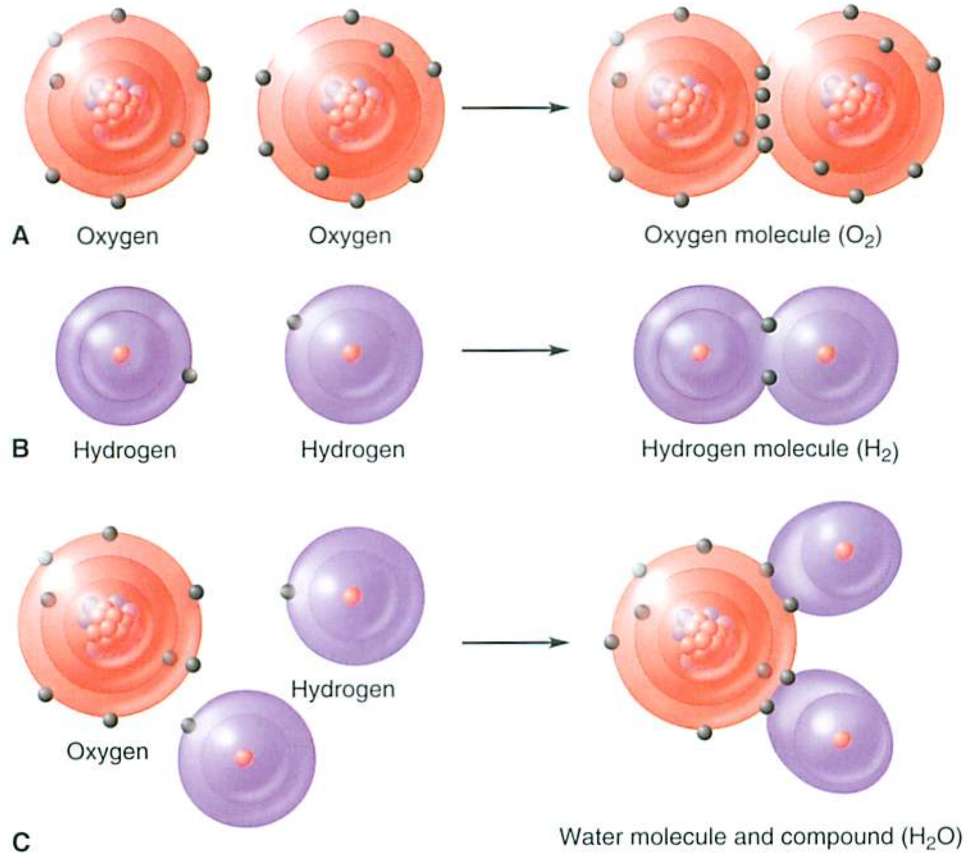


FIGURE 2-5 Molecules and compounds. **A,** Oxygen (O_2). **B,** Hydrogen (H_2). **C,** Water (H_2O).

CARBON DIOXIDE

Carbon dioxide (CO_2) is a compound that consists of one carbon atom and two oxygen atoms—hence the name carbon dioxide (*di-* means "two"). CO_2 is a waste product, so it must be eliminated from the body. It is made when food is chemically broken down for energy.

2+2 Sum It Up!

Chemistry is the study of matter. Matter is composed of elements such as hydrogen, oxygen, carbon, and nitrogen. Each element is composed of millions of the same atoms. Atoms are composed of subatomic particles called protons, neutrons, and electrons. Two characteristics of atoms are the atomic number (number of protons) and the atomic mass (number of protons and neutrons). Chemical bonds are formed through the interaction of one atom with another. The three chemical bonds are ionic, covalent, and hydrogen bonds. The transfer of electrons is responsible for the formation of ions (cations and anions). Cations are positively charged ions, whereas anions are negatively charged ions. Molecules and compounds are formed when atoms interact in a particular fashion. Water (H_2O), oxygen (O_2), and carbon dioxide (CO_2) are examples of important molecules and compounds. Water is the most abundant compound in the body and has numerous characteristics that make it essential to life.

CHEMICAL REACTIONS

A chemical reaction is a process whereby the atoms of molecules or compounds interact to form new chemical combinations. For example, glucose interacts with oxygen to form carbon dioxide, water, and energy. This chemical interaction is characterized by the breaking of the chemical bonds of glucose and oxygen and the making of new bonds as carbon dioxide and water are formed. The reaction is represented as follows:

$$\underset{\text{glucose}}{C_6H_{12}O_6} + \underset{\text{oxygen}}{O_2} \rightarrow \underset{\text{carbon dioxide}}{CO_2} + \underset{\text{water}}{H_2O} + \text{energy}$$

The rates of chemical reactions (how fast they occur) are important. Chemical substances called **catalysts** (KAT-ah-lists) speed up the rate of a chemical reaction. When proteins perform the role of catalysts, they are called **enzymes** (EN-zymes). Most chemical reactions require a catalyst.

ACIDS AND BASES

A normally functioning body requires a balance between substances classified as acids and as bases. Acid–base balance is important because the chemical reactions in the body occur only when these substances are in balance. Imbalances of acids and bases are common and cause life-threatening clinical problems. An understanding of the chemistry of acids and bases is crucial to understanding acid–base balance.

ACIDS

We all recognize the sour taste of an acid. Grapefruit juice, lemon juice, and vinegar are acids. In addition to a sour taste, very strong acids, such as hydrochloric acid (HCl), can cause severe burns. Acid splashed in your eye, for example, can damage the eye tissue to the point of blindness. An **acid** is an electrolyte that dissociates into a hydrogen ion (H^+) and an anion. Its dissociation is represented as follows:

$$\underset{\text{hydrochloric acid}}{HCl} \rightarrow \underset{\text{hydrogen ion}}{H^+} + \underset{\text{chloride ion}}{Cl^-}$$

In this reaction, HCl dissociates into H^+ and the chloride ion (Cl^-). For our purposes, the most important component is the H^+. The amount of H^+ in a solution determines its acidity.

A strong acid dissociates (breaks apart) completely into H^+ and an anion. HCl, found within the stomach, is a strong acid; it yields many hydrogen ions. A weak acid does not dissociate completely. Vinegar, or acetic acid, is a weak acid. Vinegar dissociates slightly into H^+. Most of the vinegar remains in its undissociated form, and its dissociation is represented as follows:

$$\text{vinegar} \rightleftharpoons H^+ + \text{acetate}^-$$

The heavy arrow pointing to the left indicates that the vinegar remains as vinegar, forming very little H^+. Because the number of hydrogen ions (H^+) determines the acidity of a solution, vinegar is classified as a weak acid. This weakness is the reason that vinegar does not burn your hand. HCl is so strong that it can actually burn a hole through your hand.

BASES

A **base** has a bitter taste and is slippery like soap. Bases are substances that combine with H^+. Bases often contain the hydroxyl ion (OH^-), such as sodium hydroxide (NaOH). NaOH dissociates into sodium ion (Na^+) and the hydroxyl ion (OH^-) as follows:

$$NaOH \rightarrow Na^+ + OH^-$$

OH^- is a hydrogen ion eliminator. In other words, the OH^- soaks up a hydrogen ion. The addition of a base makes a solution less acidic.

NEUTRALIZATION OF ACIDS AND BASES

When an acid is mixed with a base, as in the following example, the H^+ of the acid combines with the OH^- of the base to form water. In addition, the Na^+ and the Cl^- combine to form a salt, NaCl. The reaction is important because the H^+ is converted to water. In other words, the acid has been neutralized. This chemical reaction is represented as follows:

$$\underset{\text{acid}}{HCl} + \underset{\text{base}}{NaOH} \rightarrow \underset{\text{water}}{H_2O} + \underset{\text{salt}}{NaCl}$$

? Re-Think

1. What makes an acid an acid?
2. What makes a base a base?

MEASUREMENT: THE pH SCALE

One unit of measurement, **pH**, indicates how many H^+ ions are in a solution. The pH scale ranges from 0 to 14 (Figure 2-6). At the midpoint of the scale, pH 7, the number of H^+ ions in pure water is equal to the number

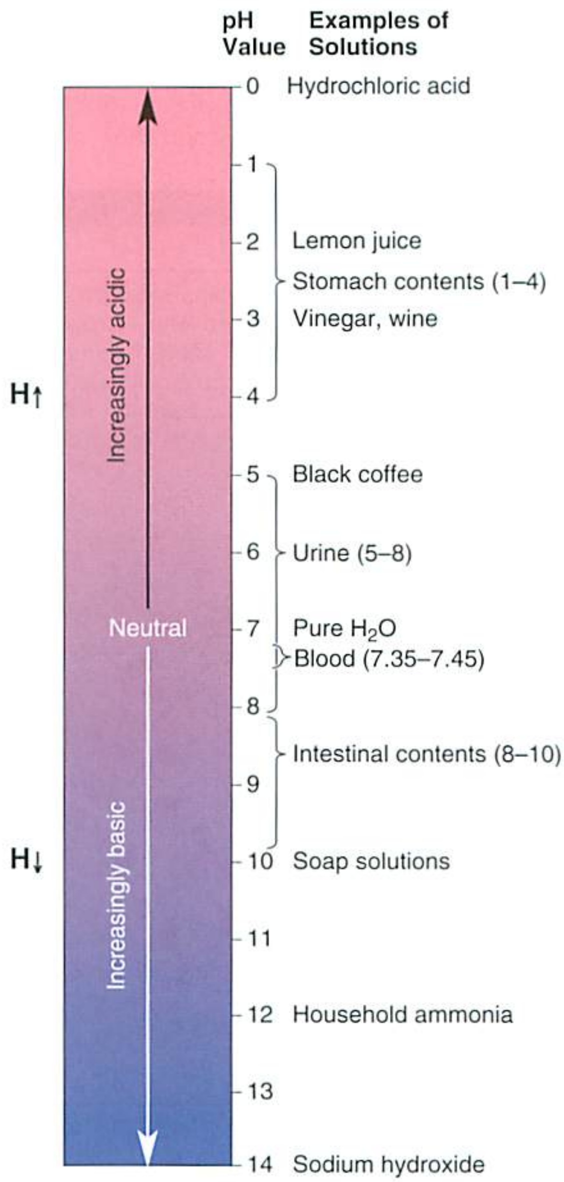


FIGURE 2-6 The pH scale. The scale indicates the H^+ concentration. Pink indicates the acidic range, and blue indicates the basic, or alkaline, range.

of OH^- ions. Therefore, the solution is neutral. A pH that measures less than 7 on the scale indicates that the solution has more H^+ than OH^-. The solution is then said to be acidic. Note the pH of lemon juice and vinegar on the scale. They are both less than 7 and are therefore acidic.

A pH measuring more than 7 indicates fewer H^+ ions than OH^- ions. These substances are bases, and the solution is said to be basic, or alkaline (AL-kah-lin). The pH scale measures the degree of acidity or alkalinity. A pH of 0 is most acidic, whereas a pH of 14 is most alkaline. Note that the intestinal contents are alkaline, the pH at which the digestive enzymes are most effective.

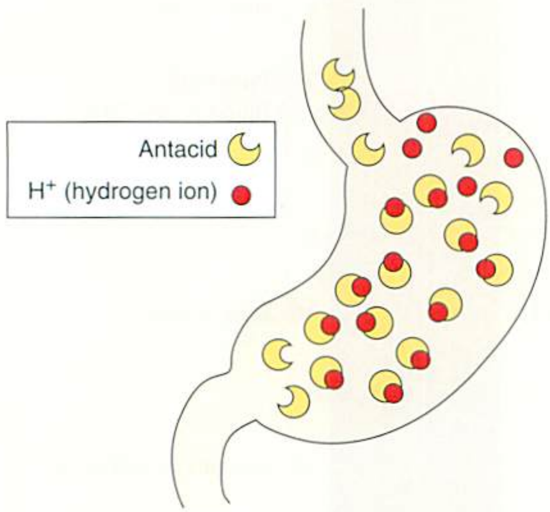
READING *THE* pH SCALE

Each pH unit represents a 10-fold change in H^+ concentration. For example, a change in 1 pH unit (from 7 to 6) represents a 10-fold increase in H^+, whereas a change in 2 pH units (from 7 to 5) represents a 100-fold increase in H^+ concentration. The important point is that very small changes in the pH reading indicate very large changes in the H^+ concentration.

Do You Know...

Why Antacids Are Used?

Patients with ulcers often have excess stomach acid. The stomach acid (HCl) can be neutralized with a drug that contains a base. Because these drugs oppose acids, they are called *antacids*. One of the most commonly used antacids contains aluminum hydroxide. The hydroxyl ion (OH^-) of the drug combines with the H^+ of the stomach acid, thereby neutralizing the acid.



pH OF BODY FLUIDS

Note the pH of some of the body fluids (see Figure 2-6). The stomach contents are very acidic, with a pH of 1 to 4. The pH of urine is normally acidic, with a pH range of 5 to 8, although a number of conditions, including diet, can change urinary pH. The intestinal secretions are alkaline, with a pH range of 8 to 10.

Blood pH is maintained within a narrow range of 7.35 to 7.45, a slightly alkaline pH. Because the blood pH is normally slightly alkaline (called the alkaline reserve), a blood pH of less than 7.35 is more acidic than normal, and the patient is said to be acidotic. If the patient's blood pH is higher than 7.45, the patient is said to be alkalotic. Because all of the body's enzymes work best at a normal blood pH, both acidosis and alkalosis cause serious clinical problems and must be corrected. The need to maintain the body's normal alkaline state is the reason for monitoring blood pH closely during the course of a patient's illness.

The blood pH is regulated on a minute-by-minute basis by three means: a buffer system, the lungs, and the kidneys. (These processes of regulation are described in Chapters 24 and 25.)

2+2 Sum It Up!

Chemical reactions are processes whereby one chemical substance is converted into a different chemical substance. The rate of a chemical reaction can be increased by a catalyst, or enzyme. A normally functioning body requires a balance between acids and bases. Hydrogen ion concentration is measured by pH. As H^+ increases, pH decreases; as H^+ decreases, pH increases. Normal blood pH is 7.35 to 7.45 and is therefore slightly alkaline. When pH falls below 7.35, the person is said to be acidotic; when pH rises above 7.45, the person is said to be alkalotic. Blood pH is regulated within normal limits by three mechanisms: buffers, lungs, and kidneys.

? Re-Think

1. Describe what is happening in a neutralization reaction to cause pH to change.
2. What blood pH is indicative of acidosis? Of alkalosis?

ENERGY

Energy is the ability to perform work. The body depends on a continuous supply of energy. Even at rest, the body is continuously working and using up energy. Heart muscle, for example, is contracting and forcing blood throughout a large network of blood vessels. The cells of the pancreas are continuously making enzymes so that we can digest our food. Without energy, the body ceases to function.

FORMS OF ENERGY

There are six forms of energy, summarized in Table 2-3. Mechanical energy is expressed as movement. For example, when the leg muscles contract, you are able to walk. Chemical energy is stored within the chemical bonds holding the atoms together. When the chemical bonds are broken, chemical energy is released. The

Table 2-3 Forms of Energy

FORM OF ENERGY	DESCRIPTION	EXAMPLE
Mechanical	Energy that causes movement	Movement of legs in running, walking; contraction of heart muscle, causing movement of blood
Chemical	Energy stored in chemical bonds	Fuel to do work, such as running
Electrical	Energy released from the movement of charged particles	Electrical signal involved in transmission of information along nerves
Radiant	Energy that travels in waves	Light stimulates the eyes for vision; ultraviolet radiation from the sun causes tanning
Thermal	Energy transferred because of a temperature difference	Responsible for body temperature
Nuclear	Energy released during the decay of radioactive substances such as isotopes	Not useful physiologically

released energy can then be used to perform other types of work, such as digesting food. This process is similar to the running of a car's engine; the energy released from the burning, or breakdown, of the gas is used to turn the engine, and the running engine then moves your car.

CONVERSION OF ENERGY

Energy is easily converted from one form to another. For example, when a log burns, the chemical energy stored in it is converted to heat (thermal energy) and light (radiant energy). In a similar way, the chemical energy stored in the muscle is converted into mechanical energy when the muscle contracts and moves your leg.

The conversion of energy in the body is generally accompanied by the release of heat. For example, when muscles contract during strenuous exercise, chemical energy is converted into both mechanical energy and heat (thermal) energy. Consider how hot you get while exercising. (Body temperature is further described in Chapter 7.)

ENERGY TRANSFER: THE ROLE OF ADENOSINE TRIPHOSPHATE

The energy used to power the body comes from the food we eat (Figure 2-7, *A*). As the food is broken down, energy is released. This energy, however, cannot be used directly by the cells of the body. The energy must first be transferred to another substance, called **adenosine triphosphate (ATP)**. ATP is an energy transfer molecule.

ATP is composed of three parts: a base, a sugar, and three phosphate groups (see Figure 2-7, *B*). Note the phosphate groups of the ATP molecule; they have unique chemical bonds. The squiggly lines connecting the second and third phosphate groups indicate that these bonds are high-energy bonds. When these bonds are broken, a large amount of energy is released. More importantly, the energy released from ATP can be used directly by the cell to perform its tasks.

The energy stored within the high-energy bonds is similar to the energy stored in a loaded mousetrap (see Figure 2-7, *C*). Energy is stored in the trap when you set the metal bar in its loaded position. When the trap is set off by the mouse, the metal bar snaps back into its original position, thereby releasing the stored energy. Similarly, when energy is needed by the body, ATP is split. The energy that was stored in ATP is released. In other words, the bond that holds the end phosphate group is broken, and energy is released. With the release of energy, the splitting of ATP also yields adenosine diphosphate (ADP) and phosphate (P). This process can be shown as follows:

$$\text{ATP} \rightarrow \text{energy} + \text{ADP} + \text{P}$$

ADP is almost identical to ATP, but the molecule now has one less phosphate group. ATP is replenished when energy, obtained from burning food, reattaches the end phosphate to ADP, as follows:

$$\text{ADP} + \text{P} + \text{energy} \rightarrow \text{ATP}$$

? Re-Think

Explain why ATP is an energy transfer molecule rather than an energy storage molecule.

MIXTURES, SOLUTIONS, SUSPENSIONS, AND PRECIPITATES

You will encounter several other chemical terms in clinical situations.

MIXTURES

Mixtures are combinations of two or more substances that can be separated by ordinary physical means. When separated, the substances retain their original properties. For example, imagine that you have a

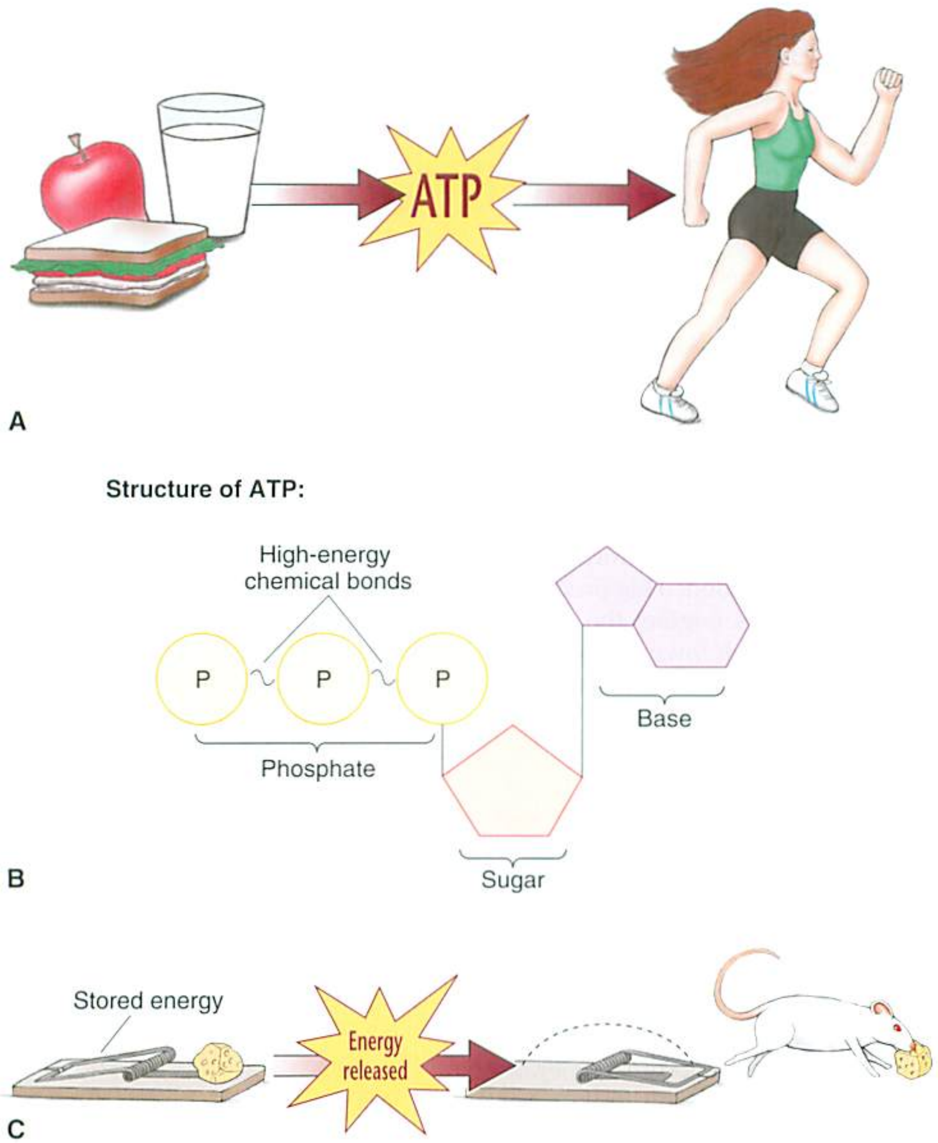


FIGURE 2-7 Energy. **A,** Source of energy. **B,** Storage of energy within the high-energy bonds of adenosine triphosphate (ATP). **C,** Release of energy.

mixture of sugar and little bits of iron. A magnet is then moved close to this sugar–iron mixture. The magnet pulls all the iron away from the sugar, thereby separating the two substances. Note that the two substances have retained their original properties. The sugar is still sugar, and the iron is still iron.

SOLUTIONS

Solutions are mixtures. In a solution, the particles that are mixed together remain evenly distributed. Salt water is an example of a solution. A solution has two parts, a solvent and a solute. The solute is the substance present in the smaller amount; it is the substance being dissolved. The salt in the salt water is the solute. The solute can be solid, liquid, or gas.

The solvent is the part of the solution present in the greater amount; it does the dissolving and is usually liquid or gas. Water is the solvent in salt water. If water is the solvent, the solution is referred to as an *aqueous solution*. If alcohol is the solvent, the solution is referred to as a *tincture*. A solution is always clear, and the solute does not settle to the bottom.

SUSPENSIONS

Suspensions are mixtures. In a suspension, the particles are relatively large and tend to settle to the bottom unless the mixture is shaken continuously. For example, if sand and water are shaken together and then allowed to sit undisturbed, the sand gradually settles to the bottom.

In a colloidal suspension, the particles do not dissolve, but they are so small that they remain suspended within the liquid, even when not being shaken. A colloid (KOL-oyd) is a gel-like substance that resembles egg whites. The body contains many colloidal suspensions. Blood plasma is a colloidal suspension because the proteins remain suspended within the plasma. Other examples of colloidal suspensions include mayonnaise and jelly.

PRECIPITATES

A precipitation reaction is the formation of a solid in a solution during a chemical reaction. The solid is called the *precipitate*. The formation of precipitates has several clinical consequences. For example, kidney stones are precipitates of salts in the urine and form especially when the salts are highly concentrated—hence, the direction to "drink plenty of fluids" as a preventive measure. Similarly, cholesterol-laden bile forms precipitates called *gallstones;* dietary teaching regarding cholesterol intake is provided in hopes of decreasing gallstone formation. Finally, you will be mixing medications; some combinations of drugs form precipitates that, if administered intravenously, act as emboli (such as moving blood clots) that could kill a patient. Clinically, precipitates are very important.

2+2 Sum It Up!

Energy is the ability to do work. Without an adequate supply of energy, the body cannot work, and it dies. Energy is derived from food and transferred to high-energy bonds in ATP. When needed, the energy is released from ATP and used to power the body. Other chemical terms include mixtures, solutions, suspensions, and precipitates.

? Re-Think

1. Normal saline (0.9% NaCl) is a salt solution. Explain why it is a solution and not a colloid. What is the solute and what is the solvent?
2. What is meant by a precipitate?

Get Ready for Exams!

Summary Outline

Our bodies are made of different chemicals. To understand the body, you need to understand some general chemical principles.

I. Matter, Elements, and Atoms
- A. Matter
  1. Anything that occupies space and has weight
  2. Exists in three states: solid, liquid, and gas
  3. Undergoes physical and chemical changes
- B. Elements
  1. Composed of atoms that have the same positive charge in their nuclei (same atomic number)
  2. Four elements (carbon, hydrogen, oxygen, and nitrogen) make up 96% of body weight.
- C. Atoms
  1. Composed of three subatomic particles: neutrons, protons, and electrons
  2. Atomic number: number of protons
  3. Atomic mass: number of neutrons and protons
  4. Isotope: atom with the same atomic number but a different atomic mass
  5. Radioisotope: an unstable isotope

II. Chemical Bonds
- A. Ionic bond: involves donation and acceptance of electrons
- B. Covalent bond: shares electrons of interacting atoms
- C. Hydrogen bond: an example, intermolecular bonds formed by polar molecules

III. Ions
- A. Ion: atom that carries an electrical charge
  1. Cation: positively charged ion
  2. Anion: negatively charged ion
- B. Electrolyte: substance that forms ions (ionization) when dissolved in water

IV. Molecules and Compounds
- A. Molecule: substance formed by two or more atoms (e.g., O_2, H_2O)
- B. Compound: substance that forms when two or more different atoms bond (e.g., H_2O)
- C. Important molecules and compounds: include water, oxygen, and carbon dioxide

V. Acids and Bases
- A. Acid: electrolyte that dissociates into hydrogen ion (H^+)
- B. Base: substance such as OH^- that combines with and eliminates H^+
- C. Neutralization reaction: acid and a base chemically react to form a salt and water
- D. pH scale: measures acidity and alkalinity. A pH of 7 is neutral. A pH less than 7 is acidic and a pH higher than 7 is basic, or alkaline.
- E. Normal pH of the blood: 7.35 to 7.45. A person with a pH less than 7.35 is acidotic, and a person with a pH higher than 7.45 is alkalotic.
- F. Regulation of blood pH: buffers, respiratory system, and kidneys

VI. Energy
- A. Definition: ability to do work
- B. Forms of energy
  1. Six forms of energy: see Table 2-3
  2. Most energy released as heat
- C. Role of adenosine triphosphate (ATP)
  1. ATP: energy transfer molecule
  2. Energy stored in high-energy phosphate bonds

VII. Mixtures, Solutions, Suspensions, and Precipitates
- A. Mixture: blend of two or more substances that can be separated by ordinary physical means
- B. Solutions, suspensions, and colloidal suspensions: types of mixtures
- C. Precipitate: solid formed during a chemical reaction

Review Your Knowledge

Matching: Atoms and Elements

Directions: Match the following words or symbols with their descriptions below.

a. atom
b. K
c. matter
d. Na
e. ion

1. ___ Composed of three particles: protons, neutrons, and electrons
2. ___ Symbol for potassium
3. ___ Symbol for sodium
4. ___ Exists in three states: liquid, solid, and gas
5. ___ Formed when sodium loses an electron

Matching: Structure of the Atom

Directions: Match the following words with their descriptions below. Some words may be used more than once, but others may not be used at all.

a. atomic mass
b. isotope
c. protons
d. electrons
e. neutrons
f. atomic number

1. ___ Number of protons in the nucleus
2. ___ Sum of number of protons and neutrons
3. ___ Same atomic number but different atomic mass
4. ___ Number of these in each atom equal to number of protons
5. ___ Circulate in orbits around the nucleus

Matching: Ions and Electrolytes

Directions: Match the following words with their descriptions below.

a. cation
b. ions
c. electrolyte
d. anion
e. ionization

1. ___ Classification of KCl
2. ___ Classification of K^+ and Cl^-
3. ___ K^+ is an ion classified as this
4. ___ Cl^- is an ion classified as this
5. ___ Dissociation of $KCl \rightarrow K^+ + Cl^-$

Matching: Acids and Bases

Directions: Match the following words or symbols with their descriptions below. Some words may be used more than once, but others may not be used at all.

a. alkalosis
b. pH
c. H^+
d. base
e. acid
f. acidosis

1. ___ Electrolyte that dissociates into H^+ and an anion
2. ___ Ion that makes a solution more acidic
3. ___ Measurement of hydrogen ion concentration $[H^+]$
4. ___ Condition characterized by pH lower than 7.35
5. ___ Condition caused by excess H^+

Multiple Choice

1. The ionization of salt (NaCl)
   a. is called a neutralization reaction.
   b. lowers pH.
   c. produces a cation (Na^+) and an anion (Cl^-).
   d. causes acidosis.
2. Which of the following is true of iodine and radioactive iodine?
   a. Both have the same atomic numbers.
   b. Both have the same atomic mass.
   c. Neither have electrons in their orbitals.
   d. Both create radiation hazards.
3. Which of the following is not true of Na^+?
   a. It is called the sodium ion.
   b. It has more protons than electrons.
   c. It is called a cation.
   d. It is measured by pH.
4. Which of the following is true of water?
   a. It is a molecule.
   b. It is an aqueous solvent.
   c. It is a compound.
   d. All of the above.
5. Which of the following best describes ATP?
   a. It is a buffer, removing H^+ from solution.
   b. It is an energy transfer molecule.
   c. It is a radioactive isotope of phosphate.
   d. It ionizes to H^+, thereby lowering pH.
6. Which of the following has donated an electron?
   a. H_2O
   b. Cl^-
   c. Na^+
   d. HCO_3^-
7. Which of the following is least descriptive of the nucleus of the atom?
   a. Its contents determine the atomic number.
   b. Its contents determine the atomic mass.
   c. It is the "home" of the electrons.
   d. It is the "home" of the protons.
8. Which of the following is descriptive of the patient with a blood pH of 7.28?
   a. The patient has a deficiency of H^+.
   b. The pH is within normal limits.
   c. The patient is acidotic.
   d. The patient is dehydrated.

Go Figure

1. **According to Figure 2-3**
   a. The stable inner shell of an atom contains eight electrons.
   b. The chloride ion has more electrons than protons.
   c. The sodium ion has more electrons than protons.
   d. Sodium and chlorine bond covalently.
2. **According to Figure 2-3**
   a. Hydrogen and oxygen bond ionically to form water.
   b. The oxygen atom has an unstable outer electron shell.
   c. The ionic bonding of sodium and chlorine changes the atomic number of the sodium and chlorine.
   d. The ionic bonding of sodium and chlorine changes the atomic mass of the sodium and chlorine.
3. **According to Figure 2-4**
   a. Ionization refers to the splitting of NaCl into Na^+ and Cl^-.
   b. Ionization refers to the formation of table salt from the sodium ion and chloride ion.
   c. NaCl cannot ionize in water.
   d. All of the above are true.