CHAPTER 2

The Molecules of Cells

Chapter Concepts

2.1 Basic Chemistry
- How is an atom organized? 20–21
- What are the two basic types of reactions between atoms? 22–25

2.2 Water and Living Things
- What characteristics of water help support life? 26–27
- What are the hydrogen ion concentration differences between water, acids, and bases? 28–29

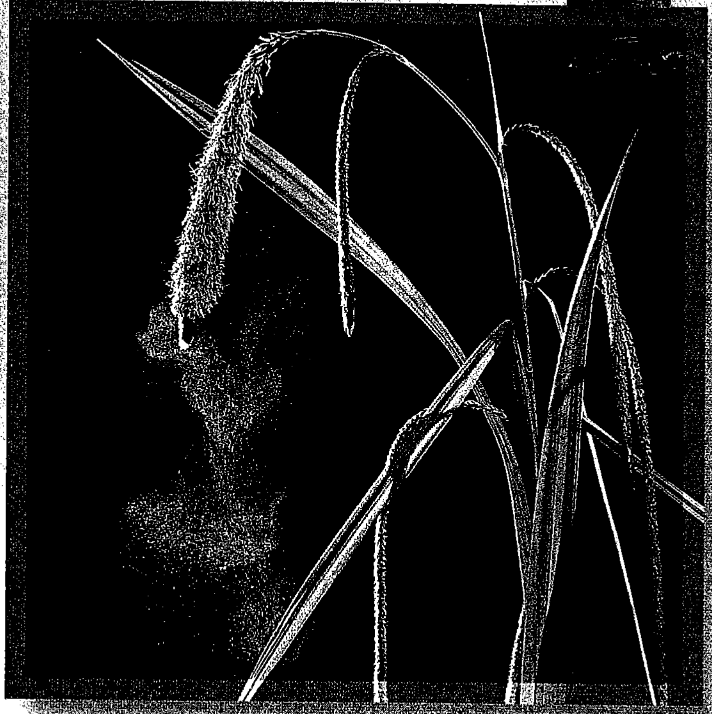
2.3 Organic Molecules
- What is a macromolecule, and what are the four classes of macromolecules in cells? 31
- What individual units comprise carbohydrate, protein, and nucleic acid polymers? 31

2.4 Carbohydrates
- What is the usual function of carbohydrates in organisms? 32
- What are some examples of different types of carbohydrates? 32–33
- What is the function of cellulose, and what type of cell would contain cellulose? 33

2.5 Lipids
- How do different types of lipid molecules differ? 34–35
- What is the function of fats and oils, and of what are they composed? 34
- What are the uses of cholesterol in animals and their cells? 35

2.6 Proteins
- What are the major functions of proteins in organisms? 37
- How does the structure of different types of proteins differ? 38–39

2.7 Nucleic Acids
- What does it mean to say that DNA is a double helix? 40
- What is the function of DNA in cells? 40–41
- How is the function of RNA related to the function of DNA? 41



When grasses pollinate, windblown pollen spreads far and wide, causing allergic symptoms in many of us.

It's a change of season. Henry knows what's coming. Grasses, trees, weeds, and garden plants are going to send out enormous amounts of pollen. The wind will blow and Henry will get the sniffles. Sneezing and coughing, he will reach for tissue after tissue as he endures the onslaught of allergy season. It's all a matter of chemistry, of course. Pollen bears molecules, chemical substances, that cause Henry's body to produce histamine, a substance that brings on his symptoms.

The evidence that we and all living things are composed of chemicals is overwhelming. Get sick and the medicine you take is a chemical. Henry will be given an antihistamine or maybe a steroid that will ameliorate his symptoms. As part of a physical exam, the doctor tests our blood chemistry. If the cholesterol count is too high, we will be put on a low-fat diet.

Certain types of molecules like carbohydrates, proteins, and fats make up the bulk of our bodies. The master molecule DNA carries genetic information which determines what we are like, whether an oak tree or a human who can study how oak trees produce so much pollen.

2.1 Basic Chemistry

Matter refers to anything that takes up space and has weight. It is helpful to remember that matter can exist as a solid, a liquid, or a gas. Then we can realize that not only are we humans matter, but so are the water we drink and the air we breathe.

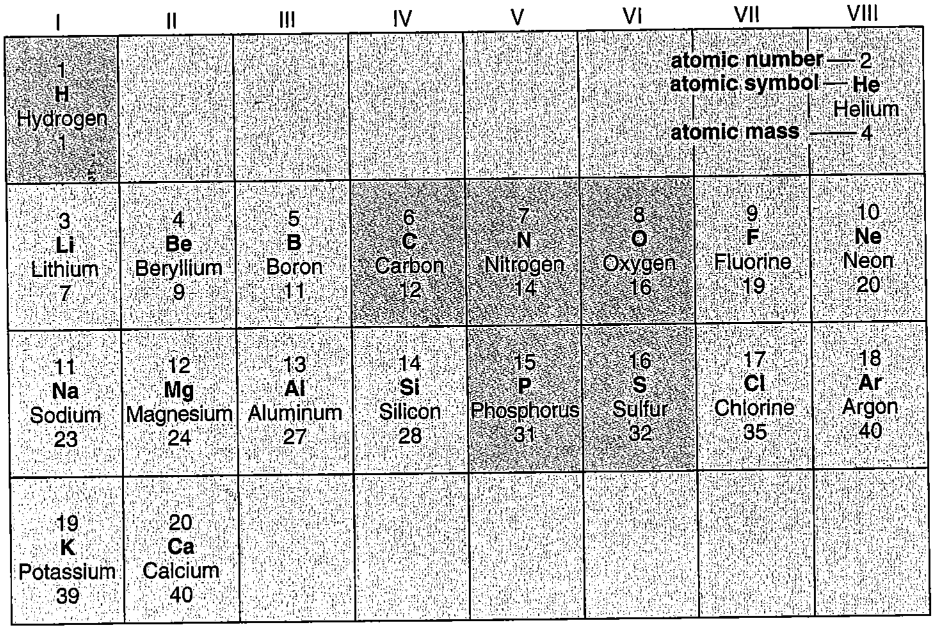
Elements and Atoms

All matter, living and nonliving, is composed of **elements.** Considering the variety of living and nonliving things in the world, it is quite remarkable that there are only 92 naturally occurring elements—other elements have been created by special processes in the laboratory. As indicated in Figure 2.1, only six elements—carbon, hydrogen, nitrogen, oxygen, phosphorus, and sulfur—make up most (about 98%) of the body weight of organisms. The acronym CHNOPS helps us remember these six elements. Instead of writing out the names of elements, scientists use symbols to identify them. The letter C stands for carbon, and the letter N stands for nitrogen, for example. Some of the symbols used for elements are derived from Latin. For example, the symbol for sodium is Na (*natrium* in Latin means sodium).

Elements contain tiny particles called atoms. The same name is given to the element and its atoms. An **atom** is the smallest unit of matter to enter into chemical reactions. Even though an atom is extremely small, it contains even smaller subatomic particles called protons, neutrons, and electrons. Atoms have a central nucleus, where the subatomic **protons** and **neutrons** are located, and shells, which are pathways about the nucleus where **electrons** orbit. The shells represent energy levels. Figure 2.2 shows a model of an atom that has only two shells. The inner shell has the lowest energy level and can hold two electrons. The outer shell has a higher energy level and can hold eight electrons. An atom is most stable when the outer shell has eight electrons.

An atom has an atomic number; the **atomic number** is equal to the number of its protons. Notice in Table 2.1 that protons have a positive (+) electrical charge and electrons have a negative (−) charge. When an atom is electrically neutral, the number of protons equals the number of electrons. The carbon atom shown in Figure 2.3 has an atomic number of 6; therefore, it has six protons. Since it is electrically neutral, it also has six electrons. The inner shell has two electrons, and the outer shell has four electrons.

In the periodic table of the elements (Fig. 2.1), atoms are horizontally arranged in order of increasing atomic number. They are vertically arranged according to the number of electrons in the outer shell. The numeral at the top of each column indicates how many electrons are in the outer shell of the atoms in that column. An exception to this format is helium (He), which has only two electrons in the outer shell because it has only one shell. The number of electrons in the outer shell determines the chemical properties of an atom, including how readily it enters into chemical reactions.



I	II	III	IV	V	VI	VII	VIII
1 **H** Hydrogen 1						**atomic number** **atomic symbol** **atomic mass**	2 **He** Helium 4
3 **Li** Lithium 7	4 **Be** Beryllium 9	5 **B** Boron 11	6 **C** Carbon 12	7 **N** Nitrogen 14	8 **O** Oxygen 16	9 **F** Fluorine 19	10 **Ne** Neon 20
11 **Na** Sodium 23	12 **Mg** Magnesium 24	13 **Al** Aluminum 27	14 **Si** Silicon 28	15 **P** Phosphorus 31	16 **S** Sulfur 32	17 **Cl** Chlorine 35	18 **Ar** Argon 40
19 **K** Potassium 39	20 **Ca** Calcium 40						

Figure 2.1 Periodic Table of the Elements (shortened).
Each element has an atomic number, an atomic symbol, and an atomic mass. The elements indicated by color make up most of the body weight of organisms. See Appendix D.

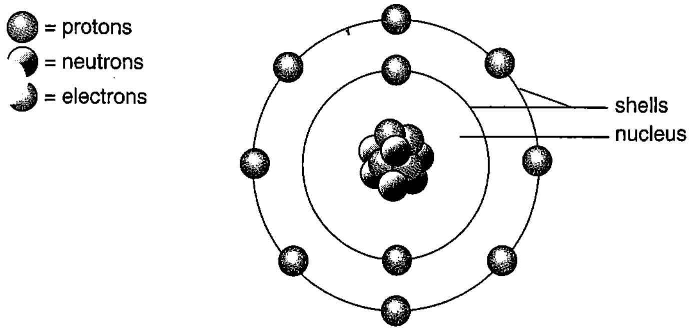


Figure 2.2 **Model of an atom.**
Protons and neutrons are located in the nucleus. Electrons are located at energy levels called shells.

Table 2.1 Subatomic Particles

Name	Charge	Mass
Electron	One negative unit	Almost no mass
Proton	One positive unit	One atomic mass unit
Neutron	No charge	One atomic mass unit

,otopes

The subatomic particles are so light that their weight is indicated by special mathematical units called atomic mass units. The **atomic mass** of each atom is noted in the periodic table beneath the atomic symbol. The atomic mass of an atom equals the number of protons plus the number of neutrons. Why should that be the case? Table 2.1 shows that electrons have almost no mass, but protons and neutrons each have a weight of one atomic mass unit. Since the atomic mass of carbon is twelve and it has six protons, it is easy to calculate that carbon has six neutrons.

The atomic masses given in the periodic table are the average mass for each kind of atom. This is because the atoms of one element may differ in the number of neutrons; therefore, the mass varies. Atoms that have the same atomic number and differ only in the number of neutrons are called **isotopes.** Isotopes of carbon can be written in the following manner, where the subscript stands for the atomic number and the superscript stands for the atomic mass:

$^{12}_{6}C$ $^{13}_{6}C$ $^{14}_{6}C^{*}$

*radioactive

Carbon 12 has six neutrons, carbon 13 has seven neutrons, and carbon 14 has eight neutrons. Unlike the other two isotopes, carbon 14 (which has 8 neutrons) is unstable; it breaks)wn into atoms with lower atomic numbers. When it decays, it emits radiation in the form of radioactive particles or radiant energy. Therefore, carbon 14 is called a **radioactive isotope.** Carbon 14 and other types of radioactive isotopes can be used as tracers in biochemical experiments. In a now-famous experiment, carbon 14 helped scientists determine how sugar is formed during photosynthesis. And because radioactive isotopes break down at a known rate, they are also used to determine the age of fossils.

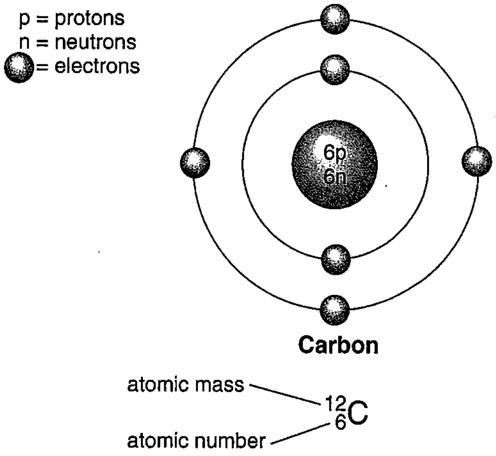


Figure 2.3 **Carbon atom.**
Carbon has an atomic number of 6; therefore, it has six protons and six electrons when neutral. Carbon has a weight of 12 atomic mass units. Therefore, it has six neutrons.

Radioactive isotopes are helpful in various forms of imaging. If a patient is injected with iodine, the thyroid gland takes it up and a scan of the thyroid shows any abnormality. Glucose labeled with a radioactive isotope is taken up by metabolically active tissues. The radiation given off can be detected by PET (positron emission tomography), which generates cross-sectional images of the body. Then researchers know which tissues are metabolically active under what circumstances.

High amounts of radiation can kill cells and compromise the immune system. When nuclear power plants employ proper safety measures, the risk of exposure to radiation is small. But accidents have occurred. On April 16, 1986, a series of explosions at the Chernobyl nuclear power plant violently threw radioactivity into the atmosphere worldwide. Over a half million people were exposed to dangerous levels of radioactivity in the immediate vicinity, and they may eventually suffer from various types of cancer and eye cataracts.

All matter is composed of atoms. Atoms have an atomic symbol, atomic number (number of protons), and atomic mass (number of protons and neutrons). Isotopes vary by the number of neutrons.

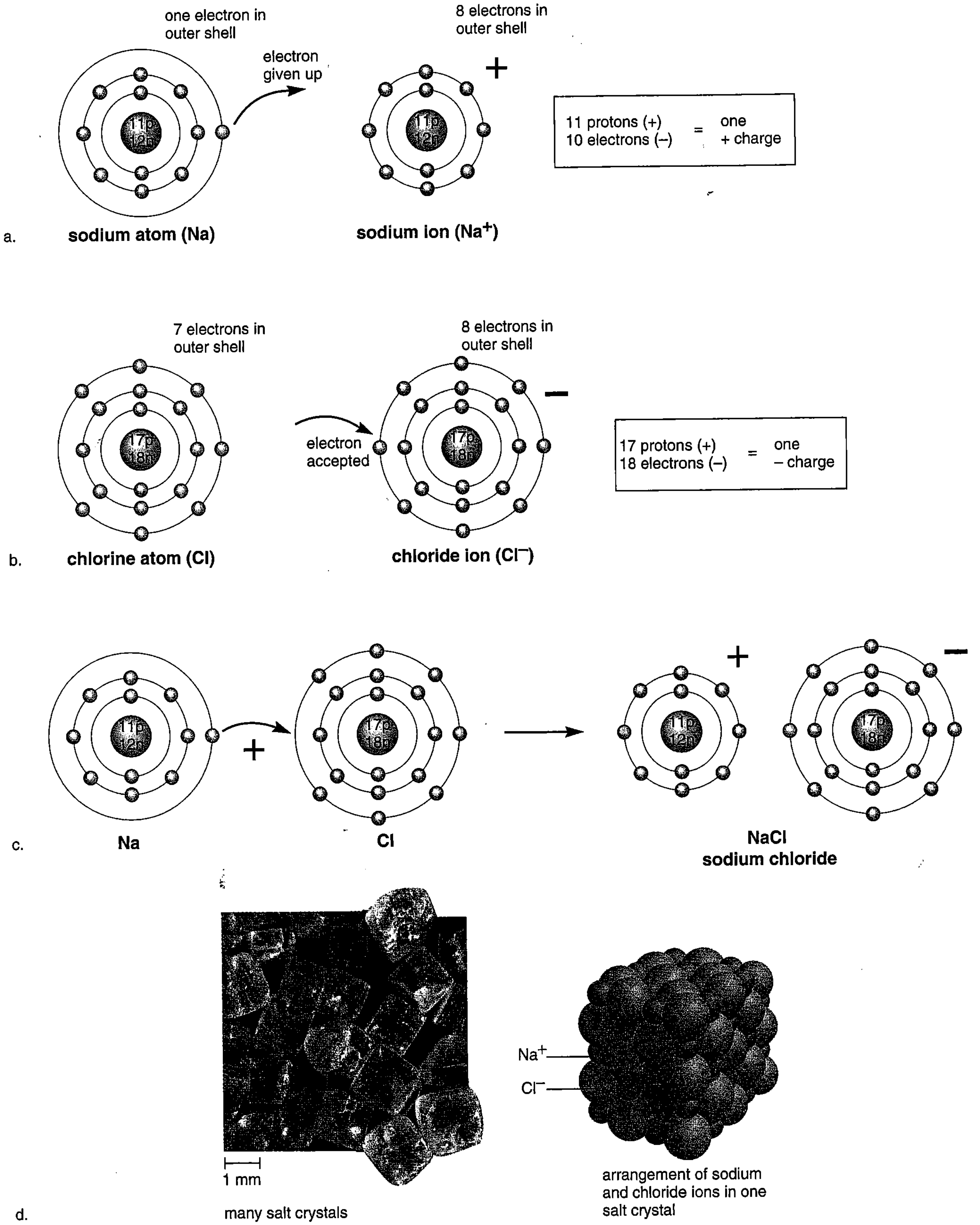


Figure 2.4 **Ionic reaction.**

a. When a sodium atom gives up an electron, it becomes a positive ion. **b.** When a chlorine atom gains an electron, it becomes a negative ion. **c.** When sodium reacts with chlorine, the compound sodium chloride (NaCl) results. In sodium chloride, an ionic bond exists between the positive Na^+ and the negative Cl^- ions. **d.** In a sodium chloride crystal, the ionic bonding between Na^+ and Cl^- causes the ions to form a three-dimensional lattice in which each sodium ion is surrounded by six chloride ions, and each chloride ion is surrounded by six sodium ions.

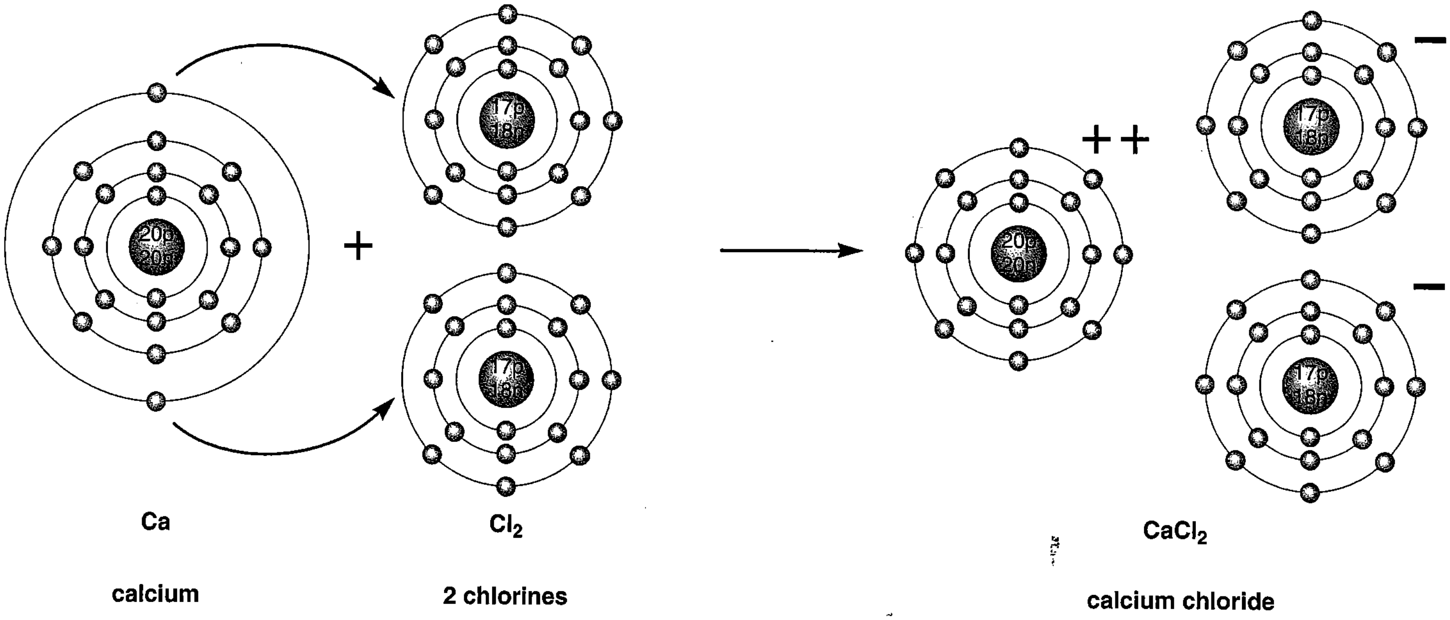


Figure 2.5 **Ionic reaction.**
The calcium atom gives up two electrons, one to each of two chlorine atoms. In the compound calcium chloride ($CaCl_2$), the calcium ion is attracted to two chloride ions.

Molecules and Compounds

Atoms often bond with each other to form a chemical unit called a **molecule.** A molecule can contain atoms of the same kind, as when an oxygen atom joins with another oxygen atom to form oxygen gas. Or the atoms can be different, as when an oxygen atom joins with two hydrogen atoms to form water. When the atoms are different, a **compound** results.

Two types of bonds join atoms: the ionic bond and the covalent bond.

Ionic Reactions

Recall that atoms (with more than one shell) are most stable when the outer shell contains eight electrons. During an ionic reaction, atoms give up or take on an electron(s) in order to achieve a stable outer shell.

Figure 2.4 depicts a reaction between a sodium (Na) atom and a chlorine (Cl) atom in which chlorine takes an electron from sodium. **Ions** are particles that carry either a positive (+) or negative (−) charge. The sodium ion carries a positive charge because it now has one more proton than electrons, and the chloride ion carries a negative charge because it now has one fewer proton than electrons. The attraction between oppositely charged sodium ions and chloride ions forms an **ionic bond.** The resulting compound, sodium chloride, is table salt, which we use to enliven the taste of foods.

Figure 2.5 shows an ionic reaction between a calcium atom and two chlorine atoms. Notice that calcium, with two electrons in the outer shell, reacts with two chlorine atoms. Why? Because with seven electrons already, each chlorine requires only one more electron to have a stable outer shell. The resulting salt ($CaCl_2$) is called calcium chloride.

Biologically important ions in the human body are listed in Table 2.2. The balance of these ions in the body is important to our health. Too much sodium in the blood can cause high blood pressure; not enough calcium leads to rickets (a bowing of the legs) in children; too much or too little potassium results in heartbeat irregularities. Bicarbonate, hydrogen, and hydroxide ions are all involved in maintaining the acid-base balance of the body.

An ionic bond is the attraction between oppositely charged ions.

Table 2.2 Significant Ions in the Body

Name	Symbol	Special Significance
Sodium	Na^+	Found in body fluids; important in muscle contraction and nerve conduction
Chloride	Cl^-	Found in body fluids
Potassium	K^+	Found primarily inside cells; important in muscle contraction and nerve conduction
Phosphate	PO_4^{3-}	Found in bones, teeth, and the high-energy molecule ATP
Calcium	Ca^{2+}	Found in bones and teeth; important in muscle contraction and nerve conduction
Bicarbonate	HCO_3^-	Important in acid-base balance
Hydrogen	H^+	Important in acid-base balance
Hydroxide	OH^-	Important in acid-base balance

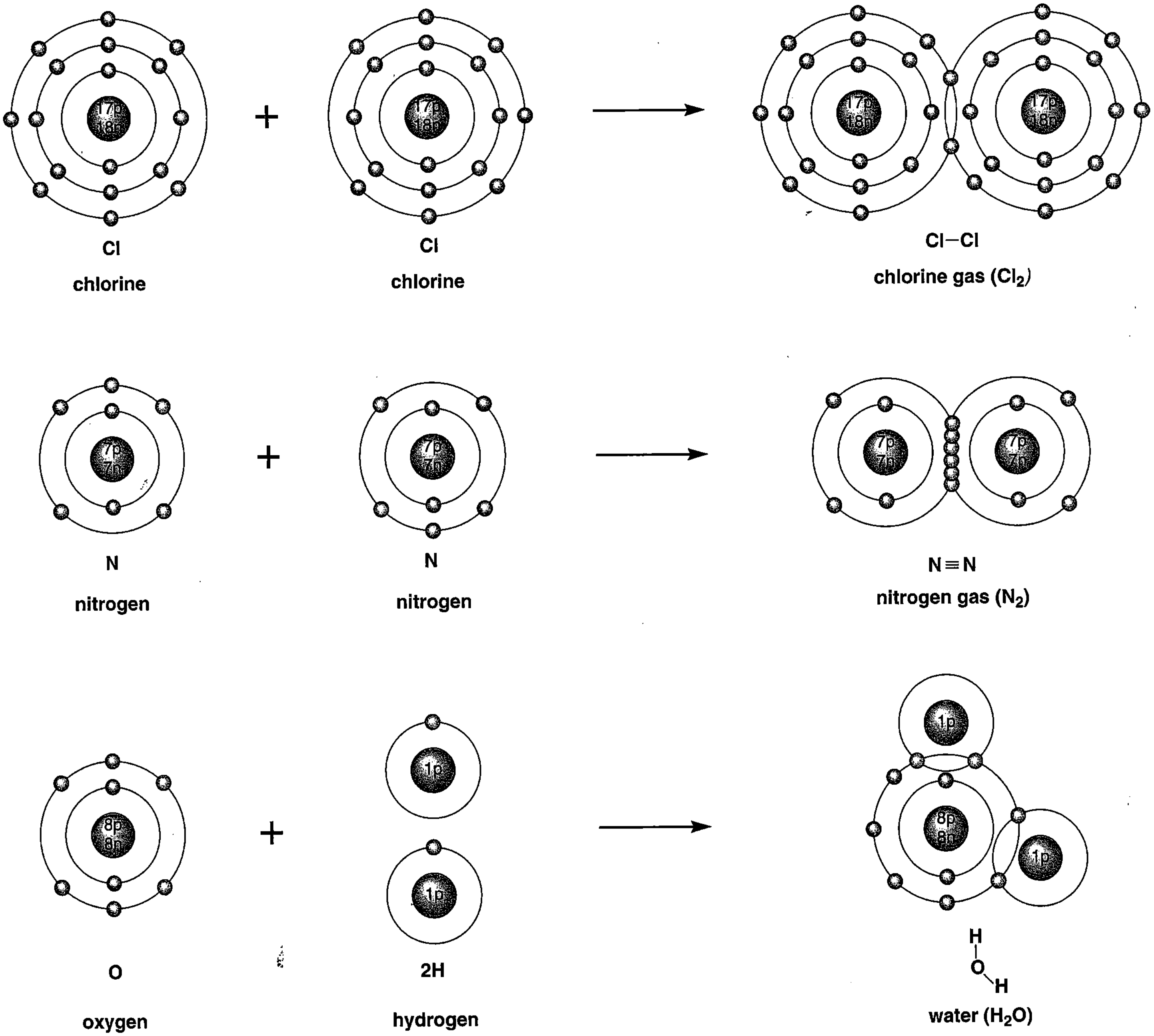


Figure 2.6 Covalent reactions.
After a covalent reaction, each atom will have filled its outer shell by sharing electrons. To determine this, it is necessary to count the shared electrons as belonging to both bonded atoms. Oxygen and nitrogen are most stable with eight electrons in the outer shell; hydrogen is most stable with two electrons in the outer shell.

Covalent Reactions

In covalent reactions, the atoms share electrons in **covalent bonds** instead of losing or gaining them. Covalent bonds can be represented in a number of ways. The overlapping outermost shells in Figure 2.6 indicate that the atoms are sharing electrons. Just as two hands participate in a handshake, each atom contributes one electron to the pair that is shared. These electrons spend part of their time in the outer shell of each atom; therefore, they are counted as belonging to both bonded atoms. When you count the electrons shared by both atoms, you can see that each atom has eight electrons in its outer shell (or two electrons in the case of hydrogen). In hydrogen, the outer shell is complete when it contains two electrons. Hydrogen can give up an electron and become H^+, or it can share and thereby have a completed outer shell.

Instead of drawing complex diagrams, electron-dot structures are sometimes used to depict covalent bonding between atoms. For example, in Figure 2.7, each chlorine atom can be represented by its symbol, and the electrons

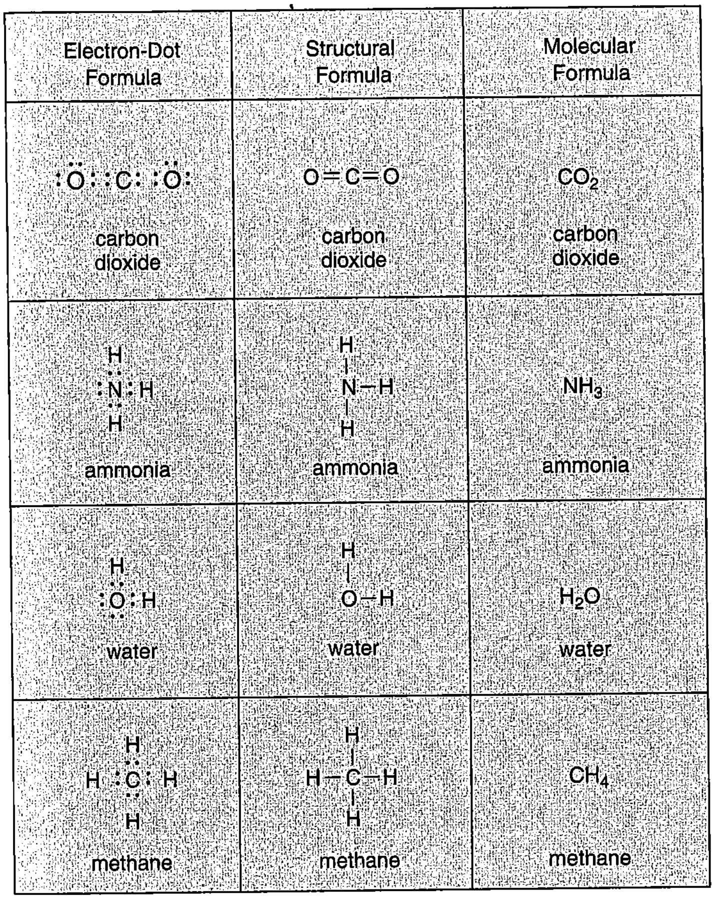
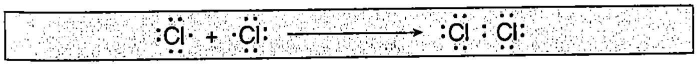


Figure 2.7 Electron-dot, structural, and molecular formulas.
In the electron-dot formula, only the electrons in the outer shell are designated. In the structural formula, the lines represent a pair of electrons being shared by two atoms. The molecular formula indicates only the number of each type of atom found within a molecule.

in the outer shell can be designated by dots. The shared electrons are placed between the two sharing atoms, as shown here:



Because electron-dot structures are cumbersome, other representations are often used. Structural formulas use straight lines to show the covalent bonds between the atoms. Each line represents a pair of shared electrons. Molecular formulas indicate only the number of each type of atom making up a molecule.

Structural formula: Cl—Cl

Molecular formula: Cl_2

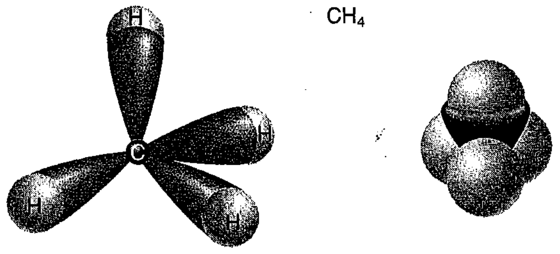
Additional examples of electron-dot, structural, and molecular formulas are shown in Figure 2.7. In each instance, notice that each atom has a completed outer shell.

Double and Triple Bonds Besides a single bond, in which atoms share only a pair of electrons, a double or a triple bond can form. In a double bond, atoms share two pairs of electrons, and in a triple bond, atoms share three pairs of electrons between them. For example, in Figure 2.6, each nitrogen atom (N) requires 3 electrons to achieve a total of 8 electrons in the outermost shell. Notice that 6 electrons are placed in the outer overlapping shells in the diagram and that three straight lines are in the structural formula for nitrogen gas (N_2). Single covalent bonds between atoms are quite strong, but double and triple bonds are even stronger.

A covalent bond arises when atoms share electrons. In double covalent bonds, atoms share two pairs of electrons, and in triple covalent bonds, atoms share three pairs of electrons.

Shape of Molecules

Structural formulas make it seem as if molecules are one-dimensional, but actually molecules have a three-dimensional shape that often determines their biological function. Molecules consisting of only two atoms are always linear, but a molecule such as methane (CH_4) with five atoms has a tetrahedral shape. Why? Because carbon is sharing electrons with four hydrogen atoms. A so-called space-filling model comes closest to the actual shape of the molecule. In space-filling models, each type of atom is given a particular color; here observe that carbon is black and hydrogen is white:



molecular model space-filling model

The shapes of molecules are necessary to the structural and functional roles they play in living things. For example, hormones have shapes that allow them to be recognized by the cells in the body. One form of diabetes occurs when certain cell receptors fail to recognize the hormone insulin. On the other hand, AIDS occurs when certain blood cells have receptors that bind to HIV, allowing the viruses to enter, multiply, and destroy the cell.

The final shape of the molecule often determines the role it plays in cells and organisms.

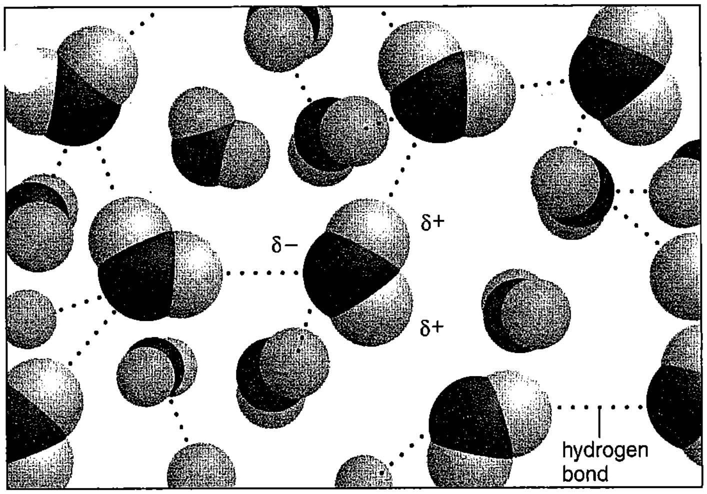
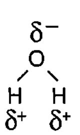


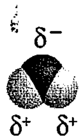
Figure 2.8 Hydrogen bonding between water molecules. The polarity of the water molecules allows hydrogen bonds (dotted lines) to form between the molecules.

2.2 Water and Living Things

Water is the most abundant molecule in living organisms, making up about 60–70% of the total body weight of most of them. We will see that the physical and chemical properties of water make life as we know it possible.

In water, the electrons spend more time circling the larger oxygen (O) atom than the smaller hydrogen (H) atoms. When the electrons spend more time near the oxygen, they impart a slight negative charge to the oxygen and a slight positive charge to the hydrogen atoms, creating negative and positive ends of the molecule. Therefore, water is a polar molecule; the oxygen end of the molecule has a slight negative charge (δ^-), and the hydrogen end has a slight positive charge (δ^+):





The diagram on the left shows the structural formula of water, and the one on the right shows the space-filling model of water.

Hydrogen Bonds

A **hydrogen bond** occurs whenever a covalently bonded hydrogen is positive and attracted to a negatively charged atom some distance away. A hydrogen bond is represented by a dotted line because it is relatively weak and can be broken rather easily.

In Figure 2.8, you can see that each hydrogen atom, being slightly positive, bonds to the slightly negative oxygen atom of another water molecule.

Properties of Water

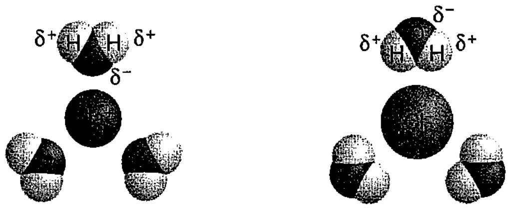
Because of their polarity and hydrogen bonding, water molecules are cohesive, meaning that they cling together. Polarity and hydrogen bonding cause water to have many characteristics beneficial to life.

1. Water is a liquid at room temperature. Therefore, we are able to drink it, cook with it, and bathe in it.

Compounds with a low molecular mass are usually gases at room temperature. For example, oxygen (O_2), with a molecular mass of 32, is a gas, but water, with a molecular mass of 18, is a liquid. The hydrogen bonding between water molecules keeps water a liquid and not a gas at room temperature. Water does not boil and become a gas until 100°C, one of the reference points for the Celsius temperature scale. (See Appendix C.) Without hydrogen bonding between water molecules, our body fluids—and indeed our bodies—would be gaseous!

2. Water is the universal solvent for polar (charged) molecules and thereby facilitates chemical reactions both outside and within our bodies.

When ions and molecules disperse in water, they move about and collide, allowing reactions to occur. Therefore, water is a solvent that facilitates chemical reactions. For example, when a salt such as sodium chloride (NaCl) is put into water, the negative ends of the water molecules are attracted to the sodium ions, and the positive ends of the water molecules are attracted to the chloride ions. This causes the sodium ions and the chloride ions to separate and to dissolve in water:



The salt NaCl dissolves in water.

Ions and molecules that interact with water are said to be **hydrophilic.** Nonionized and nonpolar molecules that do not interact with water are said to be **hydrophobic.**

3. Water molecules are cohesive, and therefore liquids fill vessels, such as blood vessels.

Water molecules cling together because of hydrogen bonding, and yet, water flows freely. This property allows dissolved and suspended molecules to be evenly distributed throughout a system. Therefore, water is an excellent transport medium. Within our bodies, the blood that fills our arteries and veins is 92% water. Blood transports oxygen and nutrients to the cells and removes wastes such as carbon dioxide from cells.

b.

c.

Figure 2.9 **Characteristics of water.**
a. Water boils at 100°C. If it boiled and was a gas at a lower temperature, life could not exist. **b.** It takes much body heat to vaporize sweat, which is mostly liquid water, and this helps keep bodies cool when the temperature rises. **c.** Ice is less dense than water, and it forms on top of water, making skate sailing possible.

4. The temperature of liquid water rises and falls slowly, preventing sudden or drastic changes.

The many hydrogen bonds that link water molecules cause water to absorb a great deal of heat before it boils (Fig. 2.9*a*). A **calorie** of heat energy raises the temperature of one gram of water 1°C. This is about twice the amount of heat required for other covalently bonded liquids. On the other hand, water holds heat, and its temperature falls slowly. Therefore, water protects us and other organisms from rapid temperature changes and helps us maintain our normal internal temperature. This property also allows great bodies of water, such as oceans, to maintain a relatively constant temperature. Water is a good temperature buffer.

5. Water has a high heat of vaporization, keeping the body from overheating.

It takes a large amount of heat to change water to steam (Fig. 2.9*a*). (Converting one gram of the hottest water to steam requires an input of 540 calories of heat energy.) This property of water helps moderate the earth's temperature so that life can continue to exist. Also, in a hot environment, animals sweat and the body cools as body heat is used to evaporate sweat, which is mostly liquid water (Fig. 2.9*b*).

6. Frozen water is less dense than liquid water, so that ice floats on water.

As water cools, the molecules come closer together. They are densest at 4°C, but they are still moving about. At temperatures below 4°C, there is only vibrational movement, and hydrogen bonding becomes more rigid but also more open. This makes ice less dense. Bodies of water always freeze from the top down, making skate sailing possible (Fig. 2.9*c*). When a body of water freezes on the surface, the ice acts as an insulator to prevent the water below it from freezing. Thus, aquatic organisms are protected and have a better chance of surviving the winter.

Because of its polarity and hydrogen bonding, water has many characteristics that benefit life.

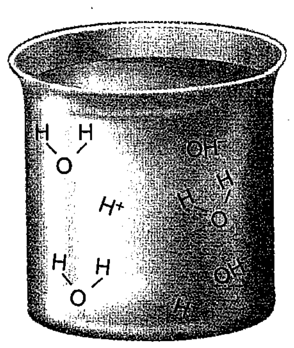


Figure 2.10 **Dissociation of water molecules.**
Dissociation produces an equal number of hydrogen ions (H^+) and hydroxide ions (OH^-). (These illustrations are not meant to be mathematically accurate.)

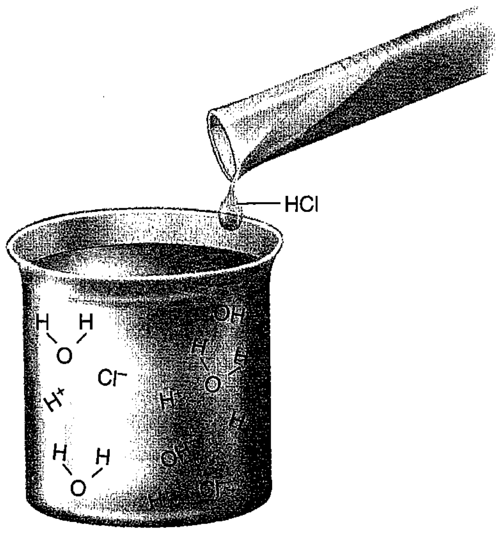


Figure 2.11 **Addition of hydrochloric acid (HCl).**
HCl releases hydrogen ions (H^+) as it dissociates. The addition of HCl to water results in a solution with more H^+ than OH^-.

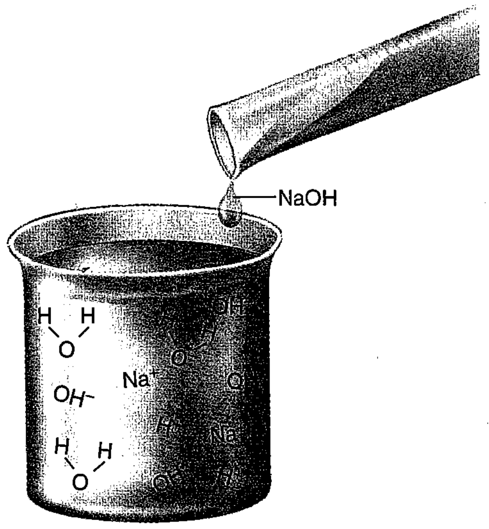


Figure 2.12 **Addition of sodium hydroxide (NaOH), a base.**
NaOH releases OH^- as it dissociates. The addition of NaOH to water results in a solution with more OH^- than H^+.

Acidic and Basic Solutions

hen water dissociates (breaks up), it releases an equal number of hydrogen ions (H^+) and hydroxide ions (OH^-):

$$\underset{\text{water}}{H{-}O{-}H} \rightleftharpoons \underset{\text{hydrogen ion}}{H^+} + \underset{\text{hydroxide ion}}{OH^-}$$

Only a few water molecules at a time are dissociated (Fig. 2.10). The actual number of ions is 10^{-7} moles/liter. A mole is a unit of scientific measurement for atoms, ions, and molecules.[1]

Acidic Solutions

Lemon juice, vinegar, tomato juice, and coffee are all familiar acidic solutions. What do they have in common? Acidic solutions have a sharp or sour taste, and therefore we sometimes associate them with indigestion. To a chemist, **acids** are molecules that dissociate in water, releasing hydrogen ions (H^+). For example, an important acid in the laboratory is hydrochloric acid (HCl), which dissociates in this manner:

$$HCl \rightarrow H^+ + Cl^-$$

Dissociation is almost complete; therefore, HCl is called a strong acid. When hydrochloric acid is added to a beaker of water, the number of hydrogen ions increases (Fig. 2.11).

Basic Solutions

Milk of magnesia and ammonia are basic solutions that most people have heard of. Bases have a bitter taste and feel slippery when in water. To a chemist, **bases** are molecules that either take up hydrogen ions (H^+) or release hydroxide ions (OH^-). For example, an important inorganic base is sodium hydroxide (NaOH), which dissociates in this manner:

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

Dissociation is almost complete; therefore, sodium hydroxide is called a strong base. If sodium hydroxide is added to a beaker of water, the number of hydroxide ions increases (Fig. 2.12).

It is not recommended that you taste a strong acid or base, because they are quite destructive to cells. Any container of household cleanser, such as ammonia, has a poison symbol and carries a strong warning not to ingest the product.

The Litmus Test

A simple laboratory test for acids and bases is called the litmus test. Litmus is a vegetable dye that changes color from blue to red in the presence of an acid and from red to blue in the presence of a base. The litmus test has become a common figure of speech, as when you hear a commentator say, "The litmus test for a Republican is . . ."

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[1] A mole is the same amount of atoms, molecules, or ions as the number of atoms in exactly 12 grams of ^{12}C.

The pH Scale

The **pH**[2] **scale** is used to indicate the acidity or basicity (alkalinity) of a solution. There are normally few hydrogen ions (H^+) in a solution, and the pH scale was devised to eliminate the use of cumbersome numbers. The pH scale (Fig. 2.13) ranges from 0 to 14. A pH of 0 to 7 is an acidic solution, and a pH of 7 to 14 is a basic solution. Further, as we move down the pH scale from pH 14 to pH 0, each unit has 10 times the $[H^+]$ of the previous unit. As we move up the scale from 0 to 14, each unit has 10 times the $[OH^-]$ of the previous unit. For example, the possible hydrogen ion concentrations of a solution (in moles per liter) are on the left of this listing and the pH is on the right:

moles/liter

$1 \times 10^{-6}\,[H^+] = \text{pH } 6$

$1 \times 10^{-7}\,[H^+] = \text{pH } 7$ (neutral)

$1 \times 10^{-8}\,[H^+] = \text{pH } 8$

Pure water contains only 10^{-7} moles per liter of both hydrogen ions and hydroxide ions. Therefore, a pH of exactly 7 is a neutral pH.

To further illustrate the relationship between hydrogen ion concentration and pH, consider the following question. Which of the pH values listed above indicates a higher hydrogen ion concentration $[H^+]$ than pH 7, and therefore would be an acidic solution? A number with a smaller negative exponent indicates a greater quantity of hydrogen ions than one with a larger negative exponent. Therefore, pH 6 is an acidic solution.

The Ecology Focus on page 30 describes some detrimental environmental consequences to nonliving and living things as rain and snow have become more acidic. In humans, pH needs to be maintained within a narrow range or there are health consequences. The pH of blood is around 7.4, and blood is buffered in the manner described next to keep the pH within a normal range.

Buffers and pH

A **buffer** is a chemical or a combination of chemicals that keeps pH within normal limits. Many commercial products, such as Bufferin, shampoos, or deodorants, are buffered as an added incentive for us to buy them. Buffers resist pH changes because they can take up excess hydrogen ions (H^+) or hydroxide ions (OH^-).

The pH of our blood is usually about 7.4, in part because it contains a combination of carbonic acid and bicarbonate ions. Carbonic acid (H_2CO_3) is a weak acid that minimally dissociates.

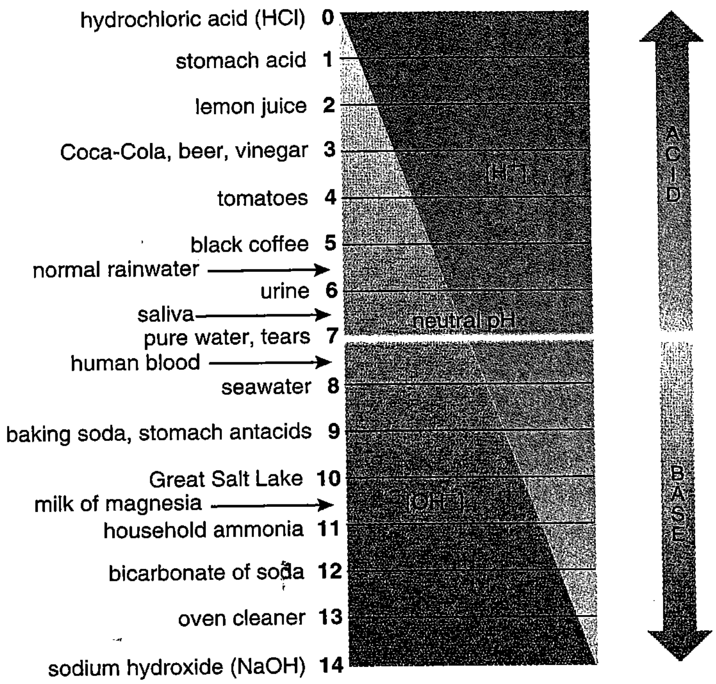

Figure 2.13 **The pH scale.**
The diagonal line indicates the proportionate concentration of hydrogen ions (H^+) to hydroxide ions (OH^-) at each pH value. Any pH value above 7 is basic, while any pH value below 7 is acidic.

The following reaction shows how carbonic acid dissociates and can reform:

$$\underset{\text{carbonic acid}}{H_2CO_3} \underset{\text{reforms}}{\overset{\text{dissociates}}{\rightleftharpoons}} \underset{\text{hydrogen ion}}{H^+} + \underset{\text{bicarbonate ion}}{HCO_3^-}$$

When hydrogen ions (H^+) are added to blood, the following reaction occurs:

$$H^+ + HCO_3^- \rightarrow H_2CO_3$$

When hydroxide ions (OH^-) are added to blood, this reaction occurs:

$$OH^- + H_2CO_3 \rightarrow HCO_3^- + H_2O$$

These reactions prevent any significant change in blood pH.

Acids have a pH that is less than 7, and bases have a pH that is greater than 7. Buffers, which can combine with both hydrogen ions and hydroxide ions, resist pH changes.

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[2] pH is defined as the negative logarithm of the molar concentration of the hydrogen ion $[H^+]$.