2.1 Atoms, Ions, and Molecules

TEKS 3E

VOCABULARY

- atom
- element
- compound
- ion
- ionic bond
- covalent bond
- molecule

TEKS 3E evaluate models according to their limitations in representing biological objects or events

KEY CONCEPT All living things are based on atoms and their interactions.

MAIN IDEAS

- Living things consist of atoms of different elements.
- Ions form when atoms gain or lose electrons.
- Atoms share pairs of electrons in covalent bonds.

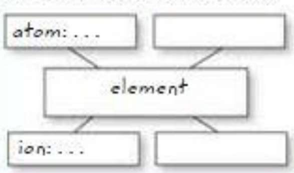
Connect to Your World

The Venus flytrap produces chemicals that allow it to consume and digest insects and other small animals, including an unlucky frog. Frogs also produce specialized chemicals that allow them to consume and digest their prey. In fact, all organisms depend on many chemicals and chemical reactions. For this reason, the study of living things also involves the study of chemistry.

READING TOOLBOX

TAKING NOTES

Use a main idea web to help you make connections among elements, atoms, ions, compounds, and molecules.



MAIN IDEA TEKS 3E

Living things consist of atoms of different elements.

What do a frog, a skyscraper, a car, and your body all have in common? Every physical thing you can think of, living or not, is made of incredibly small particles called atoms. An **atom** is the smallest basic unit of matter. Millions of atoms could fit in a space the size of the period at the end of this sentence. And it would take you more than 1 trillion (1,000,000,000,000, or 10^{12}) years to count the number of atoms in a single grain of sand.

Atoms and elements

Although there is a huge variety of matter on Earth, all atoms share the same basic structure. Atoms consist of three types of smaller particles: protons, neutrons, and electrons. Protons and neutrons form the dense center of an atom—the atomic nucleus. Electrons are much smaller particles outside of the nucleus. Protons have a positive electrical charge, and electrons have a negative electrical charge. Neutrons, as their name implies, are neutral —they have no charge. Because an atom has equal numbers of positively charged protons and negatively charged electrons, it is electrically neutral.

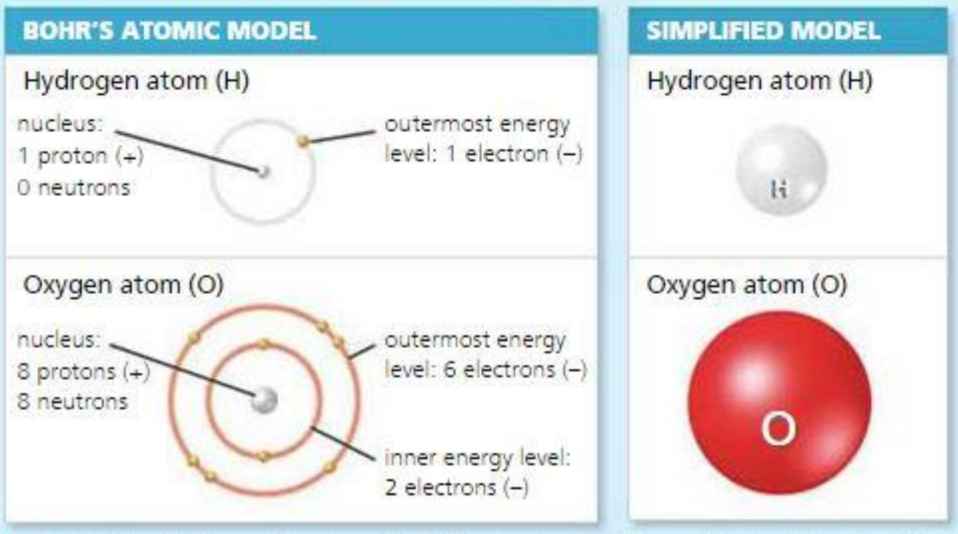
An **element** is one particular type of atom, and it cannot be broken down into a simpler substance by ordinary chemical means. An element can also refer to a group of atoms of the same type. A few familiar elements include the gases hydrogen and oxygen and the metals aluminum and gold. Because all atoms are made of the same types of particles, what difference among atoms makes one element different from other elements? Atoms of different elements differ in the number of protons they have. All atoms of a given element have a specific number of protons that never varies. For example, all hydrogen atoms have one proton, and all oxygen atoms have eight protons.

The electrons in the atoms of each element determine the properties of that element. As **FIGURE 1.1** shows, electrons are considered to be in a cloud around the nucleus. The simplified models of a hydrogen atom and an oxygen atom on the left side of **FIGURE 1.2** illustrate how electrons move around the nucleus in regions called energy levels. Different energy levels can hold different numbers of electrons. For example, the first energy level can hold two electrons, and the second energy level can hold eight electrons. Atoms are most stable when they have a full valence, or outermost energy level.

Of the 91 elements that naturally occur on Earth, only about 25 are found in organisms. Just 4 elements—carbon (C), oxygen (O), nitrogen (N), and hydrogen (H)—make up 96% of the human body's mass. The other 4% consists of calcium (Ca), phosphorus (P), potassium (K), sulfur (S), sodium (Na), and several other trace elements. Trace elements are found in very small amounts in your body, but you need them to survive. For example, iron (Fe) is needed to transport oxygen in your blood. Chromium (Cr) is needed for your cells to break down sugars for usable energy.

FIGURE 1.1 The exact position of electrons cannot be known. They are somewhere in a three-dimensional electron cloud around the nucleus.

FIGURE 1.2 Representing Atoms



The model of the atom developed by Niels Bohr (left) shows that an atom's electrons are located outside the nucleus in regions called energy levels. Different types of atoms have different numbers of electrons and energy levels.

Often, atoms are shown as simplified spheres (right). Different types of atoms are shown in different sizes and colors.

Evaluate What information does the Bohr atomic model provide that the simplified model does not provide? What is a limitation of both models? TEKS 3E

Compounds

The atoms of elements found in organisms are often linked, or bonded, to other atoms. A **compound** is a substance made of atoms of different elements bonded together in a certain ratio. Common compounds in living things include water (H_2O) and carbon dioxide (CO_2). A compound's properties are often different from the properties of the elements that make up the compound. At temperatures on Earth, for example, hydrogen and oxygen are both gases. Together, though, they can form water. Similarly, a diamond is pure carbon, but carbon atoms are also the basis of sugars, proteins, and millions of other compounds.

Biology VIDEO CLIP
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Atomic Bonding, Diamonds

Contrast How are elements different from compounds?

CONNECT TO

CELL STRUCTURE AND FUNCTION

Several different ions are transported across cell membranes during cell processes. You will learn how this transport occurs in the chapters **Cell Structure and Function** and **Cells and Energy.**

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Atoms and Bonding

MAIN IDEA

Ions form when atoms gain or lose electrons.

An **ion** is an atom that has gained or lost one or more electrons. An ion forms because an atom is more stable when its outermost energy level is full; the gain or loss of electrons results in a full outermost energy level. An atom becomes an ion when its number of electrons changes, and it gains an electrical charge. This charge gives ions certain properties. For example, compounds consisting only of ions—ionic compounds—easily dissolve in water.

Some ions are positively charged, and other ions are negatively charged. The type of ion that forms depends on the number of electrons in an atom's outer energy level. An atom with few electrons in its outer energy level tends to lose those electrons. An atom that loses one or more electrons becomes a positively charged ion because it has more protons than electrons. In contrast, an atom with a nearly full outer energy level tends to gain electrons. An atom that gains one or more electrons becomes a negatively charged ion because it has more electrons than protons.

Ions play large roles in organisms. For example, hydrogen ions (H^+) are needed for the production of usable chemical energy in cells. Calcium ions (Ca^{2+}) are necessary for every muscle movement in your body. And chloride ions (Cl^-) are important for a certain type of chemical signal in the brain.

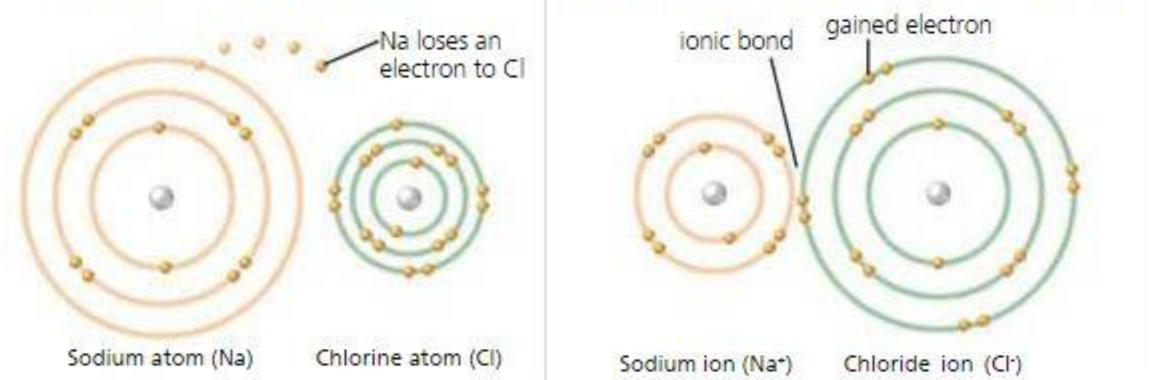
Ions usually form when electrons are transferred from one atom to another. For example, **FIGURE 1.3** shows the transfer of an electron from a sodium atom (Na) to a chlorine atom (Cl). When it loses its one outer electron, the sodium atom becomes a positively charged sodium ion (Na^+). Its second energy level, which has eight electrons, is now a full outermost energy level. The transferred electron fills chlorine's outermost energy level, forming a negatively charged chloride ion (Cl^-). Positive ions, such as Na^+, are attracted to negative ions, such as Cl^-. An **ionic bond** forms through the electrical force between oppositely charged ions. Salt, or sodium chloride (NaCl), is an ionic compound of Na^+ and Cl^-. Sodium chloride is held together by ionic bonds.

Apply **What determines whether an atom becomes a positive ion or a negative ion?**

FIGURE 1.3 IONS AND IONIC BONDS

1 The sodium atom (Na) loses its one outer electron to the chlorine atom (Cl) .

2 The positive sodium ion (Na^+) and negative chloride ion (Cl^-) attract each other and form an ionic bond.



MAIN IDEA

Atoms share pairs of electrons in covalent bonds.

Not all atoms easily gain or lose electrons. Rather, the atoms of many elements share pairs of electrons. The shared pairs of electrons fill the outermost energy levels of the bonded atoms. A **covalent bond** forms when atoms share a pair of electrons. Covalent bonds are generally very strong, and depending on how many electrons an atom has, two atoms may form several covalent bonds to share several pairs of electrons. **FIGURE 1.4** illustrates how atoms of carbon and oxygen share pairs of electrons in covalent bonds. All three atoms in a molecule of carbon dioxide (CQ) have full outer energy levels.

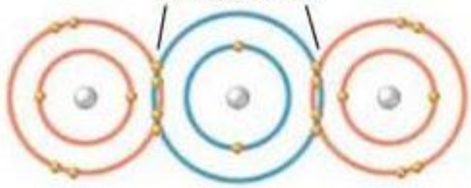
READING TOOLBOX

VOCABULARY

The prefix *co-* means "together," and the term *valent* comes from a Latin word that means "power" or "strength."

FIGURE 1.4 COVALENT BONDS

A carbon atom needs four electrons to fill its outer energy level. An oxygen atom needs two electrons to fill its outer energy level. In carbon dioxide, carbon makes a double bond, or shares two pairs of electrons, with each oxygen atom.



A **molecule** is two or more atoms held together by covalent bonds. In the compound carbon dioxide, each oxygen atom shares two pairs of electrons (four electrons) with the carbon atom. Some elements occur naturally in the form of diatomic, or "two-atom," molecules. For example, a molecule of oxygen (O_2) consists of two oxygen atoms that share two pairs of electrons. Almost all of the substances that make up organisms, from lipids to nucleic acids to water, are molecules held together by covalent bonds.

Summarize What happens to electrons in outer energy levels when two atoms form a covalent bond?

2.1 Formative Assessment

REVIEWING MAIN IDEAS

1. What distinguishes one **element** from another?
2. Describe the formation of an **ionic compound.**
3. What is the difference between an **ionic bond** and a **covalent bond** ?

CRITICAL THINKING

4. **Compare and Contrast** How does a **molecule** differ from an **atom** ?
5. **Apply** Explain why a hydrogen atom can become either an **ion** or a part of a molecule.
6. **Evaluate** Explain the benefits and limitations of atomic models.

TEKS 3E

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CONNECT TO CHEMISTRY

7. A sodium atom has one outer electron, and a carbon atom has four outer electrons. How might this difference be related to the types of compounds formed by atoms of these two elements?

2.2 Properties of Water

TEKS 4B, 9A

KEY CONCEPT **Water's unique properties allow life to exist on Earth.**

MAIN IDEAS
- Life depends on hydrogen bonds in water.
- Many compounds dissolve in water.
- Some compounds form acids or bases.

VOCABULARY
- hydrogen bond
- cohesion
- adhesion
- solution
- solvent
- solute
- acid
- base
- pH

TEKS **4B** investigate and explain cellular processes, including homeostasis, energy conversions, transport of molecules, and synthesis of new molecules and **9A** compare the structures and functions of different types of biomolecules, including carbohydrates, lipids, proteins, and nucleic acids

Connect to Your World

When you are thirsty, you need to drink something that is mostly water. Why is the water you drink absolutely necessary? Your cells, and the cells of every other living thing on Earth, are mostly water. Water gives cells structure and transports materials within organisms. All of the processes necessary for life take place in that watery environment. Water's unique properties, which are related to the structure of the water molecule, are important for living things.

MAIN IDEA **TEKS** 4B, 9A

Life depends on hydrogen bonds in water.

How do fish survive a cold winter if their pond freezes? Unlike most substances, water expands when it freezes. Water is less dense as a solid (ice) than as a liquid. In a pond, ice floats and covers the water's surface. The ice acts as an insulator that allows the water underneath to remain a liquid. Ice's low density is related to the structure of the water molecule.

Water and Hydrogen Bonds

Water is a polar molecule. You can think about polar molecules in the same way that you can think about a magnet's poles. That is, polar molecules have a region with a slight positive charge and a region with a slight negative charge. Polar molecules, such as the water molecule shown in **FIGURE 2.1,** form when atoms in a molecule have unequal pulls on the electrons they share. In a molecule of water, the oxygen nucleus, with its eight protons, attracts the shared electrons more strongly than do the hydrogen nuclei, with only one proton each. The oxygen atom gains a small negative charge, and the hydrogen atoms gain small positive charges. Other molecules, called nonpolar molecules, do not have these charged regions. The atoms in nonpolar molecules share electrons more equally.

FIGURE 2.1 In water molecules, the oxygen atom has a slightly negative charge, and the hydrogen atoms have slightly positive charges.

Opposite charges of polar molecules can interact to form hydrogen bonds. A **hydrogen bond** is an attraction between a slightly positive hydrogen atom and a slightly negative atom, often oxygen or nitrogen. Hydrogen bonding is shown among water molecules in **FIGURE 2.2**, but these bonds are also found in many other molecules. For example, hydrogen bonds are part of the structures of proteins and of DNA, which is the genetic material for all organisms.

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Hydrogen Bonding

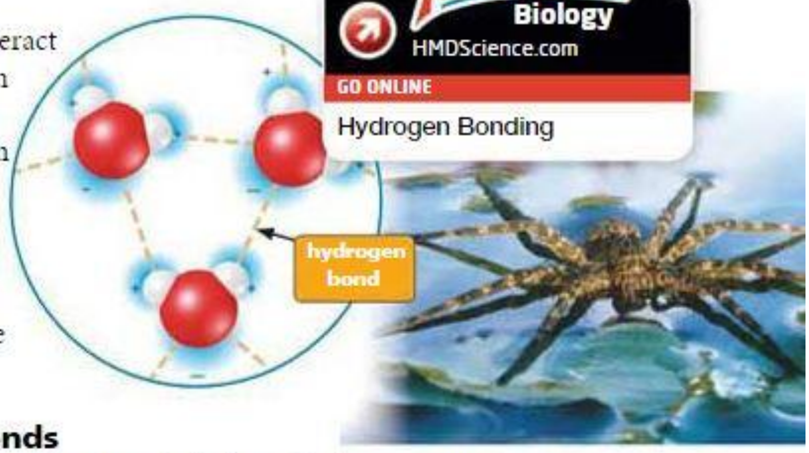


FIGURE 2.2 Water's surface tension comes from hydrogen bonds (left) that cause water molecules to stick together.

Properties Related to Hydrogen Bonds

Individual hydrogen bonds are about 20 times weaker than typical covalent bonds, but they are relatively strong among water molecules. As a result, a large amount of energy is needed to overcome the attractions among water molecules. Without hydrogen bonds, water would boil at a much lower temperature than it does because less energy would be needed to change liquid water into water vapor. Water is a liquid at the temperatures that support most life on Earth only because of hydrogen bonds in water. Hydrogen bonds are responsible for three important properties of water.

- **High specific heat** Hydrogen bonds give water an abnormally high specific heat. This means that water resists changes in temperature. Compared to many other compounds, water must absorb more heat energy to increase in temperature. This property is very important in cells. The processes that produce usable chemical energy in cells release a great deal of heat. Water absorbs the heat, which helps to regulate cell temperatures.
- **Cohesion** The attraction among molecules of a substance is **cohesion.** Cohesion from hydrogen bonds makes water molecules stick to each other. You can see this when water forms beads, such as on a recently washed car. Cohesion also produces surface tension, which makes a kind of skin on water. Surface tension keeps the spider in **FIGURE 2.2** from sinking.
- **Adhesion** The attraction among molecules of different substances is called **adhesion.** In other words, water molecules stick to other things. Adhesion is responsible for the upward curve on the surface of the water in **FIGURE 2.3** because water molecules are attracted to the glass of the test tube. Adhesion helps plants transport water from their roots to their leaves because water molecules stick to the sides of the vessels that carry water.

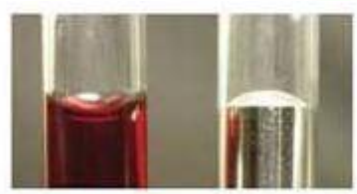


FIGURE 2.3 The water's surface (left, dyed red) is curved down because water has greater adhesion than cohesion. The surface of the mercury (right) is curved up because mercury has greater cohesion than adhesion.

Compare How are hydrogen bonds similar to ionic bonds?

MAIN IDEA TEKS 4B, 9A

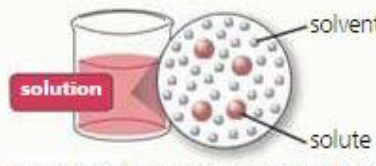
Many compounds dissolve in water.

Molecules and ions cannot take part in chemical processes inside cells unless they dissolve in water. Important materials such as sugars and oxygen cannot be transported from one part of an organism to another unless they are dissolved in blood, plant sap, or other water-based fluids.

Many substances dissolve in the water in your body. When one substance dissolves in another, a solution forms. A **solution** is a mixture of substances that is the same throughout—it is a homogeneous mixture. A solution has two parts. The **solvent** is the substance that is present in the greater amount and that dissolves another substance. A **solute** is a substance that dissolves in a solvent. The amount of solute dissolved in a certain amount of solvent is a solution's concentration. One spoonful of a drink mix in water has little flavor because it has a low concentration. But a solution with four spoonfuls in the same amount of water tastes stronger because it has a higher concentration.

VISUAL VOCAB

The **solvent** is the substance that is present in the greatest amount and is the substance that dissolves solutes.



A **solute** is the substance that dissolves.

The liquid part of your blood, called plasma, is about 95% water. Therefore, the solvent in plasma is water, and all of the substances dissolved in it are solutes. Most of these solutes, such as sugars and proteins, dissolve in the water of blood plasma because they are polar. Polar molecules dissolve in water because the attraction between the water molecules and the solute molecules is greater than the attraction among the molecules of the solute. Similarly, ionic compounds, such as sodium chloride, dissolve in water because the charges of the water molecules attract the charges of the ions. The water molecules surround each ion and pull the compound apart.

Nonpolar substances, such as fats and oils, rarely dissolve in water. Nonpolar molecules do not have charged regions, so they are not attracted to polar molecules. Polar molecules and nonpolar molecules tend to remain separate, which is why we say, "Oil and water don't mix." But nonpolar molecules will dissolve in nonpolar solvents. For example, some vitamins, such as vitamin E, are nonpolar and dissolve in fat in your body.

Connect **What are the solvent and solutes in a beverage you drink?**

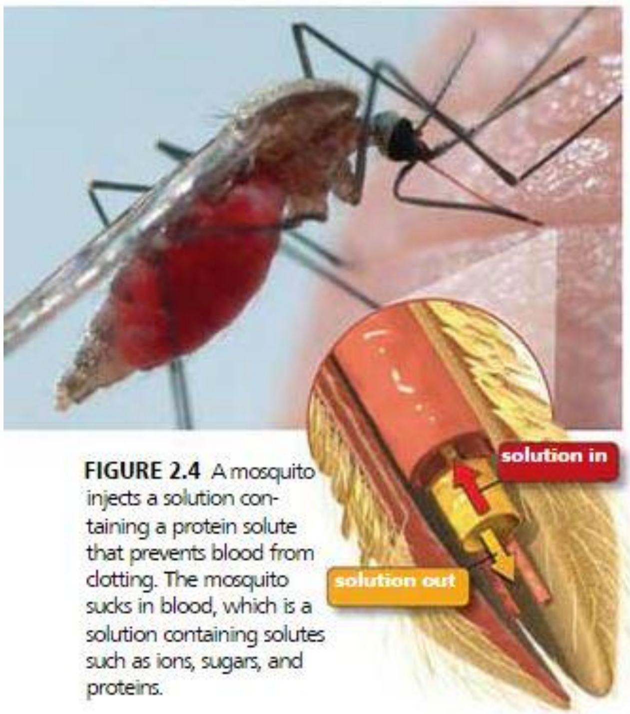


FIGURE 2.4 A mosquito injects a solution containing a protein solute that prevents blood from clotting. The mosquito sucks in blood, which is a solution containing solutes such as ions, sugars, and proteins.

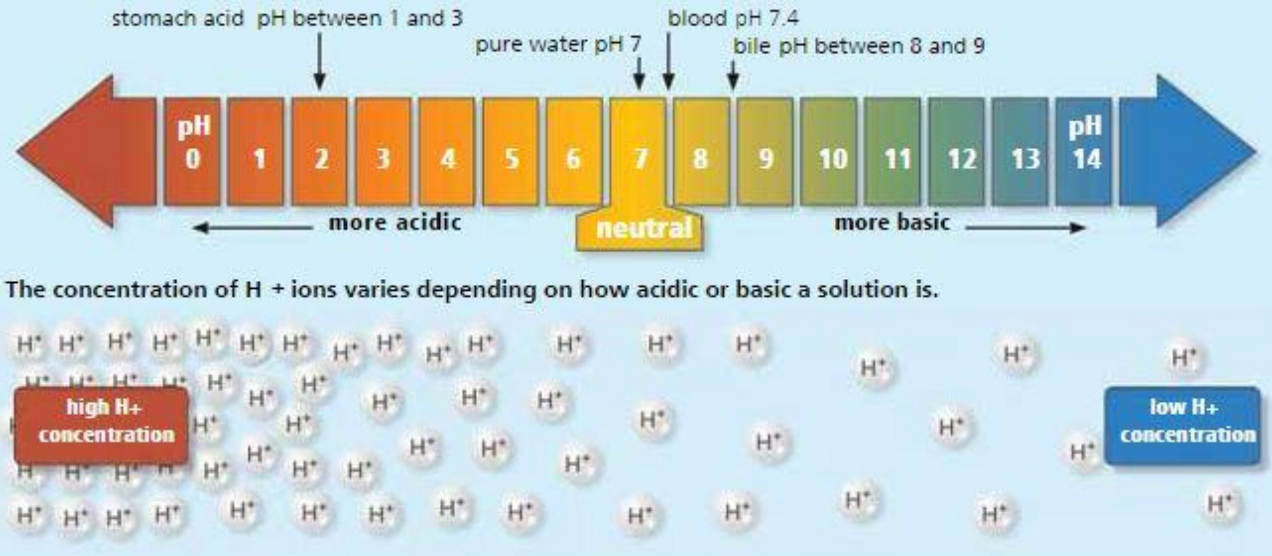
MAIN IDEA TEKS 9A

Some compounds form acids or bases.

Some compounds break up into ions when they dissolve in water. An **acid** is a compound that releases a proton—a hydrogen ion (H^+)—when it dissolves in water. An acid increases the concentration of H^+ ions in a solution. **Bases** are compounds that remove H^+ ions from a solution. When a base dissolves in water, the solution has a low H^+ concentration. A solution's acidity, or H^+ ion concentration, is measured by the **pH** scale. In **FIGURE 2.5,** you can see that pH is usually between 0 and 14. A solution with a pH of 0 is very acidic, with a high H^+ concentration. A solution with a pH of 14 is very basic, with a low H^+ concentration. Solutions with a pH of 7 are neutral—neither acidic nor basic.

FIGURE 2.5 Understanding pH

The pH of a solution depends on the concentration of H^+ ions.



Summarize Describe the relationship between the H+ concentration and the pH value.

Most organisms, including humans, need to keep their pH within a very narrow range around neutral (pH 7.0). However, some organisms need a very different pH range. The azalea plant thrives in acidic (pH 4.5) soil, and a microorganism called *Picrophilus* survives best at an extremely acidic pH of 0.7. For all of these different organisms, pH must be tightly controlled.

One way pH is regulated in organisms is by substances called buffers. A buffer is a compound that can bind to an H^+ ion when the H^+ concentration increases, and can release an H^+ ion when the H^+ concentration decreases. In other words, a buffer "locks up" H^+ ions and helps to maintain homeostasis. For example, the normal pH of human blood is between 7.35 and 7.45, so it is slightly basic. Just a small change in pH can disrupt processes in your cells, and a blood pH greater than 7.8 or less than 6.8, for even a short time, is deadly. Buffers in your blood help prevent any large changes in blood pH.

CONNECT TO
HUMAN BIOLOGY
In the human body, both the respiratory system and the excretory system help regulate pH. You will learn about human systems and homeostasis in the chapter **Human Systems and Homeostasis.**

Apply Cells have higher H^+ concentrations than blood. Which has a higher pH? Why?

2.2 Formative Assessment

REVIEWING MAIN IDEAS

1. How do polar molecules form **hydrogen bonds**? TEKS 9A
2. What determines whether a compound will dissolve in water?
3. Make a chart that compares **acids** and **bases.** TEKS 9A

CRITICAL THINKING

Compare and Contrast How do polar molecules differ from nonpolar molecules? How does this difference affect their interactions?

Connect Describe an example of **cohesion** or **adhesion** that you might observe during your daily life.

CONNECT TO
CELLULAR RESPIRATION
When sugars are broken down to produce usable energy for cells, a large amount of heat is released. Explain how the water inside a cell helps to keep the cell's temperature constant. TEKS 4B