UNIT 8

Water and the Environment

Chapter 23

Water and Solutions

Many of the foods you eat and the products you use (like shampoo) are solutions or other types of mixtures. In this chapter you will learn about water, solutions and solubility. You will also learn about two special types of solutions: acids and bases.

23.1	Water	*What are the properties of water?*

In this Investigation, you will conduct a series of experiments that demonstrate the properties of water.

23.2	Solutions	*Can you identify mixtures as solutions, suspensions, or colloids?*

You will construct an apparatus to view the Tyndall effect. The Tyndall effect is a test for determining the characteristics of a mixture. Your tests will tell you whether the mixture is a solution, colloid, or suspension.

23.3	Solubility	*What factors affect solubility?*

You will observe how temperature influences how fast a substance dissolves. Using your observations, you will develop an explanation for how temperature affects solubility. In addition, using carbonated water and a balloon, you will have the opportunity to explore how pressure affects the solubility of a gas in a liquid.

23.4	Acids, Bases, and pH	*What is pH?*

In this Investigation, a natural indicator and household chemicals are used to create a color-based pH scale. You will use your pH scale to figure out the pH of additional household chemicals and two mystery solutions.

Learning Goals

In this chapter, you will:

- ✔ Identify and describe the unique properties of water.
- ✔ Describe the shape and polarity of a water molecule.
- ✔ Discuss the nature of hydrogen bonds and their influence on the properties of water.
- ✔ Identify the components of a solution.
- ✔ Categorize mixtures as solutions, suspensions, or colloids.
- ✔ Define solubility.
- ✔ Describe saturated, unsaturated, and supersaturated solutions.
- ✔ Explain how temperature and pressure influence solubility.
- ✔ Understand solubility values.
- ✔ Interpret temperature-solubility graphs.
- ✔ Identify the characteristic properties of acids and bases.
- ✔ Relate the pH scale to examples of acids and bases.

Vocabulary

acid	electrolyte	pH	solubility value	Tyndall effect
alloy	equilibrium	pH indicator	solute	unsaturated
base	hydrogen bond	pH scale	solution	
colloid	nanometer	polar molecule	solvent	
dissociation	neutralization	saturated	supersaturated	
dissolved	nonpolar molecule	solubility	suspension	

23.1 Water

We live on a watery planet. All life on Earth depends on this combination of hydrogen and oxygen atoms. Fortunately, we have a lot of water on Earth. In fact, if you could form the water in the oceans into a giant ball, you would have a sphere that is about half the size of the moon.

While water is one of our most common substances, its combination of unique properties makes it essential to life. We cannot live without water. In fact, our bodies are made up of about 60 percent water. What are the properties of water that make it so unique?

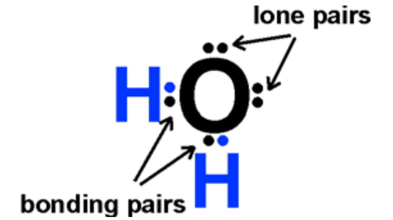
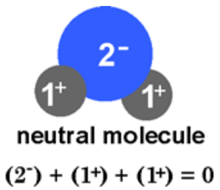


Figure 23.1: *The Lewis dot structure for water. The electron pairs involved in forming the bonds are called bonding pairs. The pairs that are not involved are called lone pairs.*

The shape of a water molecule

How a water molecule is formed



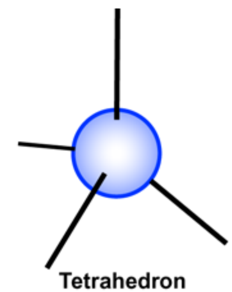
A water molecule is made of one oxygen atom that forms a chemical bond with two hydrogen atoms. Recall that oxygen has an oxidation number of 2- and has six valence electrons. Hydrogen, with an oxidation number of 1^+ has only one valence electron. When two hydrogens share their electrons with one oxygen atom, a neutral molecule is formed (shown at left). Note that the oxygen atom in the molecule now has eight valence electrons, the same number as a noble gas (as shown in Figure 23.1). Each hydrogen atom now has two valence electrons, giving them the same number of valence electrons as a helium atom.

The shape of a water molecule

A water molecule forms the shape of a "V." An oxygen atom forms the point of the "V," and the bonds with the two hydrogen atoms are the two legs. Why does a water molecule form this shape? Look at the Lewis dot structure for water (Figure 23.1). Note that there are four pairs of electrons around the oxygen atom. Only two of these pairs are involved in forming the chemical bonds. These two pairs are called *bonding pairs*. The other two pairs of electrons are not involved in forming chemical bonds and are known as *lone pairs*.

Electron pairs repel each other

Because negative charges repel, the four electrons pairs around the oxygen atom are located where they can be the farthest apart from each other. The geometric shape that allows them to be the farthest apart is called a *tetrahedron*. Since only two of the electron pairs are bonded with hydrogen atoms, the actual shape of the water molecule is a "V" (Figure 23.2).



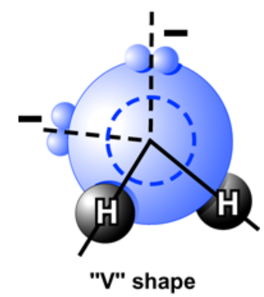


Figure 23.2: *The geometric shape that allows the electron pairs to be farthest apart is called a tetrahedron. Because only two of the pairs are involved in bonds with hydrogen, the shape of the molecule is a "V."*

Water is a polar molecule

What is a polar molecule?

Water is a **polar molecule** that is, it has a *negative* end (pole) and a *positive* end (pole). In a molecule of water, the electrons are shared *unequally* between oxygen and hydrogen. This is because oxygen atoms attract electrons. Because of this, the electrons are pulled toward the oxygen atom and away from the two hydrogen atoms. The oxygen side of the molecule (the side with the lone pairs of electrons) therefore has a partially negative charge and the hydrogen side of the molecule has a partially positive charge (Figure 23.3).

Ammonia is another polar molecule

Ammonia, NH_3, is another example of a polar molecule. This molecule has one lone pair of electrons and three bonding pairs of electrons. This gives the ammonia molecule a pyramid shape. Figure 23.4 shows the shape of the molecule with the three hydrogens forming the base of the pyramid (the positive pole). The top of the pyramid is the negative pole.

Nonpolar molecules

Methane, CH_4, is an example of a **nonpolar molecule**. Nonpolar molecules do not have distinct positive and negative poles. Figure 23.5 shows a methane molecule. This molecule does not contain any lone pairs of electrons. Since there are no lone pairs of electrons, the electrons are shared equally between the carbon atom and the four surrounding hydrogen atoms.

Comparing the physical properties of polar and nonpolar molecules

It takes energy to melt and boil compounds. The fact that the melting and boiling points of a polar molecule (water) are much higher than those of a nonpolar molecule (methane) provides evidence that there are attractions *between* polar molecules. This is because it takes more energy to pull apart molecules that are attracted to each other than those that have no attraction. Table 23.1 compares the melting and boiling points of water and methane. Notice that the melting and boiling points of water are much higher than those of methane.

Table 23.1: ***Comparing water, ammonia, and methane***

Compound	Melting point	Boiling point
Water	0°C	100°C
Methane	-182°C	-164°C

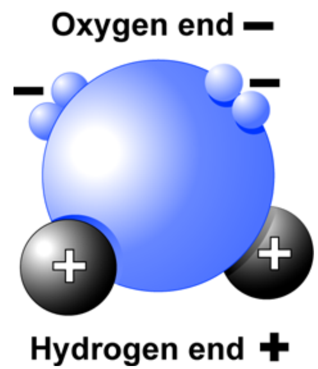


Figure 23.3: *Water is a polar molecule because it has a negative pole and a positive pole.*

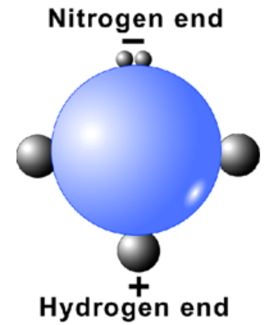


Figure 23.4: *Like water, a molecule of ammonia has a negative pole and a positive pole.*

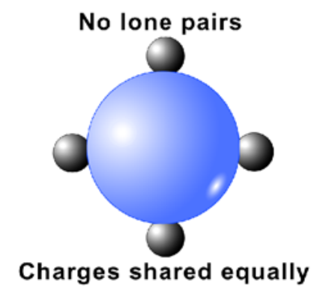


Figure 23.5: *Methane is an example of a nonpolar molecule.*

Attractions between water molecules

Water molecules behave like a group of magnets

If you place a group of magnets together, what happens? Recall that magnets have a positive side and a negative side. If you place a group of them together, you will find that they arrange themselves so that they alternate from positive to negative. The same is true if you put a group of water molecules together. The positive end of one water molecule will align with the negative end of another. When a group of water molecules is placed together, the positive and negative ends align among the molecules in the group. These *polar* attractions create organization among water molecules.

Hydrogen bonds

Figure 23.6 shows that the polar attractions in a group of water molecules are between one of the hydrogen atoms on one water molecule to the oxygen atom on another water molecule. This creates a type of chemical bond that is not as strong as the covalent bonds that hold the oxygen and hydrogen atoms in a water molecule together. The formation of a bond between the hydrogen on one molecule to another atom on another molecule is called a **hydrogen bond**. Hydrogen bonds are relatively weak. They constantly break and re-form as water molecules collide.

Water is a network of hydrogen-bonded molecules

In Figure 23.6, you can see that the oxygen atom in a water molecule has two lone pairs of electrons. Each pair of electrons is available to form a hydrogen bond with the partially positive hydrogen atom of a neighboring water molecule. Many neighboring water molecules connected by hydrogen bonds form a network of water molecules. As temperature increases, the organized structure of the hydrogen bonds among water molecules decreases. As temperature decreases, the organized structure becomes greater.

Frozen water has a honeycomb structure

Frozen water, also known as ice, has a very organized structure that resembles a honeycomb because each water molecule forms hydrogen bonds with four other water molecules (Figure 23.7). This creates a six-sided arrangement of molecules that is evident if you examine snowflakes under a microscope. As water freezes, molecules of water separate slightly from each other as a result of hydrogen bonding. This causes the volume to increase slightly and the density to decrease. This explains why water expands when it is frozen and floats. The density of ice is about 0.9 g/cm^3 whereas the density of water is about 1 g/cm^3.

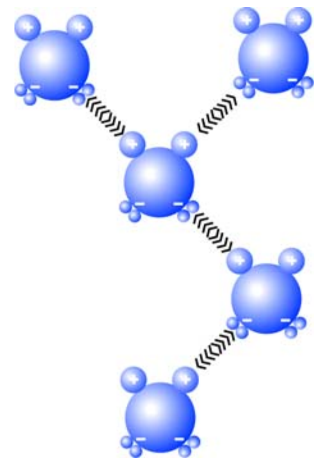


Figure 23.6: *Hydrogen bonds between water molecules.*

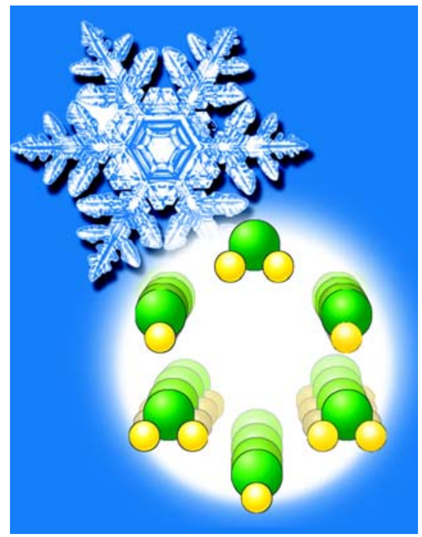


Figure 23.7: *The honeycomb structure of solid water—ice. Can you identify how each molecule forms four hydrogen bonds with other molecules?*

Hydrogen bonding and properties of water

The temperature of water changes slowly

Have you ever jumped into a lake, pond or pool at night after a hot day? If so, you may have wondered why the water temperature felt warmer than the air. This is because once water heats, it cools down slowly. In fact, water cools much slower than most other substances. You may notice that water heats much slower than most other substances. This is evident if you heat a kettle of water for tea. The kettle gets hot very fast, but the water takes a long time to boil.

Hydrogen bonds cause water to resist temperature change

Because hydrogen bonds create attractions between water molecules, it takes more heat to make molecules of water move faster. Once the molecules of water begin to move faster, the temperature rises. As molecules move faster, the temperature rises more. To cool the water, the same amount of energy that was put in must be taken out again. This explains why water cools more slowly. If a large amount of energy is needed to heat water to a certain temperature, the same amount will be have to be taken away to cool it back to the starting temperature. You will learn more about this property of water, called *specific heat*, in the next unit.

Hydrogen bonding and the gaseous state

Most of the water on Earth exists in the liquid and solid states, rather than as a gas. This is because the hydrogen bonds hold the water molecules together strongly enough so that individual molecules cannot easily escape as a gas at ordinary temperatures. The hydrogen bonds in water explain why water has such a high boiling point (100 °C). In order for water to boil and turn into a gas (water vapor), enough energy must be added to separate the hydrogen bonds that hold the molecules of water together. Once these molecules are separated, they are able to enter the gaseous state (Figure 23.8).

Hydrogen bonding and plants

Hydrogen bonding between water molecules is important to the function of plants. Plants obtain water from their roots. How then does a plant get water to its leaves? Plants have cells in their stems that are like soda straws. These sets of cells are microscopically thin. If a plant stem was transparent, you would see streams of water going from the roots to the leaves. As water molecules evaporate from the leaves, more water molecules are pulled into place. It is as if water molecules hold hands. If one molecule moves, the ones behind follow because they are connected by hydrogen bonds!

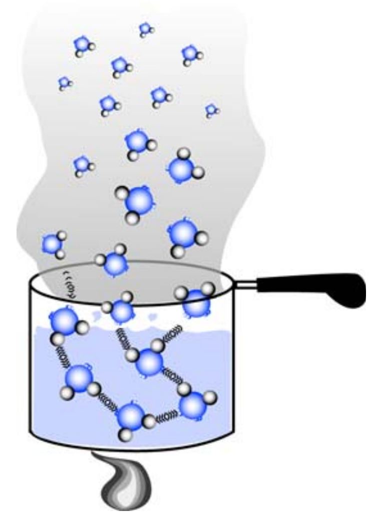


Figure 23.8: *In order for water to boil, enough energy must be added to separate the hydrogen bonds that hold the water molecules together.*

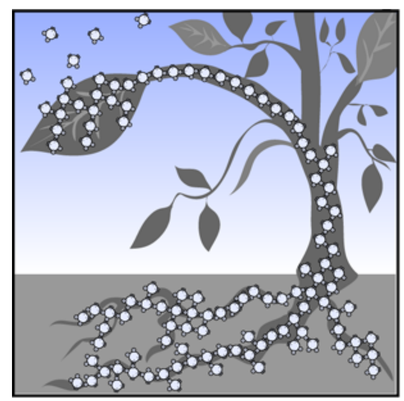


Figure 23.9: *Hydrogen bonds help water travel from root to stem to leaves.*

23.2 Solutions

If you walk down the beverage aisle of your local grocery store, you might see mineral water, spring water, flavored water and seltzer (carbonated water) for sale. While the labels on the bottles might call what's inside "water," each bottle contains more than just pure water. These varieties of water are actually *solutions* that also contain dissolved substances.

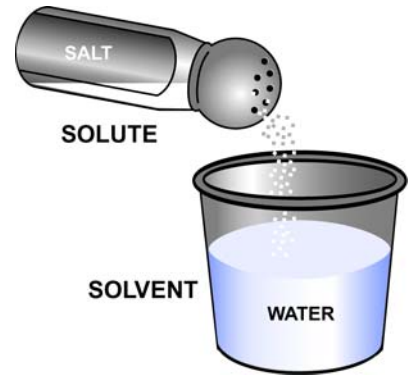


Figure 23.10: *Solutions are made when solutes dissolve in solvents. Here, salt is the solute, and water is the solvent.*

What is a solution?

A solution is homogeneous at the molecular level

In chemistry terms, we call different types of bottled water *solutions*. A solution is a mixture of two or more substances that is homogeneous at the molecular level. The word *homogeneous* means the particles in the water are evenly distributed. For example, in mineral water, there are no clumps of hundreds of mineral ions. The particles in a solution exist as *individual* atoms, ions, or molecules. Each has a diameter between 0.01 and 1.0 nanometer. A nanometer is one-billionth of a meter. It is represented by writing "nm."

A solution is a mixture of two or more substances that is homogeneous at the molecular level.

An alloy is a solution of two or more metals

Although we often think of solutions as mixtures of solids in liquids, solutions exist in every phase, be it solid, liquid, or gas. Carbonated water is a solution of a gas in a liquid. Fourteen-karat gold is a solution of two solids, silver and gold. "Fourteen-karat" means that 14 out of every 24 atoms in the solution are gold atoms. Likewise, ten-karat means that 10 out of every 24 atoms in the solution are gold. Solutions of two or more metals are called alloys.

A solution is a mixture of solute dissolved in a solvent

A solvent is the component of a mixture that is present in the greatest amount. The remaining components are called the solutes. When the solute particles are evenly distributed throughout the solvent, we say that the solute has dissolved (Figure 23.10). Figure 23.11 shows some other examples of solutions.

Solution	Solvent	Solute(s)
air	nitrogen (gas)	other gases
carbonated water	water (liquid)	CO_2 (gas)
saline solution	water (liquid)	salt (solid)
rubbing alcohol	alcohol (liquid)	water (liquid)
sterling silver	silver (solid)	copper (solid)

Figure 23.11: *Some examples of solutions. Notice that solutions are not always liquids.*

Colloids and suspensions are not solutions

Colloids Mixtures such as mayonnaise, egg whites, and gelatin are **colloids**. They look like solutions, but the particles in these mixtures, at one to 1,000 nanometers, are larger than those found in solutions. True solutions contain single atoms and molecules (less than 1 nanometer in size). By comparison, colloid particles are formed of *clusters* of atoms or molecules. Nevertheless, colloid particles are too small (1-1,000 nanometers) to settle to the bottom of their container. Instead, they stay evenly distributed throughout the mixture because they are constantly tossed about by the movement of the liquid particles.

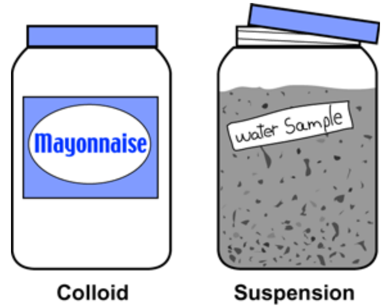


Figure 23.12: *Mayonnaise is a colloid. Water and silt make a suspension.*

Suspensions You may notice that when you step into a pond or lake to go swimming, you suddenly make the water cloudy. Your feet cause the mud on the bottom of the pond or lake to mix with the water. However, if you stand very still, eventually the water becomes clear again. This is because the individual mud particles sink. In **suspensions** like muddy water, the particles are greater than 1,000 nanometers in diameter. Atoms and molecules are much smaller than 100 nanometers. Suspensions are mixtures that settle upon standing (Figure 23.12). If you filter a suspension you can separate the different components.

The Tyndall effect It isn't easy to separate colloids by filtering. However, there is a way to visually distinguish colloids from true solutions. It is called the **Tyndall effect**. If you shine a flashlight through a jar of a translucent colloid, the particles scatter the light, making the beam visible (Figure 23.13). Fog is an example of a colloid. This is why an automobile's headlight beams can be seen on a foggy evening.

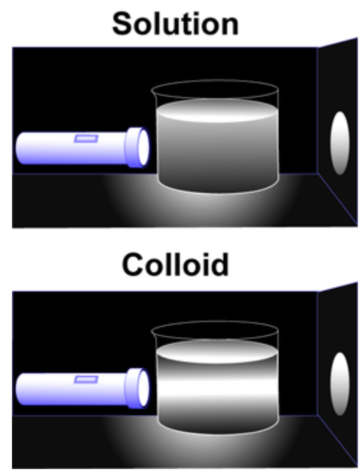


Figure 23.13: *The Tyndall effect helps you tell the difference between colloids and solutions.*

Table 23.2: ***Properties of solutions, suspensions, and colloids***

	Approximate size of solute particles	Solute particles settle	Can be separated by filtering	Particles scatter light
solutions	0.01 - 1.0 nm	no	no	no
colloids	1.0 - 1,000 nm	no	only with special equipment	yes, if transparent
suspensions	>1000 nm	with time	yes	yes, if transparent

Why is water called the universal solvent?

Water readily dissolves many different substances

Have you ever looked at the label on a bottle of spring water? Often the label will read "bottled at the source" and will show the dissolved mineral content. In fact, most of the water you come in contact with contains many dissolved substances. For this reason, water is often called the "universal solvent." While water doesn't dissolve *everything*, it does dissolve many different types of substances such as salts and sugars. Water is a good solvent because it is a polar molecule. This gives it the ability to dissolve ionic compounds and other polar substances.

Sodium chloride is an ionic compound

Recall that sodium chloride (NaCl) is an ionic compound that is made of sodium ions (Na^+) and chlorine ions (Cl^-). If you look closely at a single crystal of NaCl, you will notice that it is a cube. Millions of sodium (Na) and chlorine (Cl) atoms, each too small to see with your naked eye, are a part of a single crystal of NaCl.

Water dissolves sodium chloride

When a sodium chloride crystal is mixed with water, a reaction occurs. The polar water molecules surround the sodium and chlorine atoms in the crystal. This causes the atoms in the crystal to *dissociate*, or separate into Na^+ and Cl^- ions. Because opposites attract, the negative ends of the water molecules are attracted to the Na^+ ions and the positive ends are attracted to the Cl^- ions. Eventually, water molecules surround the Na^+ and Cl^- ions, making a solution (Figure 23.14).

Water dissolves many ionic compounds. The process by which ionic compounds dissolve, that is, become separated into positive and negative ions is called **dissociation**.

The equation for the dissociation of sodium chloride

You can show the dissociation of sodium chloride as a chemical equation:

$$NaCl_{(s)} \xrightarrow{H_2O} Na^+_{(aq)} + Cl^-_{(aq)}$$

The "aq" symbol is shorthand for "aqueous" and symbolizes that the Na^+ and Cl^- ions are dissolved in water.

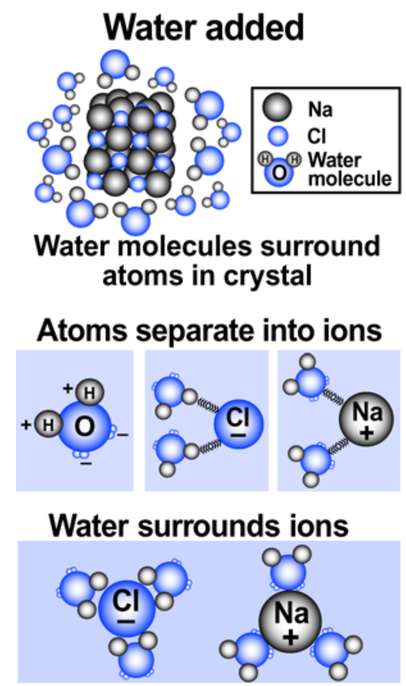


Figure 23.14: *When sodium chloride crystals come in contact with water molecules, the Na+ and Cl- ions become separated and surrounded by water molecules. This process is called dissociation.*

Water also dissolves many covalent substances

Sucrose is a covalent compound

Covalent compounds *share* electrons and are not made of ions. A good example of a covalent compound is *sucrose* ($C_{12}H_{22}O_{11}$), better known as sugar. You know that sugar dissolves easily in water if you have ever made sweetened tea. Like water, sucrose is a polar molecule because it has positive and negative ends.

Water dissolves sucrose

Like water, sucrose molecules are also held together by hydrogen bonds. In the case of sugar, these bonds hold the molecules together as crystals. When sucrose is mixed with water, the individual molecules of sucrose become separated from each other and are attracted to the opposite poles of the water molecules. Because sucrose is a covalent compound, the sucrose molecules do not dissociate into ions but remain as neutral molecules in the solution (Figure 23.15). The dissolving of sucrose in water can be represented by the following simple equation:

$$C_{12}H_{22}O_{11}\,(s) \xrightarrow{H_2O} C_{12}H_{22}O_{11}\,(aq)$$

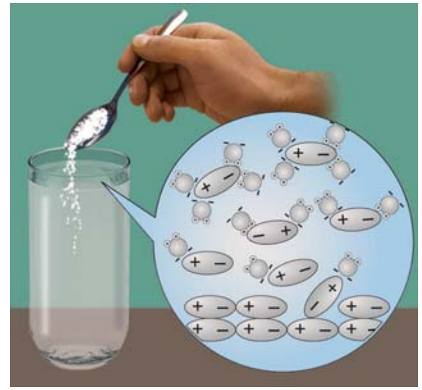


Figure 23.15: *When sucrose and water are mixed, the sugar molecules separate from each other and become surrounded by water molecules.*

Water does not dissolve oil

Have you ever tried to mix oil and water? You may have discovered that you cannot make a solution out of these two substances. Why does water dissolve sugar and not oil? The answer is because water is a polar molecule and oil molecules are nonpolar. Water dissolves sugar because they both have hydrogen bonds and their molecular interactions are *alike*. Oil is nonpolar and does not have hydrogen bonds so it is *unlike* water.

Like dissolves like

In chemistry, a good rule of thumb is that "like dissolves like." In other words, dissolving occurs when both the solute and the solvent are polar molecules, or both the solute and solvent are nonpolar molecules.

Try this at home

You can easily observe a nonpolar substance dissolving in another nonpolar substance if you mix olive oil (which is green) with soybean oil (which is nearly colorless). The two mix when you stir them together and remain mixed. You have created a solution made from two nonpolar substances.

How does soap work?

If you have ever washed greasy dishes with soap, you know that soap can make oil and water mix. The reason is that soaps have molecules with polar and nonpolar ends. The nonpolar ends surround oil molecules and the polar ends are attracted to water molecules. This causes the soap molecules to surround oil molecules. The combined oil-soap molecules become suspended in water molecules and can be rinsed away easily.

Solution concentrations

How do you express solution concentration?

In chemistry, it is important to know the exact concentration of a solution—that is the exact amount of solute dissolved in a given amount of solvent. There are many ways of expressing the concentration of a solution. We'll take a look at two of the most common ways: *molarity* and *mass percent*.

Molarity

The most common way of expressing concentration in chemistry is to use *molarity* (M). Molarity is equal to the moles of solute per liter of solution. Recall that one mole of a substance contains 6.02 x 10^{23} particles (atoms or molecules) and allows you to express the formula mass in grams.

$$\text{Molarity (M)} = \frac{\text{Moles of solute}}{\text{Liters of solution}}$$

Molarity example

Suppose you dissolve 5.00 moles of NaCl in enough water to make 1.0 L, what is the molarity of the solution?

$$\text{Molarity (M)} = \frac{\text{5.0 moles NaCl}}{\text{1.0 L of solution}} = 5.0\text{M}$$

Mass percent

The *mass percent* of a solution is equal to the mass of the solute divided by the total mass of the solution.

$$\text{Mass percent} = \frac{\text{mass of solute}}{\text{total mass of solution}} \times 100$$

Mass percent example

Suppose you dissolve 10.0 grams of sugar in 100.0 grams of water. What is the mass percent of sugar in the solution?

$$\text{Mass \% sugar} = \frac{\text{10.0 g sugar}}{\text{10.0 g sugar + 100.0 g water}} \times 100 = 9.09\%\text{ sugar}$$

Concentrations in the environment

Parts per million (ppm), parts per billion (ppb), and parts per trillion (ppt) are commonly used to describe very small concentrations of pollutants in our environment. But what do these terms represent? They are measures of the amount of one material in a much larger amount of another material. For example, a pinch of salt in 10 tons of potato chips is equal to 1 part salt per billion parts chips, or a concentration of 1 ppb salt.

In the Great Lakes, the concentration of PCB (a toxic waste chemical) in drinking water is about *4 ppt* while the concentration of PCB in fish is *2 ppm*. This means that fish have about a million times more PCB than the drinking water! Which would you rather do, eat the fish or drink the water?

23.3 Solubility

Have you ever noticed that sugar dissolves more easily in a hot cup of tea than in a glass of iced tea? You may also have noticed that you can dissolve *more* sugar in a hot liquid than in a cold liquid. You can deduce that there is a relationship between the temperature of the solvent and the *solubility* of the solute. In this section you will learn about solubility and the factors that influence solubility.

Figure 23.16: *You may have already deduced that there is a relationship between temperature and solubility.*

What is solubility?

What is solubility? The term **solubility** means the amount of solute that can be dissolved in a specific volume of solvent under certain conditions. The solubility of a solute is influenced by several factors including the chemical nature of the solvent, the volume of solute, and temperature.

Volume affects solubility For a solute to dissolve completely, you need a specific volume of solvent. For example, to dissolve an amount of sodium chloride (NaCl) in water, you need enough water molecules to pull apart and surround all the Na^+ and Cl^- ions.

The solubility of a solid usually increases with temperature The solubility of a solid substance usually increases as temperature increases. The effect of temperature on solubility has to do with molecular motion and the energy of the solute-solvent system. At higher temperatures, molecules move faster so that there are more molecular collisions between solute and solvent molecules. The rate of collisions between these molecules is usually directly related to the rate at which the solute dissolves.

Solubility values The **solubility value** for table salt (NaCl) is 1 gram per 2.8 milliliters of water at 25°C. The solubility value for NaCl tells you how much can dissolve in a certain volume (or, sometimes, mass) of water as long as the water is at 25°C. Using this information, how much salt would dissolve in 280 milliliters of water at that temperature? If you said 100 grams, you are correct!

Some substances do not dissolve in water Figure 23.17 shows the solubility values for common substances. Notice that chalk and talc do not have solubility values. These substances are said to be *insoluble* because they do not dissolve in water.

Common name	Solubility at 25 °C (grams per 100 mL H_2O)
table salt (NaCl)	37.7
sugar ($C_{12}H_{22}O_{11}$)	200
baking soda ($NaHCO_3$)	approx. 10
chalk ($CaCO_3$)	insoluble
talc (Mg silicates)	insoluble

Figure 23.17: *Solubility values for common substances.*

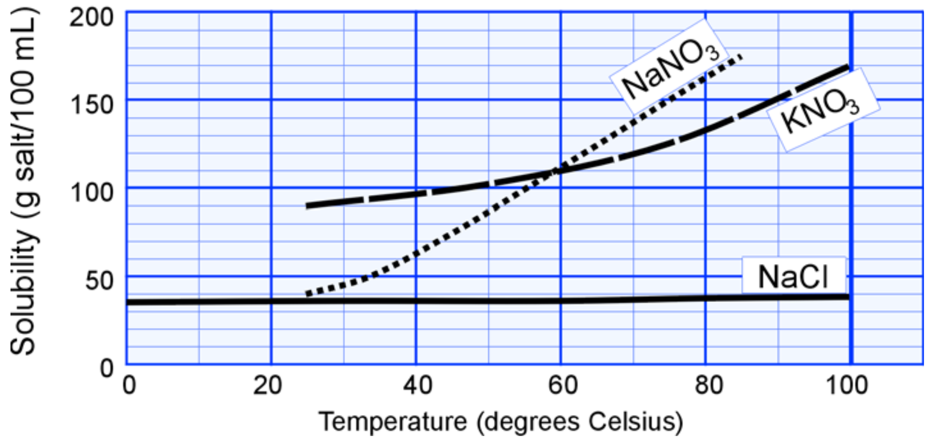
Temperature-solubility graphs

Temperature-solubility graphs show how much substance dissolves at a given temperature

The solubility values for solutes are easily determined if you have a temperature-solubility graph. The *y*-axis on these graphs represents how many grams of solute (in this case, salts) will dissolve in 100 milliliters of water. The *x*-axis represents temperature in degrees Celsius.

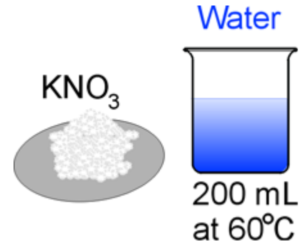
You will notice in the graph that the salts (NaCl, KNO_3, $NaNO_3$) dissolve differently as temperature increases. For something to dissolve in water, the water molecules need to break the bonds between the solute molecules. Water dissolves substances differently because the chemical bond strengths between atoms found in different solutes are not the same.

Temperature-Solubility Graph for Salts



Interpreting the graph

The graph above is a temperature-solubility graph for sodium chloride (NaCl), potassium nitrate (KNO_3), and sodium nitrate ($NaNO_3$). The solubility of NaCl does not change much as temperature increases. The effect of temperature on the solubility of KNO_3 and $NaNO_3$ is more noticeable. More KNO_3 and $NaNO_3$ will dissolve in 100 milliliters of water at higher temperatures than NaCl.



Example:

How many grams of potassium nitrate (KNO_3) will dissolve in 200 mL of water at 60°C?

Solution:

(1) You are asked for the mass in grams of solute.

(2) You are given temperature and volume.

(3) The relationship between solubility and temperature for KNO_3 can be seen on a graph to the left.

(4) From the graph, you see that 110 grams of KNO_3 dissolve in 100 mL of water at 60°C.

(5) Plug in numbers.

200 mL / 100 mL = 2

2 x 110 g = 220 g

(6) Answer:

220 grams of KNO_3 will dissolve in 200 mL of water at 60°C.

The solubility of gases

The solubility of gases in liquids decreases as temperature increases

You now know that temperature tends to increase the solubility of solids in liquids. In contrast, temperature tends *to decrease* the solubility of gases in liquids. For example, you may have noticed that a can of soda at room temperature is more likely to fizz and spill over when opened than a cold can of soda. As temperature increases, the gas and water molecules begin to move around more. The increased motion means that more dissolved gas molecules rise to the surface of the soda and escape.

The solubility of gas also depends on pressure

The solubility of gases also depends on pressure. When you drink fizzy, carbonated beverages, you are consuming solution that contains gaseous carbon dioxide (CO_2). Soda is fizzy because the carbon dioxide has been dissolved in the liquid by using pressure (Figure 23.18). When you pop the tab on a can of soda, you release pressure. You can hear carbon dioxide rapidly escaping. Shaking a can of soda before opening it also forces some carbon dioxide to come out of solution by getting more carbon dioxide molecules to the surface of the liquid.

Figure 23.18: *The CO_2 in a can of soda like ginger ale has been dissolved in water with the use of pressure.*

Fish need dissolved oxygen to live

Dissolved oxygen is an important component of lake, river, and ocean water. Oxygen is produced by underwater plants as a by-product of *photosynthesis*. It is mixed into the water through the action of waves. When the water temperature rises, the amount of dissolved oxygen decreases. Less dissolved oxygen means less oxygen for fish. When the weather is very warm, fish stay near the bottom of ponds and rivers where there is cooler, more oxygenated water.

How temperature affects the amount of dissolved oxygen in water

Electrical generating facilities are often built near bodies of water so that they have an inexpensive source of water for their cooling system. However, when this water is discharged back into the river or bay while it is still warm, it can significantly reduce the amount of dissolved oxygen available in the waterway. At the same time, the warming of the water increases the metabolic rate of the fish so that their need for dissolved oxygen increases. The combination of these two factors endangers fish and may cause large disturbances to the local *ecosystem*. An ecosystem is a term that describes a particular physical environment and its interconnections with plants and animals.

How did soda get its name?

In 1767, Joseph Priestly, an English chemist best known for discovering oxygen, figured out how to carbonate beverages. Initially, carbon dioxide was obtained from baking soda (sodium bicarbonate). This is why we often use the name “soda” for carbonated beverages.

How much will dissolve?

The solubility of a substance stops at equilibrium

When talking about solubility, **equilibrium** is the balance of solute molecules coming and going from a solution for a given set of conditions. For every set of conditions, a solute will dissolve in and come out of solution at a certain rate. When the rate of dissolving equals the rate of coming out of solution, we say equilibrium has been reached (Figure 23.12).

Equilibrium is reached when the rate of dissolving equals the rate of coming out of solution.

Saturated means the maximum amount has dissolved

A solution is **saturated** when the solution has dissolved all the solute it can hold at a given temperature. In other words, the solution will not dissolve any more solute under these conditions. If you raise the temperature of the system, however, you may be able to dissolve a little more solute. When the solution cools back down again, some of the dissolved solute recrystallizes (Figure 23.19).

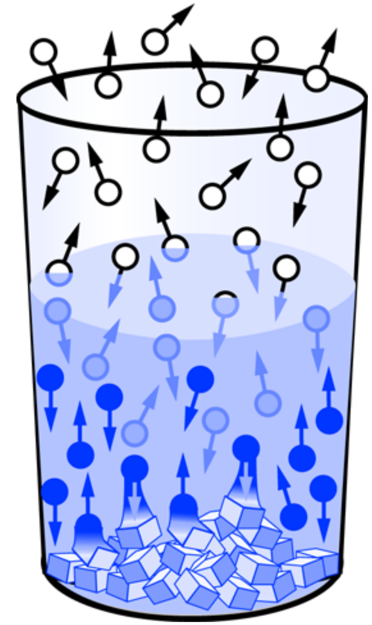


Figure 23.19: *A solute dissolves until equilibrium is reached. This diagram shows gas molecules (the open circles) dissolving and coming out of solution at the surface of the solution. At the bottom of the glass, molecules of a solid (the closed circles) are dissolving and recrystallizing.*

Unsaturated means more solute can be dissolved

Rock candy consists of large sugar crystals usually attached to a rough surface such as a piece of cotton string. The candy is made by heating water to boiling and then stirring in granulated sugar. As long as the sugar dissolves, the solution is said to be **unsaturated**. When no more sugar will dissolve, the solution is said to be saturated. Next, the saturated, sugar-water solution is poured into a jar with a suspended cotton string. As the solution cools, it becomes **supersaturated**.

Supersaturated means more is dissolved than normally possible

Supersaturated solutions are unstable. In making rock candy, if the jar of supersaturated sugar-water is jiggled, the suspended string moves even slightly, or another granule of sugar is dropped in, crystals of solute begin to form. The crystals stick to the rough surface of the string. After five to seven days, all the excess sugar returns to its solid form, and the string is covered with large crystals. The solution left behind now contains only the amount of sugar that can remain dissolved at room temperature. It is once again a *saturated* solution.

Scuba diving

You now know that gases dissolve in liquids and that pressure is an important factor in determining how much gas will dissolve in a liquid. In scuba diving, a deep descent underwater poses some problems that have to do with the solubility of gases in blood.

Atmospheric pressure is measured in units called *atmospheres*. The abbreviation of this unit is “atm.” At the Earth’s surface, atmospheric pressure is 1 atm. The pressure increases by 1 atm every 10 meters (about 33 feet) as a diver descends through sea water. In other words, at a depth of 10 meters, the pressure acting on the diver has doubled to 2 atmospheres, or twice what we are used to on the Earth’s surface. At 30 meters (99 feet), the pressure has quadrupled to 4 atm. Because one atm is equal to 14.5 pounds per square inch (psi), at 40 meters, you would be under 72.5 psi. That’s equal to about twice as much air pressure as a car tire!

A diver is under increased pressure during a dive and the concentrations of gases in the blood and tissues of the diver are higher. The diver’s body can easily process the extra oxygen and carbon dioxide. However, nitrogen is an unreactive gas that stays in the tissues when a diver is in deep water. High concentrations of nitrogen in the body cause a condition called *nitrogen narcosis*. This causes divers to be either extremely carefree, or extremely suspicious and fearful. In either case, the diver loses his or her ability to function safely underwater. Diving partners (called “dive buddies”) keep up constant communication to check that they are not confused because of nitrogen narcosis. The best way to treat nitrogen narcosis is to slowly rise to the water surface with a dive buddy. A slow ascent with normal breathing allows gases to come back out of the blood and tissues easily. Scuba divers should never hold their breath underwater. As a diver rises to the surface, expanding gases can rupture lung tissue!

Decompression sickness occurs when body tissues get supersaturated with nitrogen. Bubbles of nitrogen form in the bloodstream and tissues. These bubbles can block important arteries and cause a stroke or heart attack. When they are trapped in the diver’s joints, back, or abdomen, the bubbles are painful. To release pressure in the back or stomach due to bubble formation, individuals with decompression sickness bend over, which is why decompression sickness is often called “the bends.”

Depth (meters)	Pressure (atm)
0	1
10	2
20	3
30	4
40	5

Figure 23.20: *How pressure changes with water depth.*

How did scuba get started?

SCUBA stands for self-contained underwater breathing apparatus. A number of inventors have contributed to the development of scuba diving technology. The invention of the aqualung by Jaques-Yves Cousteau and Emile Gagnan in 1943 made scuba diving available to anyone who wanted to do underwater exploring. This device made breathing air underwater easy, safe, and reliable.

23.4 Acids, Bases, and pH

Acids and bases are among the most familiar of all chemical compounds. Some of the acids you may have encountered include acetic acid (found in vinegar), citric acid (found in orange juice), and malic acid (found in apples). You may be familiar with some bases including ammonia in cleaning solutions and magnesium hydroxide found in some antacids. The pH scale is used to describe whether a substance is an acid or a base. In this section, you will learn about the properties of acids and bases, and how the pH scale works.

Figure 23.16: *You should NEVER taste a laboratory chemical!*

What are acids?

Properties of acids

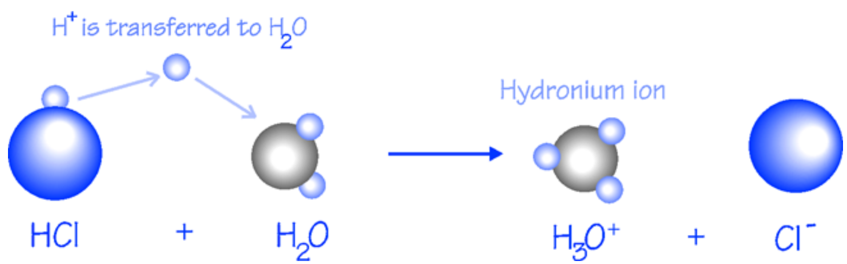
An **acid** is any substance that produces *hydronium ions* (H_3O^+) when dissolved in water. The properties of acids include: they have a sour taste such as lemons (you should NEVER taste a laboratory chemical!); they react with metals to produce hydrogen gas (H_2); and they change the color of a plant dye (called *litmus*) from blue to red.

What are hydronium ions?

When an acid is dissolved in water, it separates, or *ionizes*, into *hydrogen ions* (H^+) and a negative ion. Hydrogen ions do not exist by themselves for very long. Each hydrogen ion is attracted to the oxygen end of a water molecule. The two combine to form hydronium ions (Figure 23.17).

HCl is an acid

When hydrochloric acid (HCl) dissolves in water, it separates into H^+ and Cl^- ions (Figure 23.17). The H^+ ions are transferred to water molecules to form hydronium ions. The Cl^- ions are left over. HCl is therefore an acid because it *transfers* H^+ ions to water molecules causing the production of hydronium ions.



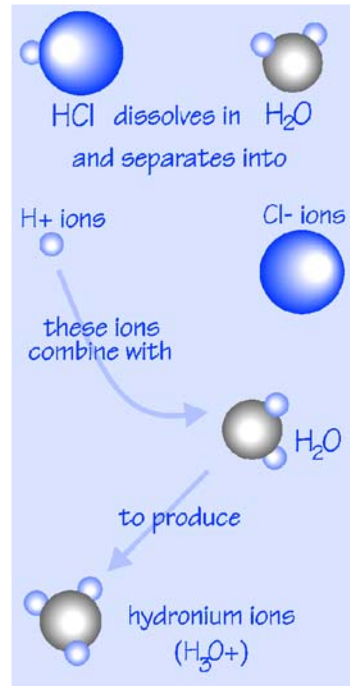


Figure 23.17: *Hydrogen ions do not exist in water for very long. They quickly become attached to water molecules to form hydronium ions.*

Strong and weak acids

HCl is a strong acid

Acids can be classified according to the degree to which they produce hydronium ions when dissolved in water. Hydrochloric acid (HCl) is a *strong acid* because no HCl molecules are present in a solution of HCl and water. This means that every molecule of HCl separates into positive (H^+) and negative (Cl^-) ions. Since all of the HCl molecules ionize, every H^+ ion becomes attached to a water molecule and all of them become hydronium ions.

Acetic acid is a weak acid

Acetic acid ($HC_2H_3O_2$), found in vinegar, is an example of a *weak acid*. This is because in a solution of acetic acid and water, most of the acetic acid molecules remain as molecules and only a small number of them ionize. This means that only a small number of hydronium ions are produced (Figure 23.18).

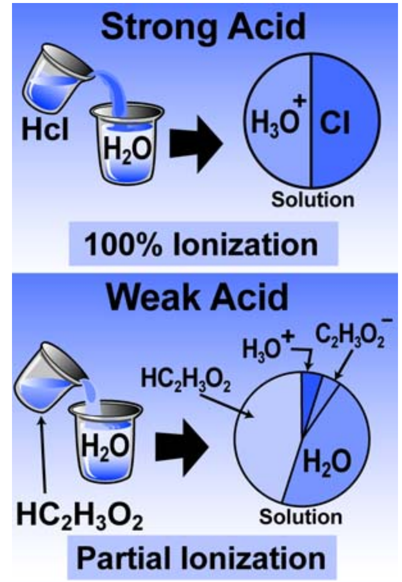


Figure 23.18: *Strong acids produce the maximum number of hydronium ions. Weak acids do not fully ionize and produce relatively smaller numbers of hydronium ions.*

What are bases?

Properties of bases

A **base** is any substance that produces *hydroxide ions* (OH^-) when dissolved in water. While you should never touch a laboratory chemical, the bases you use everyday, such as soap, have a slippery feel. Bases also have a bitter taste and they change the color of litmus from red to blue. Figure 23.19 compares bases and acids. A good example of a base is sodium hydroxide (NaOH), found in many commercial drain cleaners. This compound ionizes in water to form sodium (Na^+) and hydroxide ions:

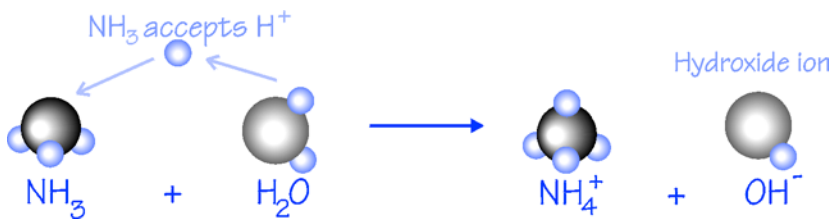
$$NaOH \longrightarrow Na^+_{(aq)} + OH^-_{(aq)}$$

Acids	Bases
Produce H_3O^+ in water	Produce OH^- in water
Sour taste	Bitter taste
Turn blue litmus to red	Turn red litmus to blue
React with metals to produce H_2 gas	Have s slippery feel

Figure 23.19: *A quick comparison of acids and bases.*

Ammonia is also a base

Ammonia (NH_3), found in cleaning solutions, is a base because it *reacts* with water to form hydroxide ions. How is this different than NaOH? Notice that a hydroxide ion is formed when ammonia *accepts* H^+ ions from water molecules in solution as shown below.



Strong and weak bases

Strong and weak bases The strength of bases depends on the relative amount of hydroxide ions (OH^-) produced when the base is mixed with water. Sodium hydroxide (NaOH) is considered a strong base because it ionizes completely in water to form Na^+ and OH^- ions. Ammonia (NH_3) on the other hand, is a weak base because most of its molecules do not react with water to form NH_4^+ and OH^- ions.

Weak does not mean unimportant! Just because an acid or a base is classified as weak does not mean that it is not important. Most of the acid-base chemistry that occurs inside of your body occurs through reactions involving weak acids and bases. For example, the coiling of a DNA molecule into a "double-helix" is due to hydrogen bonding between weak bases (Figure 23.20).

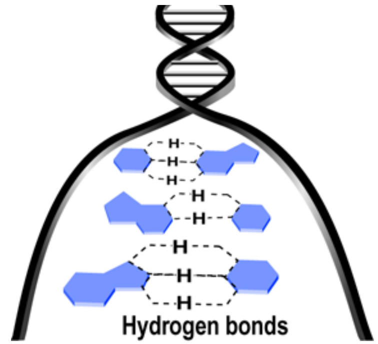
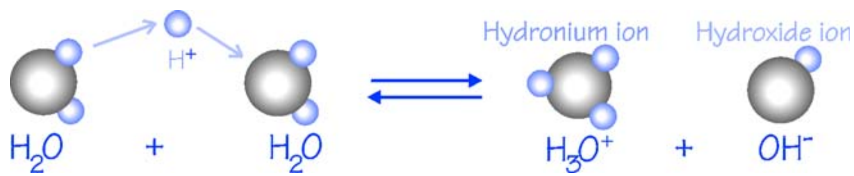


Figure 23.20: *The coiling of a DNA molecule into a double helix is due to the interactions between weak bases.*

The dissociation of water and mixing acids and bases

The dissociation of water One of the most important properties of water is its ability to act as both an acid and as a base. In the presence of an acid, water acts as a base. In the presence of a base, water acts as an acid. In pure water, the molecule ionizes to produce both hydronium and hydroxide ions. This reaction is called the *dissociation of water*.



What does the double arrow mean? The double arrow in the equation means that the dissociation of water can occur in *both* directions. This means that water molecules can ionize and ions can also form water molecules. However, water ionizes so slightly that most water molecules exist whole, not as ions.

Mixing acid and base solutions When acid and base solutions are mixed in the right proportions, their characteristic properties disappear, and new ionic substances known as *salts* are formed. Water is also a product of this type of reaction, called a **neutralization** reaction. Figure 23.21 shows what happens when you mix hydrochloric acid solution with sodium hydroxide solution.

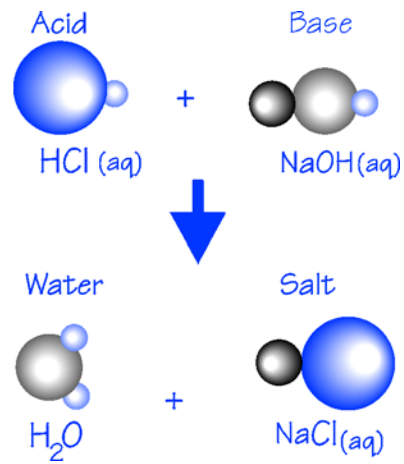


Figure 23.21: *When an acid in solution is mixed with a base in solution, the products are water and a salt. The "aq" symbol indicates that these compounds are dissolved in water and really exist as ions.*

pH and the pH scale

What is pH? Just as centimeters describe length, **pH** describes the exact concentration of hydronium ions in a solution. Most instruments that measure pH use a **pH scale** that runs from 0 to 14. At pH 1, a solution is strongly acidic and has a high concentration of hydronium ions. At pH 14, a solution is strongly basic, or *alkaline* and has a low concentration of hydronium ions.

Why do we need a pH scale? Why do we need a scale to describe the hydronium concentration of different solutions? First, the range of possible hydronium ion concentrations in a solutions is huge (from 1 M to 10^{-14} M). Second, the numbers used to measure hydronium ion concentration are very small. Is it easy to write 10^{-14} as a decimal? The pH scale allows you to represent hydronium ion concentrations using whole numbers. It was developed by S.P.L. Sørenson, a Danish biochemist, in 1909 while working on brewing beer. *pH* is an abbreviation of "the power of hydrogen." A scale of 0 to 14 is much easier to work with than a scale from 1 to 10^{-14}.

Determining pH Think about the pH numbers 0 to 14 and the range of hydronium ion concentrations 1 to 10^{-14}. You will notice that the pH value is equal to the *negative* of the exponent of the hydronium ion concentration. (In a more advanced course, you will learn that pH is equal to the negative *logarithm* of the hydronium ion concentration.) For example, a solution with a hydronium ion concentration of 10^{-9} M has a pH value of 9. Likewise, a solution with a hydronium ion concentration of 10^{-1} has a pH of 1. Since the pH value of a solution is equal to the negative of the exponent of the hydronium ion concentration, it makes sense to say that the higher the hydronium ion concentration, the lower the pH value. The lower the hydronium ion concentration, the higher the pH value (Figure 23.22).

Example: Calculating pH A solution contains a hydronium ion concentration of $10^{-4.5}$ M. What is the pH value of the solution?

pH is the negative value of the exponent of the hydronium ion concentration:

The hydronium ion concentration is $10^{-4.5}$ M. The exponent is -4.5.

pH = -(-4.5)

pH = 4.5

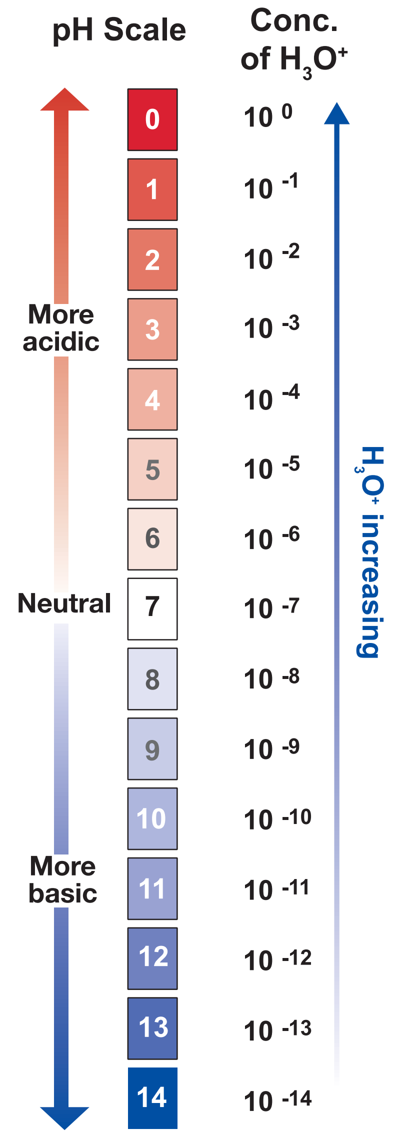


Figure 23.22: *The pH scale is based on the concentration of hydrogen ions in solution.*

The pH of common substances

Many foods are acidic and many cleaning products are basic

Table 23.3 contains a list of some common substances and their pH values. What do you notice about this list of substances? Where would you find acids in your kitchen? Where would you find bases?

Table 23.3: ***The pH of some common chemicals.***

Household chemical	Acid or base	pH
lemon juice	acid	2
vinegar	acid	3
soda water	acid	4
baking soda	base	8.5
bar soap	base	10
ammonia	base	11

It turns out that many of the foods we consume or use for cooking are acidic. On the other hand, many of our household cleaning products are basic.

A pH indicator

In the investigation, you will be testing the pH of common chemicals using another item that you may find in your kitchen. You will measure pH using a **pH indicator**—a chemical that changes color at different pH values.

Some pH indicators are made from common foods. In the investigation, your indicator is made from the juice of a red cabbage.

Acids, bases, and taste

Our taste buds are sensitive to acids and bases. We taste acids as sour and bases as bitter. Lemon juice is strongly acidic, and soap is strongly basic. Acids that are stronger than lemon juice and bases that are stronger than ammonia are so reactive that they can harm your skin and damage clothing.

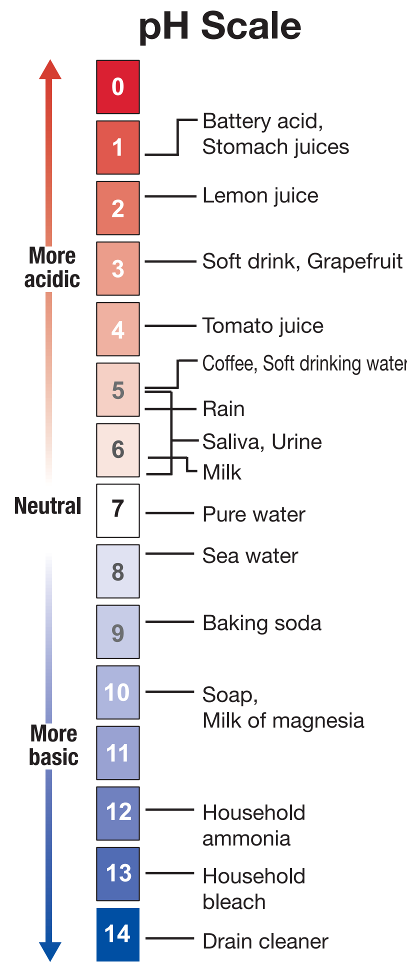


Figure 23.23: *The pH scale showing common substances.*

Acids and bases in your body

Acids and bases play a role in digestion

Many reactions, such as the ones that occur in your body, work best at specific pH values. For example, acids and bases are very important in the reactions involved in digesting food. As you may know, the stomach secretes hydrochloric acid (HCl), a strong acid (pH 1.4). The level of acidity in our stomachs is necessary to break down the protein molecules in our food so that they can be absorbed. A mucus lining in the stomach protects it from the acid produced. As food and digestive fluids leave the stomach, however, other organs in the digestive system also need to be protected from the acid. This is accomplished by two parts of the system—the pancreas and liver. These two organs secrete bicarbonate to neutralize the stomach acid before it reaches other organs.

pH and your blood

It is very important for your blood pH to stay within the normal range. At higher or lower pH values, your body does not function properly. Fortunately, you can regulate the pH of your blood simply by breathing!

Blood contains dissolved gases

Blood is a watery solution that contains many solutes including the dissolved gases carbon dioxide and oxygen. Carbon dioxide appears in your blood because it is produced by respiration. Recall that *respiration* is the combustion of sugar by your body. You breathe in oxygen to get this process going. The end products of this reaction are energy, water, and carbon dioxide.

Breathing rate controls carbon dioxide levels

The rate at which you breathe controls the concentration of carbon dioxide in your blood. For example, if you hold your breath, more carbon dioxide enters your blood. If you hyperventilate, you blow off carbon dioxide, so that significantly less is in your blood. These two processes influence blood pH. The chemical equations for the reactions are shown in Figure 23.24.

CO_2 increases the acidity of your blood

When CO_2 dissolves, H_3O^+ ions are produced in solution. Therefore, the more CO_2 in your blood, the more acidic your blood will become. If you breathe slowly, the added CO_2 makes your blood more acidic. However, if you breathe too often and too quickly (hyperventilating), the loss of CO_2 makes your blood more basic. You can offset this effect by breathing into a paper bag. This forces you to re-breathe carbon dioxide. When you breathe normally, your blood pH ranges between 7.35 and 7.45 (Figure 23.25).

Reaction 1

$$CO_2 + H_2O \rightleftharpoons \underset{\text{Carbonic acid}}{H_2CO_3}$$

Reaction 2

$$H_2CO_3 + H_2O \rightleftharpoons \underset{\text{Hydronium ion}}{H_3O^+} + HCO_3^-$$

Figure 23.24: *An increase in carbon dioxide causes an increase in hydronium ions in the blood.*

Figure 23.25: *Some causes of low blood pH include holding your breath and producing excess lactic acid during heavy exercise. High blood pH can be caused by hyperventilating. Under normal conditions, your blood pH ranges between 7.35 and 7.45.*

Electrolytes and nonelectrolytes

Electrolytes conduct current

Current is the flow of electrical charge. When a solution contains dissolved ions (charged particles), it can conduct current. Chemicals that conduct current when dissolved in water are called **electrolytes**. These chemicals form ions when dissolved.

Salt dissociates in water

Ionic compounds, molecular compounds, and even atoms can contribute ions to a solution. When an ionic compound is dissolved in water, the polar ends of the water molecule attract the positive and negative ions in the solution. In previous sections, you learned how water dissolves table salt (NaCl). Recall that the attraction of the polar ends of the water molecule is strong enough to break the weak ionic bonds of NaCl. When an ionic compound is brought into solution by water it is said to *dissociate*. The term *ionization* is used if a molecular compound or atom forms an ion.

For example, when NaCl dissolves in water we say it *dissociates*. When the element Na loses an electron, it *ionizes* to Na^+.

Acids and bases are electrolytes

All acids and bases are electrolytes because they contribute ions to a solution. Some chemicals, like salt (NaCl), dissociate to form ions in solution but are not acidic or basic. Acids, bases, and salt water are examples of electrolytes.

Non-electrolytes do not have ions and are not acidic or basic

Other chemicals do not form ions when they are dissolved in solution. They are called *non-electrolytes*. Non-electrolytes are not acidic or basic. Sugar dissolved in water is an example of a non-electrolyte.

Electrical appliances and water

Because tap water contains small amounts of dissolved ions, it is an electrolyte. Remember that even a small amount of current is dangerous if it enters your body directly? Water provides a way for electric current to enter your body, so always take care when using electrical appliances near water!

Electrolytes and your body

When you perform a strenuous activity, your body cools itself by sweating. Sweat contains water and dissolved salts (or electrolytes) like sodium and potassium. Before, during, and after exercising, you can replenish fluids and your body's electrolytes by drinking diluted fruit juice, slightly salty water, or by consuming a sports drinks. The water in these fluids helps your body continue to cool itself so that you don't get overheated. By replacing electrolytes, you may be helping your body speed up resorption of fluids. Diluted fruit juice or a sports drink contains small amounts of carbohydrates to give your body the energy boost it may need during strenuous exercise.

Chapter 23 Review

Vocabulary review

Match the following terms with the correct definition. There is one extra definition in the list that will not match any of the terms.

Set One

1. polar molecule
2. nonpolar molecule
3. hydrogen bond
4. water molecule
5. lone pairs

a. A bond between the hydrogen atom on one molecule to another atom on another molecule
b. A molecule that has positive and negative ends or poles
c. An example of a polar molecule
d. A molecule that does not have positive and negative ends
e. Electrons that are involved in the formation of chemical bonds in a molecule
f. Electrons that are not involved in the formation of chemical bonds in a molecule

Set Two

1. solution
2. solvent
3. solute
4. colloid
5. suspension

a. The process by which ionic compounds dissolve
b. A mixture that will separate if left to stand for a period of time
c. The substance that is present in the greatest amount in a solution
d. A mixture that cannot be separated by filtering but does scatter light rays
e. A mixture of two or more substances that is homogeneous at the molecular level
f. A substance that is dissolved in a solution

Set Three

1. solubility
2. insoluble
3. equilibrium
4. saturated
5. unsaturated

a. Contains the maximum amount of a solute that will dissolve for a given set of conditions
b. The amount of solute that will dissolve in a given amount of solvent for a given set of conditions
c. An unstable solution containing more solute than will usually dissolve for a given set of conditions
d. Contains less than the maximum amount of solute that will dissolve for a given set of conditions
e. Substances that do not dissolve in water
f. The state of the formation of a solution in which as many molecules are dissolving as are coming back out of solution

Set Four

1. acid
2. base
3. neutralization
4. pH
5. electrolytes

a. Chemicals that form ions when dissolved in water and conduct electrical current
b. A substance that produces hydronium ions in solution
c. A substance that tells you whether or not a solution is acidic or basic
d. This occurs when acids and bases are mixed in the right proportions to produce a salt and water
e. A substance that produces hydroxide ions in solution
f. Describes the exact concentration of hydronium ions in a solution

Concept review

1. Why do hydrogen bonds form in a group of water molecules?
2. Explain why water, a polar molecule, has a higher boiling point than methane, a nonpolar molecule.
3. Give an example of a solution in which the solute is not a solid and the solvent is not a liquid.
4. Name two ways to distinguish between suspensions and colloids.
5. What would happen to the solubility of potassium chloride in water as the water temperature increased from 25°C to 100°C?
6. What happens to the solubility of oxygen in a pond as the pond temperature decreases from 25°C to 10°C?
7. When you open a can of room-temperature soda, why is it more likely to fizz and spill over than a can that has been refrigerated?
8. What happens to a supersaturated solution when more solute is added?
9. Name three ways to increase the dissolving rate of sugar in water.
10. What information goes on the *x*-axis and the *y*-axis of a temperature-solubility graph?
11. A piece of rock candy in a sugar solution is at equilibrium with the solution. What does this mean on a molecular level? In other words, what are the rock candy molecules doing, and what are the sugar molecules in solution doing? You may want to draw a picture to help answer this question.
12. Many foods are acidic. List four examples.
13. Explain the meanings of a strong acid and a weak acid. Give examples of each.
14. What is the difference between an electrolyte and a nonelectrolyte? Give an example of each.

Problems

1. Draw the Lewis dot structure for water. Label lone pairs, bonding pairs, positive pole, and negative pole.
2. One solubility value of sodium chloride is 1 gram/2.8 milliliters of water at 25°C. Use this value to figure out the following: (a) the volume of water needed to dissolve 100 grams of NaCl; (b) the mass of NaCl that would dissolve in 100 mL of water.
3. Use the temperature-solubility graph on page 419 to answer the following questions:
   a. What is the solubility value of $NaNO_3$ at 25°C?
   b. Which salt has the highest solubility value at 75°C?
   c. Temperature affects the solubility of which salt the least?
   d. Temperature affects the solubility of which salt the most?

4. What is the pH of a solution that has a hydronium ion concentration of 10^{-11} M?

5. Suppose you dissolve 6.5 moles of sugar in enough water to make 2.0 liters, what is the molarity (M) of the solution?

6. Suppose you dissolve 25.0 grams of NaCl in 50.0 grams of water. What is the mass percent of NaCl in the solution?

7. CHALLENGE! You have a 0.5L container of a 2.0 M solution of sugar dissolved in water. How many moles of sugar does the container have?

8. CHALLENGE! Suppose you have a solution that is 12.0 percent sugar by mass. The solution was mixed by dissolving a certain amount of sugar in 350.0 grams of water. How many grams of sugar were mixed with the water?

Applying your knowledge

1. Explain why ice forms on the *top* of ponds and lakes, not on the bottom. Use the following terms in your explanation: water molecules, organized structure, hydrogen bonds, and density. How does this property of water help support life in lakes and ponds?

2. When you shake a bottle of oil-and-vinegar salad dressing, the two liquids stay mixed only for a short period of time. Some food manufacturers add a substance called an emulsifying agent to help keep the oil and vinegar mixed. Emulsifying agents help keep polar and nonpolar substances (like vinegar and oil) mixed in a product. Make a list of all of the food products you can find that contain emulsifying agents. For each food, identify the name of the emulsifying agent.

3. Solutions that contain two or more metals are called *alloys*. Conduct some research on the uses of alloys. Identify 10 alloys and the metals they contain. Make a table that lists each alloy, its constituent metals, and its uses.

4. Create an interesting handout for fourth graders that explains how to make rock candy. The handout should include safety instructions, including supervision, and definitions of these words: *dissolve*, *unsaturated*, *saturated*, and *supersaturated*.

5. One remedy for an upset stomach is to take an antacid. Find out the definition of this word. Explain why an antacid might make someone's stomach feel better.

6. Blood pH values that are too high or too low indicate a health problem. Acidosis occurs when your blood pH is less than 7.4. Alkalosis occurs when your blood pH is more than 7.4. Sometimes the way your body works affects your blood pH. For instance, individuals with diabetes mellitus do not produce enough insulin to help them metabolize nutrients. This is why diabetics need to administer insulin to themselves on a regular basis. They can gauge whether they have enough insulin by testing their blood pH. If their blood is too acidic, they are producing ketone acids—a condition that occurs when their blood doesn't have enough insulin. Use the Internet or your local library to research body metabolism and ketone production as it relates to diabetes and blood pH.

UNIT 8

Water and the Environment

Chapter 24

Earth's Water Systems

Water on Earth is continuously cycled through different systems including rivers, lakes, groundwater, and the oceans. In this chapter, you will learn how water is transported through these different systems and about human impact on water systems.

24.1	The Water Cycle	*What is the quality of your local surface water?*

Your task is to meet with a local water quality official and learn how water is tested. You will monitor data for levels of coliform bacteria, pH, dissolved oxygen, biological oxygen demand, nitrate, phosphate, and turbidity. Since this data is extremely important to public health, you will summarize your findings in a report.

24.2	Water Quality	*What is the quality of your tap water?*

How pure is the water you drink? In this Investigation, you will collect hot and cold water samples at home. You will then test the pH, hardness, and levels of chlorine, copper, and iron in your water samples.

24.3	Acid Rain	*What is acid rain?*

In this Investigation, you will model the effects of acid rain on a natural ecosystem. You will observe the effect of different dilutions of an acid on the activity of water fleas (*Daphnia magna*). Water fleas are an important source of food for fish and other organisms in fresh water environments.

24.4	Oceans	*How does carbon dioxide affect the oceans?*

In this Investigation, you will simulate a chemical reaction that occurs when carbon dioxide from the atmosphere dissolves into seawater.

Learning Goals

In this chapter, you will:

- ✔ Describe the set of process through which water is continuously recycled on Earth.
- ✔ Describe how water quality is analyzed.
- ✔ Understand the cause of acid rain.
- ✔ Understand the environmental effects of acid rain.
- ✔ Demonstrate the effect of acid on a natural ecosystem.
- ✔ Explain how the oceans were formed.
- ✔ Describe the composition of seawater.
- ✔ Explain how the oceans remove carbon dioxide from the atmosphere.
- ✔ Discuss how toxic pollutants travel through marine food chains.

Vocabulary

acid rain	food chain	producer	transpiration
aquifer	groundwater	reservoir	water cycle
carnivore	herbivore	salinity	watershed
condensation	hydrosphere	surface runoff	
evaporation	precipitation	surface water	

24.1 The Water Cycle

The amount of water on Earth is about the same as it was during the age of the dinosaurs, 65 to 220 million years ago. With about 70 percent of its surface covered with water, Earth is truly a water planet. However, only a small amount of this water available for household use. If this is true and Earth has been around for such a long time, why haven't we run out of water?

Having water depends on the *water cycle*—an important set of processes driven by the sun that ensure that water moves from place to place. In this section, you will learn how water moves naturally around Earth so that it is available to use and appreciate.

Where is water on Earth?

The distribution of water

Of the total amount of water on Earth, less than 1 percent is available for our consumption because all the rest is either in the salty oceans—97 percent, or frozen at the planet's two poles—about 2 percent (Figure 24.2).

What is the source of water for your community?

An important role for governments is to manage water resources. Some of the water that is available for people comes from **reservoirs** (protected artificial or natural lakes), dammed rivers, and **groundwater** (water that collects underground). Moisture in the atmosphere replenishes our water supplies when it becomes rain and falls back to Earth.

The table below lists how water is distributed on Earth. Do these distribution percentages surprise you? Why or why not?

Table 24.1: ***The distribution of water on Earth***

Body of water	Description
oceans	97.1%
polar ice	2.24%
groundwater	0.61%
lakes	0.016%
moisture in the atmosphere	0.001%
rivers	0.0001%

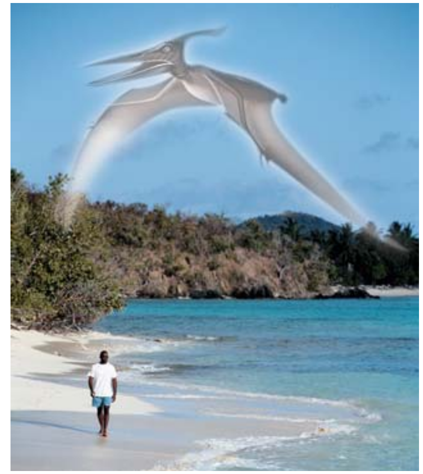


Figure 24.1: *The amount of water on Earth is about the same as it was when dinosaurs lived on Earth 65-220 million years ago.*

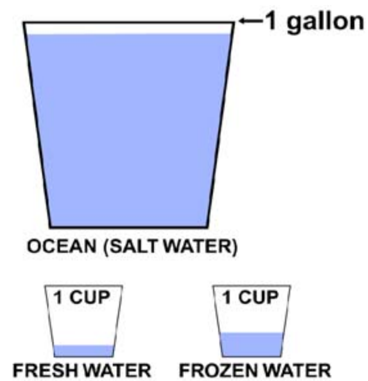


Figure 24.2: *If all the water on the Earth could fit into a one-gallon container, the amount of fresh water available for human consumption would be equal to about one-sixth of a cup!*

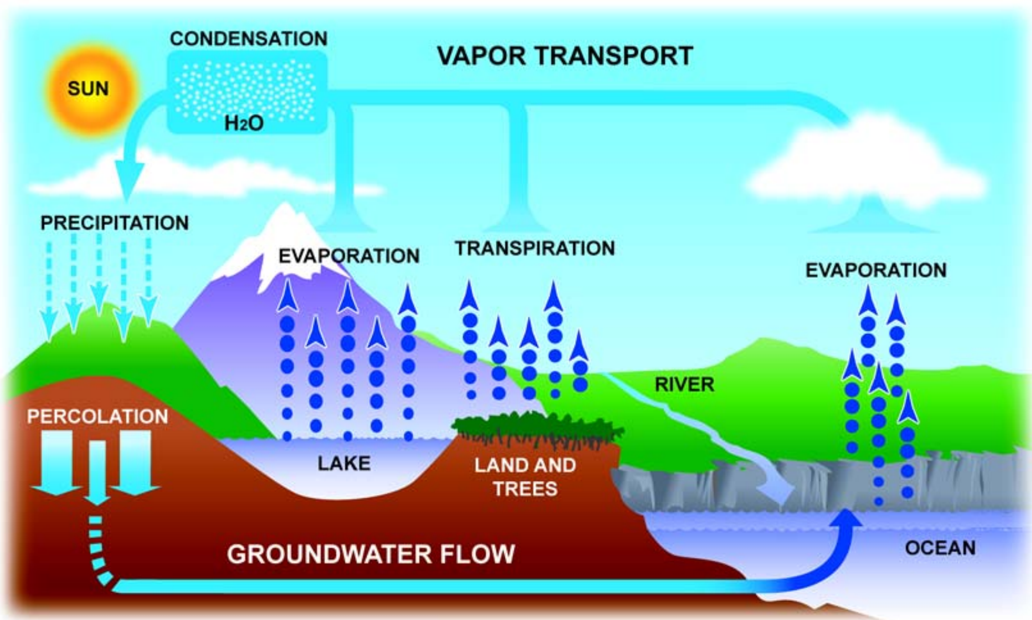
The water cycle

The water cycle continuously recycles and filters our water

For millions of years only a small percentage of water has been available to meet the basic needs of people, animals, and plants. Remember that our water supply today is the same as when the dinosaurs were around. Therefore, the water you drink was used by another person or organism millions of years ago. What keeps our water continuously recycled and naturally filtered is a set of processes called the **water cycle**. The sun is the source of energy that drives the water cycle. Wind, weather, and gravity are additional natural forces that keep water moving from place to place. Of course, people also play a role in transporting water on Earth.

The water cycle includes four processes

The four main processes of the water cycle are **evaporation**, **transpiration**, **condensation**, and **precipitation**. *Evaporation* and *transpiration* occur when the water molecules have enough kinetic energy to leave the liquid phase and become a gas. The source of this kinetic energy is heat from the sun. The *condensation* of water occurs when water in its gaseous state loses energy. Water vapor molecules slow down so much that they group and form droplets of liquid. When these droplets are heavy enough, they fall to Earth as *precipitation*.



Water's journey

Water on Earth is transported from place to place through a series of processes called the water cycle. The picture below illustrates the water cycle. Trace the path of water from the ocean to groundwater and back to the ocean. Explain how the sun, wind, and gravity help move this water along on its journey. How might people get in the way of the water following a direct path through the water cycle?

How the water cycle works

Water vapor in the atmosphere comes from evaporation and transpiration

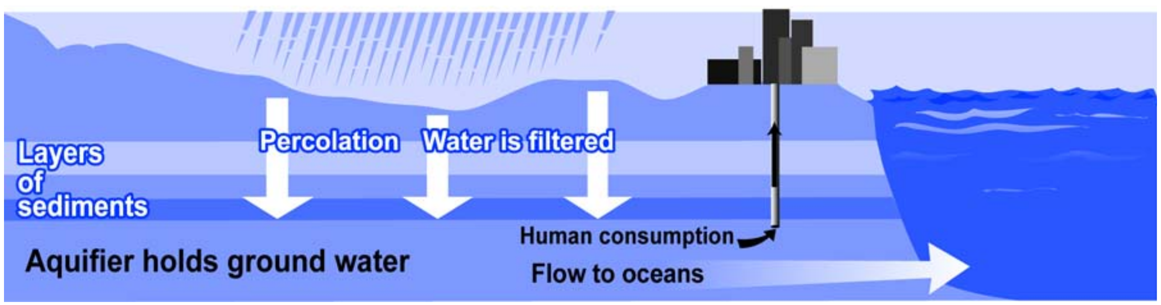
Energy from the sun causes liquid water at Earth's surface to *evaporate* and become water vapor. Water is continuously entering the atmosphere from **surface water**. Surface water includes the oceans, lakes, ponds, rivers, streams, and reservoirs. Plants also contribute water to the atmosphere. You may recall that plants need carbon dioxide (CO_2) to make sugar. Whenever plants open tiny pores on their leaves to get CO_2, they also lose some water through a process called *transpiration*. The water vapor in the atmosphere eventually falls back to Earth's surface as precipitation in the form of rain, hail, sleet, or snow.

Precipitation becomes surface water or ground water

Surface water is replenished when precipitation reaches Earth's surface. This water flows over land until it flows into lakes, rivers, and the oceans. The water that flows over land before reaching surface water is called **surface runoff**. As this water flows over the ground, it dissolves and collects minerals and nutrient-rich soil (thereby causing some soil erosion). Many of the nutrients in freshwater and saltwater come from surface runoff. Precipitation may also be re-evaporated or it may percolate through the soil to become groundwater.

Aquifers contain groundwater

Because soil is porous, groundwater is naturally filtered. Groundwater also contains dissolved carbon dioxide and is acidic enough to dissolve minerals. The destination of groundwater is an underground area of sediment and rocks called an **aquifer**. When groundwater is removed from an aquifer for human consumption, it takes 300 to 1,000 years to replenish the supply. Groundwater that is not collected for use will continue to flow through sediments and eventually enter the ocean, thus continuing the water cycle.

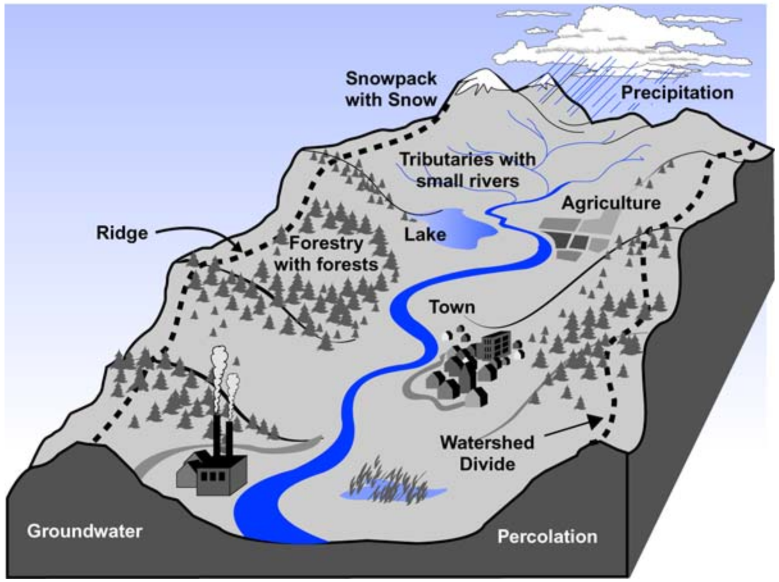


Aquifers

Aquifers are very important sources of water for communities. For example, the Florida Aquifer is very extensive with a boundary in South Carolina. Fresh water springs above ground are fed by aquifers. One-third of the major springs in the United Sates are found in Florida.

The largest aquifer in the world is the Ogallala Aquifer in the mid-western part of the United States (Kansas, Texas, Oklahoma and Nebraska) The water obtained from this aquifer has made agriculture very profitable in this otherwise dry region. However, it is expected that by 2020, a quarter of this aquifer's water supply will be depleted unless there is an effort to conserve water. It will take 1,000 years to replenish the water in this aquifer.

Watersheds



What is a watershed?

The water that comes to your home is most likely from a shared source called a **watershed**. Neighboring towns often get their water from the same watershed. A watershed is an area of land that catches all rain and snow and collects it one place like a river. The boundaries of a watershed are often steep hillsides and mountain ridges. From the graphic, can you see why?

Watersheds are important natural resources

Watersheds provide important resources that support and enrich our lives. In addition to supplying our drinking water, they also provide habitat for plants and animals, areas of natural beauty, and bodies of water for recreation. As communities grow and change, it is important to protect these natural resources. What is the watershed that your town uses? Is there a local organization that monitors the water quality of your watershed?

Finding out about your local watershed

The Environmental Protection Agency (EPA) website has a feature that allows you to find out about your local watershed. If you enter your zip code, you can find out the name of your watershed, and a list of links that will provide you with more information. The website address is:

www.epa.gov/surf

Find the following information about your local watershed:

- What are the major bodies of water in your watershed?
- What other communities depend on this watershed?
- Which organizations monitor the water quality?
- What are some environmental concerns or issues regarding your watershed?

24.2 Water Quality

All water on Earth is part of the water cycle. Therefore, the quality of our water—whether from a faucet or in a pond—is important. In this section, you will learn how the quality of our available water is tested and maintained.

Water quality at home

Standards are used to judge water quality

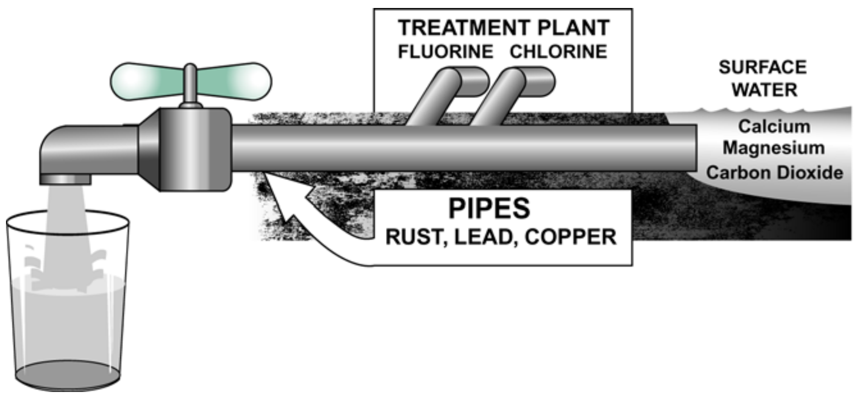
Because water is important to our health and way of living, state and federal governments have set strict standards for water quality. Water that meets these standards is safe for drinking, cooking, and other household activities.

What occurs naturally in tap water?

Calcium, magnesium, and carbon dioxide occur naturally in water that's available for human consumption. If your water has a lot of dissolved calcium and magnesium, it is called *hard water*. It is difficult to get things clean in hard water because calcium and magnesium ions interfere with how soap works. *Soft water* has very few dissolved ions. Soap works very well in this kind of water.

What else is in your tap water?

Tap water may also contain iron, zinc, and copper depending on where you live. Iron (rust), lead, and copper can dissolve into your water supply from plumbing. Additionally, the water that we drink from a faucet may be treated with sodium fluoride to prevent tooth decay and with chlorine to kill bacteria. The picture below illustrates the source of ions that are in your tap water. The variety and amount of ions in your tap water give it a certain taste.



The Clean Water Act

In the past, our rivers, lakes, and oceans were used as dumping grounds for consumer and industry waste. Citizen interest in preventing further pollution of our water supply caused the United States government to pass the Federal Water Pollution Control Act Amendments of 1972.

The Clean Water Act of 1977 is the amended version of the 1972 laws. This act, which is still in use today, entitles the Environmental Protection Agency (EPA) to regulate what can be added to our water. Only within certain guidelines and with a permit can pollutants be discharged into waterways.

Table 24.2: ***What is in your tap water?***

Possible component	Source	Description
acid (high H_3O^+)	Dissolved carbon dioxide from soils	Corrodes pipes; leaches lead and copper into water supply; causes deposits in pipes
base (high OH-)	Calcium and magnesium salts occurring naturally in the water supply	Components of hard water; essential minerals for human health
chlorine (Cl_2)	An additive in water treatment	Changes taste; smells; kills bacteria
fluorine (F-)	Added as sodium fluoride in water treatment	Prevents tooth decay by making teeth stronger
iron (Fe^{2+} and Fe^{3+})	Dissolved from pipes	Causes orange stains in sinks and tubs
copper (Cu^+ and Cu^{2+})	Dissolved from copper pipes	Changes taste in high concentrations; causes blue stains in sinks and tubs; trace amounts are essential to human health
lead (Pb^{2+})	Dissolved from pipes or the solder for pipes	Toxic even in very low concentrations

Analyzing water quality

Analyzing water quality is important

It is important to know the quality of your tap water because you rely on this water for drinking, cooking, and washing. The quality of natural bodies of water like rivers, streams, lakes, and ponds is also important because all the water on Earth is connected via the water cycle. The water that we obtain at home was once in a river, lake, or pond. Before that, the water was rain that resulted from moisture in the atmosphere that was evaporated from surface water (the oceans, rivers, lakes, or ponds).

You can perform water quality tests

Water quality is evaluated using a series of tests. In the Investigation for this section, you will have the opportunity to use these tests to study a pond, lake, or river near your school. These tests and the procedures for using them are explained in the next section.

Figure 24.3: *Many tests for water quality are performed by adding an indicator to a water sample. The color change that results is related to how much of a substance is in the water.*

Make observations and ask a question

If you were going to analyze the water quality of a pond, river, or lake, you would first make careful observations. A way to guide observations is to ask simple questions. If you were studying a pond, you might ask, “What does the pond water look like or smell like? What animals and plants are living in the pond? Where is the pond located? Are there houses or farms nearby? Is the pond near any industry?”

Recording information

It is always useful to record the time of year, date, and time that you are making your observations and testing. Describing the weather for the day and for previous days will help identify reasons why the water quality may be high or low. For example, water quality may be affected when storms or heavy rains cause soil or pollutants to be washed into the pond or lake.

Water quality testing

Common tests that are used to evaluate water quality are described below. Pay attention to the methods for performing each test. For example, think about why would you want to take a sample “three or more inches below the surface of the water” (see paragraph for “Water temperature”). How would the water at the surface of the pond or river be different from water at the bottom? Also, think about why it is important to have standard procedures for water quality testing.

Water temperature

Water temperature should be measured three or more inches below the surface of the water. The higher the water temperature, the less dissolved oxygen there may be in the water. Dissolved oxygen is required by all organisms living in the pond.

Dissolved oxygen test

Oxygen enters surface water mainly from the air. The solubility of oxygen in water is higher at cooler temperatures. As you might expect, the quality of water in a pond is higher when levels of dissolved oxygen are high. Water samples for dissolved oxygen should be taken away from the edge of the pond and three or more inches below the surface of the water. Dissolved oxygen is measured in parts per million (or ppm) often using a special test called the *Winkler method* (see sidebar). A good level of oxygen is 9 ppm, meaning there are 9 milligrams of oxygen for every one liter of water. What would be the concentration of oxygen in parts per thousand? If you said 0.009 grams of oxygen per liter, you are correct!

Winkler Titration

Winkler titration is a method used to measure the amount of dissolved oxygen in fresh and salt water. The method works by adding a manganous sulfate solution and an alkaline-iodide solution to a water sample. These two solutions cause the formation of an insoluble oxygen-manganese complex. This precipitate is then dissolved with sulfuric acid. The result is that an amount of free iodine is released into the solution that is equal to the amount of dissolved oxygen. The method used to measure the iodine is called titration. The iodine solution is titrated with a known amount of sodium thiosulfate solution. Starch, which has a color reaction with iodine, is used as a color indicator during the titration.

Biological oxygen demand test The biological oxygen demand (BOD) test measures dissolved oxygen in two water samples taken at the same time. Oxygen is measured in the first sample when it is collected. The second sample is shielded from light (to prevent photosynthetic organisms from producing oxygen) and measured at a later time. The amount of oxygen in the first and second samples is compared to find out how much oxygen is being used by bacteria as they decompose organic material. When a pond or lake contains a lot of organic material, the bacteria consume too much oxygen and endanger other organisms, like fish, that also need oxygen.

Turbidity test The turbidity test measures the cloudiness of water. The easiest way to measure turbidity is with a Secchi disk (see Figure 24.4). The disk is lowered into the water until the black and white panels on the disk are no longer visible to a person looking into the water from above the water's surface. The rope holding the disk is marked at meter or half-meter intervals to measure the depth of the Secchi disk when it disappears from view underwater.

Nitrate test Nitrogen is used by all organisms to make protein. Nitrogen is most available to organisms when it is combined with oxygen to form nitrate (NO_3^-). Fertilizers are high in nitrates. If a pond is near a fertilized lawn or farm, the pond may have too much nitrate. Excess nitrate can cause *algal blooms*, large growths of algae in a body of water. Even though algae are plants that produce oxygen, when the plants die, they are decomposed by organisms that *use* oxygen. Algal blooms therefore reduce the amount of dissolved oxygen, harming other organisms in the water.

Phosphate test Phosphate (PO_4^{3-}) is the form in which organisms get phosphorus. Phosphorus is an essential element in DNA. Although all organisms use phosphorus, this element tends to enhance the growth of algae in particular. As with excess nitrogen, excess phosphorus in a body of water can cause algal blooms.

pH test The pH scale ranges from 0 to 14. Pure water is pH 7 (a neutral value). The pH of acids is below 7 and the pH for bases is above 7. Surface water pH ranges from 6.5 to 8.5. Most plants and animals function best when pH is nearly neutral. At the extreme ends of the pH scale, where you find strong acids and strong bases, many life processes will not occur. For example, fish have trouble reproducing when the pH of their watery environment is too acidic.

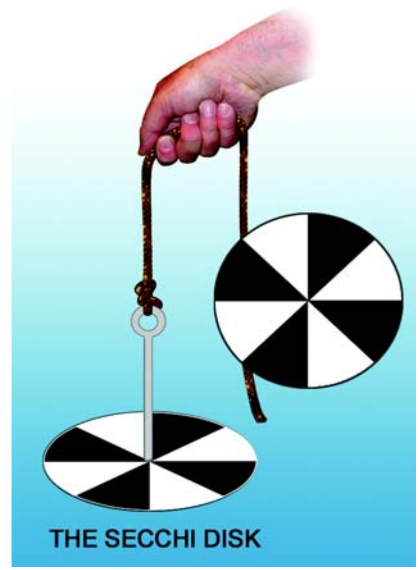


Figure 24.4: *A Secchi disk can be used to measure the turbidity of water. If water is too cloudy, sunlight is blocked. Photosynthetic organisms use sunlight to grow. These organisms are food for larger animals in the pond or lake.*
How to use a Secchi disk: The disk is lowered into the water until it is no longer visible. Then, it is pulled up slightly until it is seen again. The length of the rope between the disk and the surface of the water is related to the clarity of the water. Secchi disks usually have an alternating black and white pattern. Why is it important that a portion of the disk is white?

24.3 Acid Rain

Pollutants from industry and traffic cause acid rain. Due to weather patterns, natural places like forests or lakes can be harmed by acid rain if they are downwind from a city or industrial area. A sign that acid rain has occurred in a forest is that trees are more susceptible to disease. Also, the soil may lack calcium because acid rain dissolves calcium and carries it into the groundwater. Snails and birds need calcium. Loss of calcium for snails means that snail-eating birds do not get enough calcium. These birds lay eggs with thin shells that crack easily (Figure 24.5).

With continued exposure to acid rain, the populations of plants and animals in a forest or lake decline. In this section, you will learn what causes acid rain and how it can be prevented.

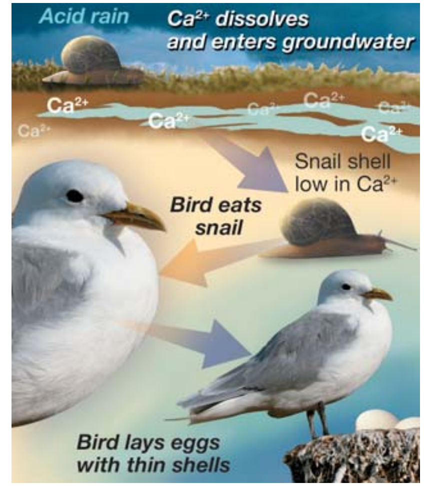


Figure 24.5: *Acid rain reduces the amount of calcium in the soil. A sign that acid rain has occurred is that some birds lay eggs with thin shells.*

What is acid rain?

The pH of acid rain is less than 5.6

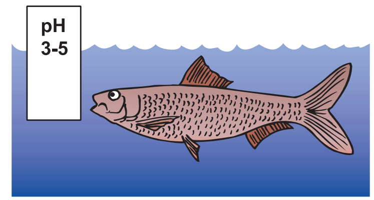
All precipitation is naturally acidic because rain, snow, or fog mixes with carbon dioxide in the air and forms small amounts of carbonic acid. Before the Industrial Revolution of the 1700s, the pH of rain was around 5.6. Therefore, the normal pH of rain is 5.6. Any rain, snow, or fog that has a pH *lower* than 5.6 is called **acid rain** or *acid precipitation*.

A review of the pH scale

What does it mean to say that the pH of acid rain is lower than 5.6? pH refers to the concentration of hydronium ions (H_3O^+) in a solution. The lower the pH value, the higher the concentration of hydronium ions present. The pH scale ranges from 0 to 14. Acids range in pH from 0 to 7 and have a high concentration of hydronium ions. Bases range in pH from 7 to 14 and have a low concentration of hydronium ions. Solutions with very high or low pH are irritating and harmful. For example, strong acids are used to etch glass. In some regions that experience acid rain, the average pH of rain is 3. This is the pH of vinegar! Given this information, it is not surprising to learn that acid rain erodes statues and buildings.

Life functions when pH is nearly neutral

Acid rain is harmful to natural environments because most life and life processes function in nearly neutral environments. For example, the ideal conditions for fish are when the water pH ranges from 6 to 8. Fish have trouble reproducing when the pH of their environment is too acidic, and plants do not grow well if soil is acidified below pH 5.1 (Figure 24.6).



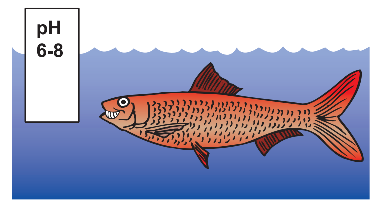


Figure 24.6: *The ideal pH of a pond or other body of water is nearly neutral. Ideally, fish require water within the 6 - 8 pH range.*

What causes acid rain?

Sulfur and nitrogen oxides cause acid rain

The chief indicators of acid rain in the atmosphere are the gases sulfur dioxide (SO_2), sulfur trioxide (SO_3), nitrogen oxide (NO), and nitrogen dioxide (NO_2). A large part of SO_2 in the atmosphere is created by the burning of coal and oil that contain sulfur, and by industrial processes such as metal purification. Nitrogen oxide is a leading by-product of fuel combustion from traffic and power plants.

Formation of sulfur and nitrogen oxides

Sulfur trioxide and nitrogen dioxide are created from the reactions of sulfur dioxide and nitrogen oxide, respectively, with oxygen-containing compounds in the atmosphere. Both of these reactions speed up due to chemicals in air-borne particles that come from traffic and industrial processes.

Formation of sulfuric and nitric acid

Sulfur dioxide in the air mixes with water, ozone, or hydrogen peroxide to form sulfuric acid (H_2SO_4). This strong acid is the number one cause of acid rain. Nitrogen oxides react with components in the atmosphere to form nitric acid (HNO_3), the second greatest cause of acid rain. Simplified equations for each reaction are shown below:

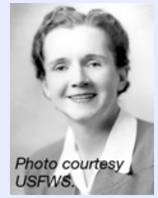
$$SO_2 \text{ (pollutant)} + H_2O_2 \text{ (hydrogen peroxide in air)} \rightarrow H_2SO_4 \text{ (acid)}$$

$$4NO_2 \text{ (pollutant)} + 2H_2O \text{ (water)} + O_2 \text{ (oxygen gas)} \rightarrow 4HNO_3 \text{ (acid)}$$

Sulfur and nitrogen gases cause health problems

Even before acid rain is formed, the four gases that cause acid rain (SO_2, SO_3, NO, and NO_2) create health problems in cities. These gases irritate the respiratory system. In particular, sulfur dioxide can cause airways to constrict in both healthy people and individuals with asthma. Exposure to either sulfur or nitrogen oxides may increase the incidence of asthma, bronchitis, or other respiratory infections and ailments in people.

Rachel Carson



Rachel Carson was born in Pennsylvania in 1907. At age 11, Rachel submitted a story she wrote to *St. Nicholas* magazine. She won a silver medal! She hoped to have a career in writing. When Carson went to college, she enjoyed both English and biology, but she didn't know that she could be both a writer *and* a scientist.

During World War II, Carson wrote for the U.S. Fish and Wildlife Service, where she eventually became chief of publications. In her job, Carson learned of the growing problems caused by pesticides and herbicides like DDT. In 1958, Carson received a letter from a friend telling of birds killed in Massachusetts after a plane dropped DDT for mosquito control. DDT was found at toxic levels in the dead birds. Carson published a book, *Silent Spring*, in 1962, to show that DDT and other pesticides and herbicides were responsible for environmental poisoning. The book was a wake-up call that got the attention of citizens, Congress and the President. They started the Environmental Protection agency in 1970. DDT was banned in 1972.

What can be done about acid rain?

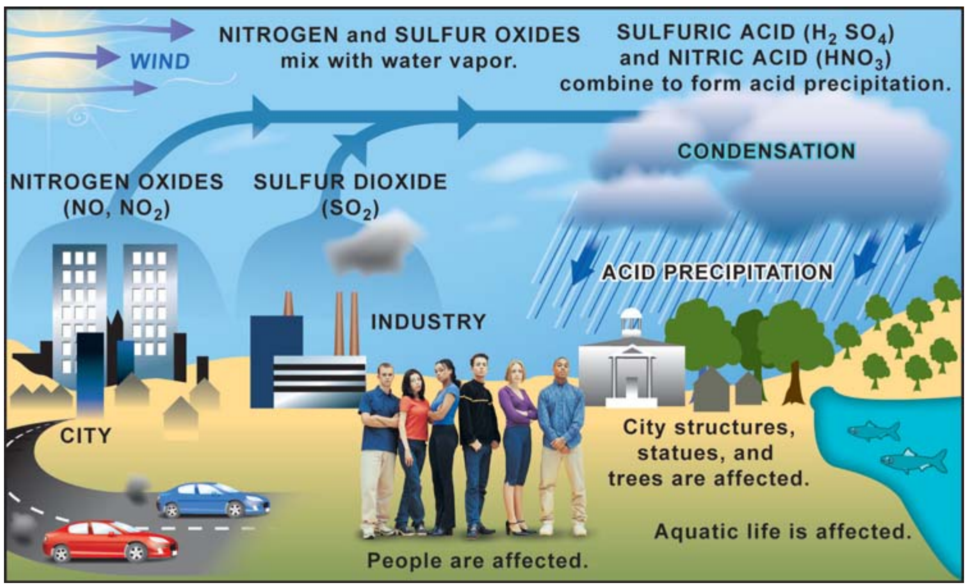
Catalytic converters

Catalytic converters in cars reduce acid rain-causing emissions. A catalytic converter is a device that converts nitrogen oxide to nitrogen gas (N_2) and oxygen (O_2) before these emissions enter the atmosphere. Nitrogen and oxygen are non-polluting gases (Figure 24.7). Catalytic converters also reduce carbon monoxide and hydrocarbon emissions. Unfortunately, catalytic converters do not reduce emissions under all driving conditions. When the accelerator is held down to accelerate quickly, the emissions by-pass the sensors that maintain the chemical conditions for the catalytic converter to work.

Scrubbing reduces power plant emissions

In the case of power plants that burn sulfur-containing coal, emissions are made less toxic by exposing them to a solution of lime (CaO). The lime reacts with sulfur dioxide (SO_2) to produce calcium sulfate ($CaSO_3$). Although this by-product of the reaction is not harmful, it is not useful and must be added to landfills. This process for treating power plant emissions is called *scrubbing*.

The diagram below shows how acid precipitation is formed.



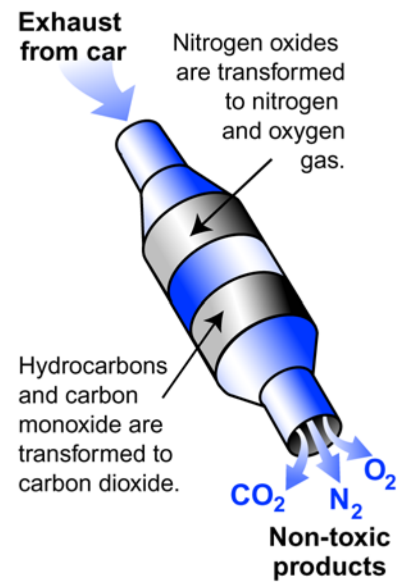


Figure 24.7: *The chemical reactions that reduce emissions to non-toxic products occur in two places in the catalytic converter. Each of these has a "honeycomb" structure so that the surface area at which the reactions take place is maximized.*

24.4 Oceans

Although we can't drink ocean water, the oceans contribute to our water supply via the water cycle. The sun's energy evaporates pure water from the oceans, leaving behind salt. The resulting water vapor in the atmosphere eventually condenses to form rain. In this section, you will learn more about why the oceans are important to life on Earth. You will also learn about the chemistry of Earth's oceans, and the impact of human activities.

Where did the oceans come from?

How were the oceans formed?

Earth is about 4.6 billion years old. As our planet formed, it started out very hot and then cooled. As Earth's crust solidified during this cooling process, water vapor was released from its crust. Continual cooling then caused this atmospheric water to condense. The resulting rains filled the original ocean basins. Some of the water in our oceans is also thought to have been brought from space by large, icy comets entering our atmosphere millions of years ago. The amount of water in the oceans is about the same as it was when dinosaurs lived on Earth between 220 and 65 million years ago.

Oceans are part of the hydrosphere

Earlier, you learned that 97 percent of Earth's water is found in the oceans. Oceans are part of the water layer of Earth's surface, called the **hydrosphere**. This layer covers much of its surface. You are probably familiar with Earth's *atmosphere*. This layer of gases blankets the planet. The *lithosphere* is a thin, solid, rocky layer that covers Earth's surface (Figure 24.8).

Supply of water to the oceans

How is water supplied to the oceans today? You learned that the water cycle distributes water on Earth. This cycle carries water to the oceans and also removes it. As you can see in Figure 24.9, sources for ocean water include rivers, rain, and groundwater. These sources also bring dissolved minerals and salts into the oceans. You have just learned that the amount of water in the oceans is the same as it was many millions of years ago. It is also true that the saltiness of the oceans has also remained relatively constant for millions of years. From here forward, we will refer to ocean water as *seawater* and learn how it is different from the *freshwater* that resides in rivers, lakes, ponds, and groundwater.

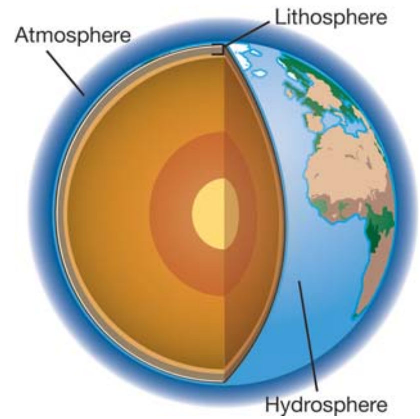


Figure 24.8: *The diagram above shows the atmosphere, lithosphere, and hydrosphere. In this section, you will learn about oceans—part of the hydrosphere.*

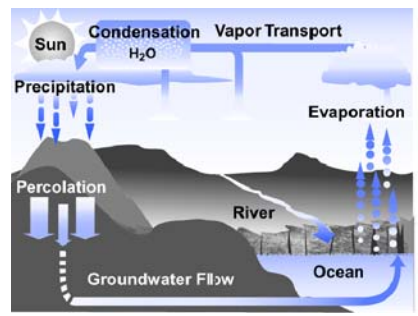


Figure 24.9: *The water cycle distributes ocean water to freshwater bodies of water, and returns freshwater to the oceans.*

What is an ocean?

Water covers about 70 percent of Earth's surface

Oceans are massive bodies of seawater that cover much of the surface of Earth. In fact, the land on which we all live covers only about 25% of Earth's surface. In comparison, the majority—about 75%—of the surface is covered with water (the hydrosphere) and much of this space is occupied by oceans. There are five major oceans on Earth.

Earth has five major oceans

The United States has boundaries on two major oceans. If you are from the east coast, you are familiar with the Atlantic Ocean. If you are from the west coast of the United States your are more familiar with the Pacific Ocean. These are two of the major oceans. The Arctic Ocean and the Indian Ocean are two smaller oceans. The Southern Ocean, the fifth ocean, was recently named as a separate ocean in 2000 by the International Hydrographic Organization (IHO). The IHO includes representatives from 68 countries that border the world's oceans.

Why are oceans salty?

There are three main sources that have contributed to the saltiness of seawater over time: (1) chemical weathering of rocks on land, (2) chemical reactions between seawater and volcanic eruptions on the ocean floor, (3) volcanic eruptions on land. Weathered rocks contribute silica, sodium, calcium, potassium, and magnesium to oceans. Bicarbonate (HCO_3) is added to the oceans from rivers and comes from dissolved limestone.

Panthalassa and Pangaea

About 225 million years ago, there was one large ocean we refer to as *Panthalassa*. This ocean surrounded a single landmass we refer to as *Pangaea*. Around 200 million years ago, Pangaea began to separate into parts so that we now have seven continents and five major oceans rather than one large one. The Atlantic and Indian Oceans formed around 180 million years ago. The Pacific, Arctic, and Southern Oceans are what remain of Panthalassa.

The composition of seawater

Ions in seawater Many of the salts in seawater are dissolved, and exist as ions. There are six main ions in seawater that together account for 99% of the dissolved salts (Figure 24.10). In addition, there are more than 70 additional *trace elements* that make seawater a very complex solution. The concentration of trace elements is very low and ranges from parts per million (ppm) to parts per billion (ppb). For example, the concentration of iron in seawater is 0.06 ppb.

Salinity The term salinity describes the "saltiness" of seawater. **Salinity describes how much salt is dissolved in one kilogram of water**. On average, one kilogram of seawater has 35 grams of salt. This means there are 35 grams of salt mixed with 965 grams of water to make one kilogram of seawater. To describe the concentration of salt in the seawater, we say that the salinity is 35 parts per thousand (ppt), or 35 $^{o}/_{oo}$.

Other components of seawater Additional components of seawater include organic materials and dissolved gases. Organic materials come from marine animals and plants that live in the ocean. Dissolved gases include nitrogen, oxygen, carbon dioxide, hydrogen, and trace gases. This is not surprising since the surface of the ocean is continuously exposed to the atmosphere. The amount of dissolved gases in the ocean is directly related to water temperature. At higher temperatures, there are fewer dissolved gases. Salinity is also higher at higher temperatures. Because the Dead Sea is very warm (about 21 °C), it has few dissolved gases, and high salinity (250 ppt).

Salinity remains constant The salinity of the oceans has remained relatively constant for 600 million years because physical and chemical processes create a balance. Rivers that flow toward the oceans constantly bring in salts and minerals. Microscopic organisms remove some of these salts and minerals as they use calcium and carbonate ions or silica to build their skeletons. Excess metals (like manganese) come out of solution and form deposits on rocks on the ocean floor (Figure 24.11). Organisms also contribute to the reduction of salts when they metabolize nitrate, phosphate, and metals. As these processes reduce the amounts of salts and minerals, pure water is constantly being removed from the oceans through evaporation. The sum of these processes stabilizes the salinity of the oceans.

Ion name	Ion symbol	%
chloride	Cl^-	55
sodium	Na^+	31
sulfate	SO_4^{2-}	8
magnesium	Mg^{2+}	4
calcium	Ca^{2+}	1
potassium	K^+	1

Figure 24.10: *The six main ions in seawater.*

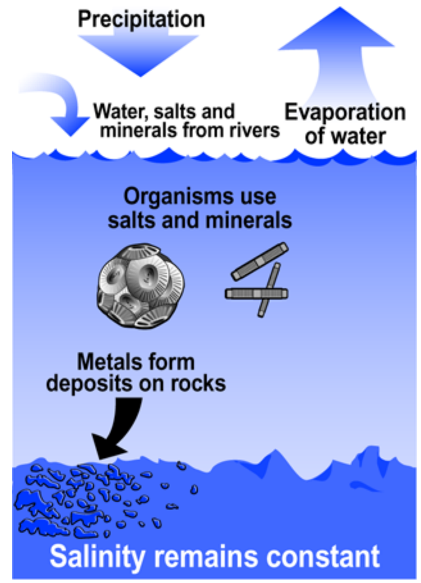


Figure 24.11: *The above diagram shows why the salinity of the oceans has remained relatively constant for 600 million years.*

The impact of increased carbon dioxide in the atmosphere

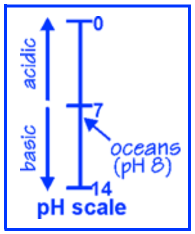
Seawater contains dissolved carbon dioxide

Some of the dissolved gases in the oceans such as oxygen (O_2) and carbon dioxide (CO_2) are produced and used by organisms in the ocean. For example, through the process of *respiration*, some organisms use O_2 and produce CO_2. These gases also enter the oceans from the atmosphere. Recall that when CO_2 dissolves in water it produces an acidic solution.

More CO_2 in the atmosphere could mean a more acidic ocean

CO_2 is a global warming gas. Global warming refers to the increase in the average temperature of Earth as a result of an increase in certain atmospheric, heat-trapping gases such as CO_2, methane (CH_4), and nitrous oxide (N_2O). Since the Industrial Revolution, the amount of CO_2 in the atmosphere has been steadily rising. As the concentration of this gas increases, more will dissolve in the oceans, which could cause the oceans to become more acidic.

Calcium carbonate buffers the ocean



The oceans contain a natural *buffer* called calcium carbonate ($CaCO_3$). A buffer is a substance that helps maintain the pH of a solution (pH scale shown at left). $CaCO_3$ is an ingredient in the shells of many microscopic marine organisms (Figure 24.12). When these organisms die, their shells settle to the bottom of the ocean floor. The $CaCO_3$ dissociates into calcium (Ca^{2+}) and carbonate (CO_3^{2-}) ions. The ocean floor releases carbonate ions as an “antacid” in response to acidic conditions. The carbonate ions neutralize the acid and keep the pH of the oceans at around pH 8 (Figure 24.16).

Rising CO_2 levels

Is there enough $CaCO_3$ to buffer the ocean if the levels of CO_2 continue to rise in the atmosphere? Presently, the amount of CO_2 in the atmosphere is 370 ppm. Scientists project that CO_2 levels will rise to 700 ppm by 2100. If there isn’t enough $CaCO_3$ to balance the increase in CO_2, the result could be an increase in the acidity of the oceans (decrease in pH).

The impact on life in the oceans

Recent scientific studies indicate that the oceans seem to be capable of handling a lot of dissolved CO_2 without experiencing a change in pH. However, in order to effectively buffer CO_2, carbonate ions are used up. This means that they are not as available to marine organisms that use these ions to make their shells. Because these organisms provide food for larger organisms, all life in the oceans could be affected by increased CO_2 levels.

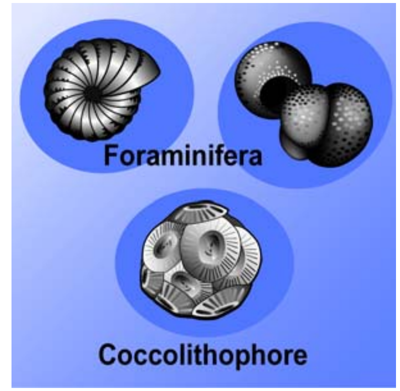


Figure 24.12: *Calcium carbonate is an ingredient in the shells of microscopic marine organisms like coccolithophores and foraminifera. When these organisms die, their shells settle to the bottom of the ocean floor.*

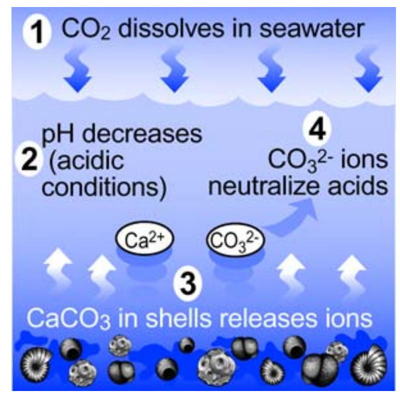


Figure 24.13: *Calcium carbonate on the ocean floor releases calcium and carbonate ions in response to acidic conditions. Carbonate ions neutralize the acid to stabilize the pH of the oceans.*

Pollution and the ocean food chain

Pollution in the oceans

Pollution is a big problem that affects the oceans. Pollution from the land enters the oceans through rivers and streams. Also, some waste materials are dumped directly into ocean water. Pollutants that enter the ocean include raw sewage, toxic chemicals (such as pesticides), heavy metals (such as mercury), and petroleum. When these substances enter the oceans, they *diffuse* (spread out) through large volumes of water and become less concentrated.

Marine organisms concentrate pollutants

The fact that pollutants become less concentrated as they spread out does not mean that they cannot harm marine organisms. In fact, some toxic pollutants become concentrated in the tissues of these organisms. High concentrations of toxins can cause problems such as slowed growth and development, decreased reproduction, reduced ability by plants to photosynthesize, and even death. To understand how this concentration occurs, you need to understand the marine *ecosystem* (the combination of living and nonliving factors present) and marine food chains.

Energy is transferred from organism to organism through a food chain.

The food chain

A **food chain** is a series of steps through which energy and nutrients are transferred, from organism to organism, in an ecosystem (Figure 24.14). The first step of a food chain consists of **producers**. Producers are plants and one-celled organisms that concentrate energy from the sun through photosynthesis. In a marine food chain, the most numerous producers are the *phytoplankton*—microscopic organisms that float near the surface. Most producers are very small.

Herbivores and carnivores

The next step on a food chain consists of **herbivores**. These organisms feed on producers. Herbivores are usually larger than producers, and exist in smaller numbers. There are many different species of herbivores in the oceans including “grazing” fish, snails, and organisms that “filter” phytoplankton out of the water. Many **carnivores**, the next step on a food chain, feed on herbivores. They are usually larger than herbivores and are less numerous. Because some carnivores eat other carnivores, there are several levels of these organisms on food chains. In marine food chains, carnivores include dolphins, sharks, and many species of fish.

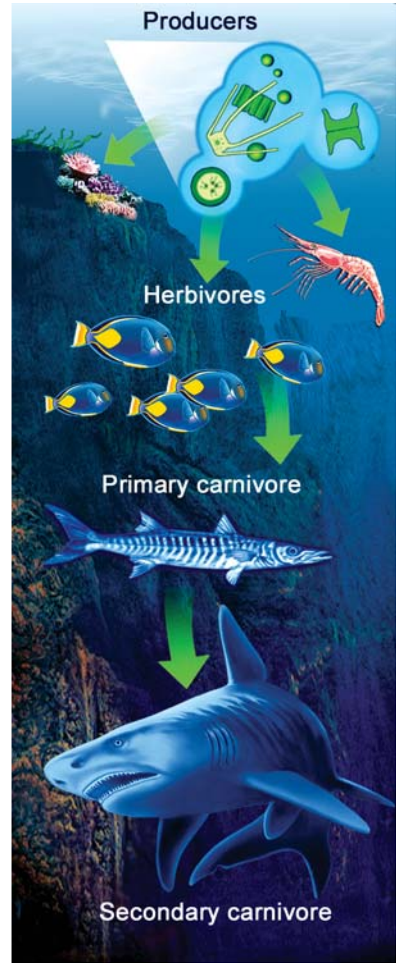


Figure 24.14: *A simple marine food chain. The arrows show the direction of energy and nutrient flow.*

The food chain as a pyramid

All living things need energy to survive. To obtain energy, herbivores eat plants and carnivores eat herbivores or other carnivores. Producers do not eat other organisms to obtain energy because they produce their own. A food chain (sometimes called a *food web* because it is more complex than a chain) can be represented as a *pyramid*, with producers forming the base, herbivores next, and carnivores at the top as shown in Figure 24.15. This arrangement represents how energy is lost in the food chain. It also explains how toxic pollutants travel through food chains and become more concentrated with each step.

Energy is lost at each level

Food chains, like other systems, obey the law of conservation of energy. So, how is energy lost at each level of a food chain? The pyramid in Figure 24.15 illustrates that the available food energy decreases moving up a food chain from producers to herbivores to carnivores. For example, an herbivore consumes large amounts of tiny, energy-rich producers. The herbivore uses the energy obtained from eating to continue to swim and search for more food. Some of the energy is also spent on growing, building a skeleton and body tissues, and reproducing. Some energy is lost as heat or waste products. When an herbivore is eaten by a carnivore, only its tissues are a source of energy. The carnivore cannot obtain energy from eating the skeleton, or recover the energy used by the herbivore for its daily activities. However, some of this lost energy can be put back in the ecosystem. *Decomposers*, like crabs, break down waste products, bones, and shells. They recycle some energy and nutrients back to the food chain. The animals that eat the decomposers also help recover some of the lost energy.

Toxic pollutants are concentrated at each level

The pyramid also shows why toxic pollutants, if present, can become highly concentrated in the tissues of top carnivores. As producers store energy, they also absorb small amounts of toxic pollutants in the water. Next, herbivores eat large numbers of producers to obtain enough energy. Because the toxins are soluble in fat, not water, they are stored in the fatty tissues of these animals and are not passed out of their bodies. When the primary carnivores eat many herbivores, they accumulate even higher levels of toxins in their tissues. Top carnivores, who prey on other carnivores, can accumulate dangerous levels of toxic pollutants. These toxins can sometimes be passed on to their young. Figure 24.16 shows how the amount of a toxic pollutant can multiply as it travels up the food chain.

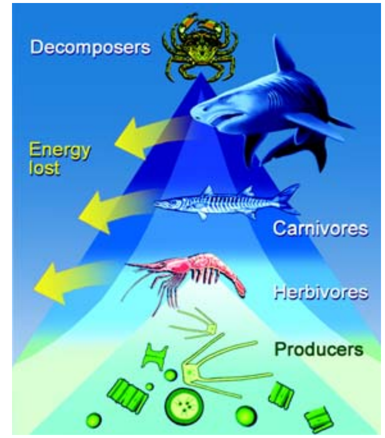


Figure 24.15: *The energy pyramid is a simple way to show how energy moves through an ecosystem.*

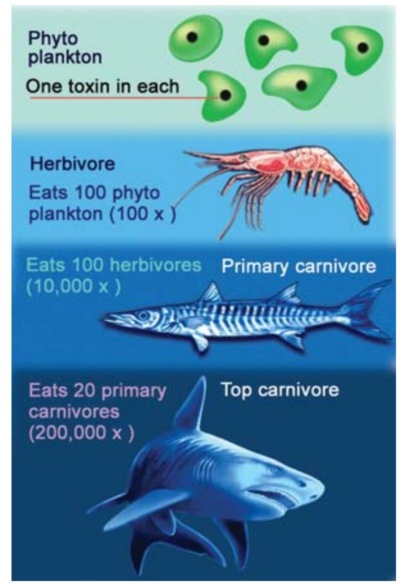


Figure 24.16: *How toxic pollutants become concentrated in the tissues of top carnivores.*

Chapter 24 Review

Vocabulary review

Match the following terms with the correct definition. There is one extra definition in the list that will not match any of the terms.

Set One

1. water cycle	a. The process by which water vapor transforms to liquid water
2. precipitation	b. The sun-driven process by which water is moved from place to place on Earth
3. condensation	c. The release of water vapor from plants
4. surface runoff	d. A general term for water (in liquid or frozen form) released from clouds
5. aquifer	e. An underground area of rock and sediment where groundwater concentrates
	f. Water, usually resulting from precipitation, that flows from land to surface water

Set Two

1. surface water	a. A measure of the clearness of water
2. biological oxygen demand	b. An artificial lake that is used as a main water supply by a community
3. dissolved oxygen	c. The concentration of oxygen in a body of water
4. turbidity	d. The amount of oxygen consumed by bacteria in a body of water over a certain time period
5. watershed	e. Natural formations of water including streams, rivers, ponds, and lakes
	f. The place where all a region's groundwater and surface runoff collect

Set Three

1. nitrogen oxides	a. One of the gases that cause acid rain
2. acid precipitation	b. One of the acidic components of acid rain
3. scrubbing	c. Rain, snow, or fog with a pH lower than 5.6
4. sulfuric acid	d. The use of lime to reduce the emissions from power plants that burn sulfur-containing coal
5. catalytic converter	e. A by-product of the reaction of lime with sulfur dioxide
	f. A car part that is designed to reduce polluting emissions from automobile exhaust

Set Four

1. salinity	a. An organism that eats herbivores and carnivores
2. herbivore	b. A single huge landmass that existed on Earth 254 million years ago
3. food chain	c. An organism that eats only producers
4. producer	d. A term that describes the environment and organisms that are associated with oceans
5. carnivore	e. An organism that stores energy from the sun
	f. A term that describes how much salt is dissolved in one kilogram of water

Concept review

1. Explain the difference between an aquifer and a reservoir. In your answer, explain where the water in each comes from.
2. Think about a water molecule in a lake. Referring to the water cycle, describe all the different things that might happen next to the molecule. How might it leave the lake? Where will it go?
3. List two dissolved substances that may be found in tap water. Explain the source of these.
4. What is the difference between hard water and soft water?
5. List two factors that you may measure to test the water quality of a pond. Explain why measuring these factors is important.
6. Explain why you would expect to find a lower level of dissolved oxygen in a warm lake than in a cold lake.
7. List the four gases formed from human activities that result in acid precipitation.
8. Identify the two most common acids found in acid rain.
9. What are the five big oceans on Earth?
10. Describe the composition of seawater. What are the six main ingredients in seawater?
11. Explain why warmer oceans usually have a higher salinity than cooler oceans.
12. Draw a simple marine food chain. Show the flow of energy in the food chain.
13. Why is energy lost in a food chain? Use the term *law of conservation of energy* in your answer.
14. Explain why toxic pollutants can become concentrated in the body tissues of top carnivores.

Problems

1. Design an original diagram to illustrate how water is distributed on Earth. Use the percentages provided in Table 24.1 to make your diagram.
2. The volume of the oceans is 1.37×10^9 km^3. One km^3 is equivalent to 1×10^{12} liters. Using these numbers, figure out how many liters of water are in the ocean. One Olympic swimming pool holds about 500,000 liters of water. How many Olympic-sized swimming pools could be filled by the oceans?
3. What does it mean to say that the pH of acid rain is 5.6?
4. You measure the oxygen content in a pond as 5 ppm. How many milligrams of oxygen are in one liter of this water? How many grams of oxygen are in one liter of water? Does this pond have a healthy amount of dissolved oxygen?
5. You measure the salinity of a seawater sample to be 33 ‰. How many grams of salt are in this sample if the mass is 2.5 kilograms?
6. What is the salinity of a sample that you know contains 1800 grams of water and 20 grams of salt?

Applying your knowledge

1. What is the history of your community's water supply or water treatment? Go to the library to read your local newspapers or magazines from the past and present. Look for stories about the water supply or water treatment. Write a one- or two-page report about your findings.

2. Two years ago, you joined a project to study the water quality of a local pond. During the second spring, you notice that there are not as many tadpoles as there were the previous year. You want to know if the number of tadpoles is related to the pH of the pond. The records that document the water quality and frog population started 10 years ago. Describe the steps you would take to determine whether a change in pH of the pond water is affecting the population of frogs.

3. Gases that cause acid rain are all end-products of chemical reactions. These reactions are useful for our economy in that they are involved in keeping cars and industry going. However, do the economic benefits of keeping cars and industry going outweigh the economic impact of acid rain? Research this issue in your library or on the Internet and prepare a short report or presentation on the topic.

4. The Environmental Protection Agency (EPA) recommends setting limits on the amount of certain types of fish that a person consumes each month. Some marine species with recommended limits include swordfish, shark, and barracuda.
   a. Why do you think there are limits set on only certain types of fish? Why would some species of fish be more safe to eat than others?
   b. EPA limits are even more strict for pregnant women. Explain why consuming lots of swordfish, shark, or barracuda would not be safe for a pregnant woman.

5. Many businesses, schools, and homes use the services of bottled-water companies. For a monthly fee, these companies provide drinking water and dispensers. Bottled-water services cost much more than tap water. Why do people pay for such a service? In answering this question, you will make *inferences* based on information that you collect. An inference is a statement that can be made based on observations and known facts. Inferences can be used to make a hypothesis that can be tested in an experiment.

   Collecting your data:

   a. Interview three people who use the services of a bottled-water company. Ask them why they use the service.
   b. Look in your local phone book to find advertisements for three bottled-water services. Call each company and ask them why they recommend using bottled water in your area.
   c. Perform an Internet search for information about bottled water and tap water. For example, search according to the phrase "bottled water versus tap water." Make a table that lists three reasons you *would* use a water service (pros) and three reasons you *would not* use a bottled water service (cons).
   d. Examine the data from parts 7 (a-c). Based on your data, make three inferences as to why people might purchase bottled-water services.
   e. Based on your data, make at least one inference as to why someone might *not* choose to use a bottled-water service.