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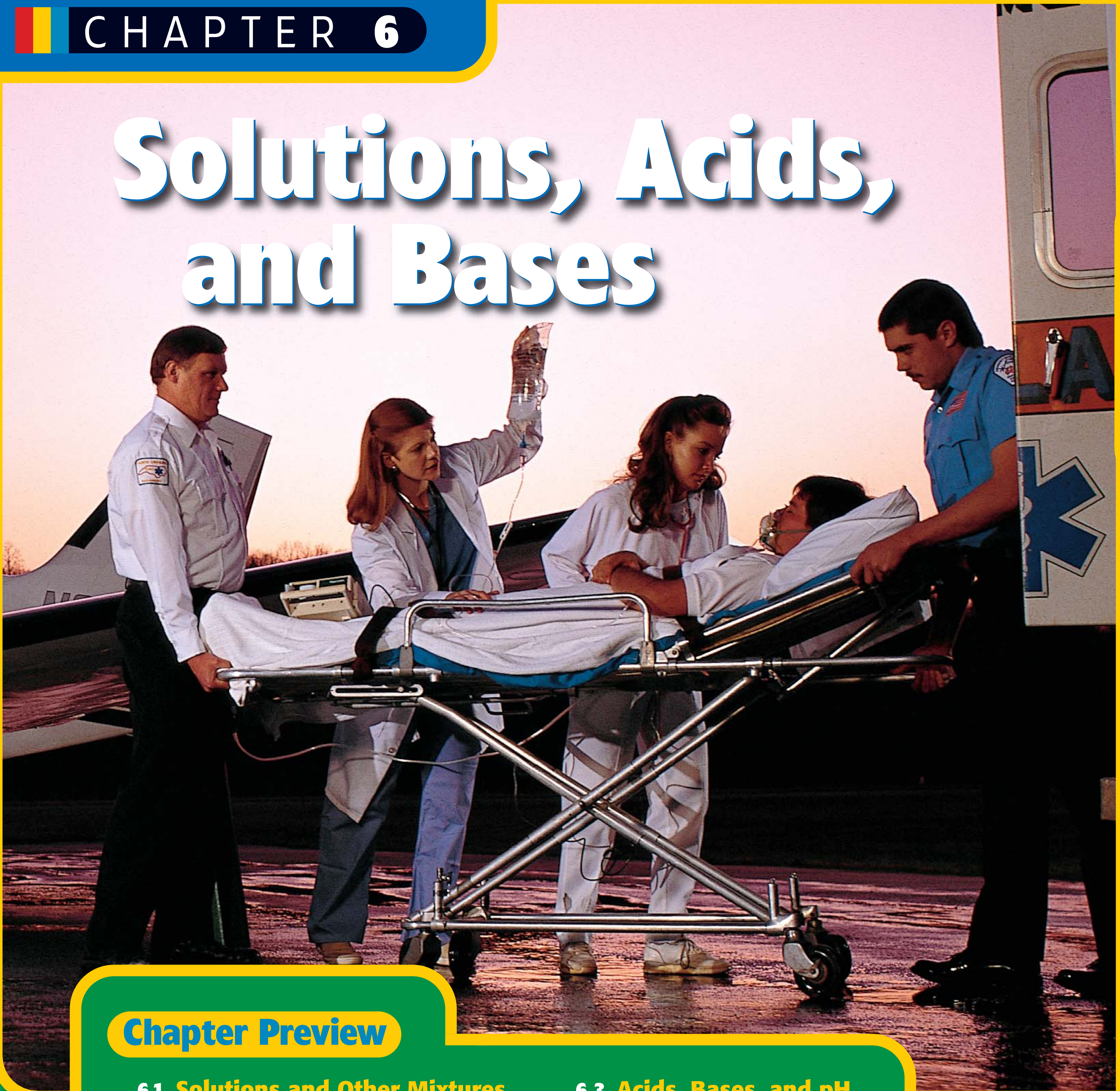
CHAPTER 6

Solutions, Acids, and Bases



Chapter Preview

Many solutions can be life-saving. Some solutions replace vital fluids in your body if you are injured, while others protect you from potentially deadly diseases.

Focus ACTIVITY

Background Paramedics rush to the scene of an accident. Someone has been injured, and the person's blood pressure has become dangerously low. Paramedics pump a *saline solution,* a mixture of water and sodium chloride that is similar to blood, into the person's veins. This mixture maintains the blood pressure that is needed to keep the person alive on the way to the hospital.

Throughout your life, you have received many shots, or vaccinations. These shots have helped protect you from many diseases. Surprisingly, vaccines are mixtures that have a tiny amount or some parts of the disease-causing bacterium or virus you are trying to protect yourself from. The shot you get is harmless because the bacterium or virus contained in it is dead, or inactivated. But the shot keeps you from getting the disease. That's because if your body "sees" this harmful bacterium or virus again, your body is able to recognize it and fight it.

Activity 1 Look up the word *saline* in the dictionary. Which group of elements in the periodic table form ionic compounds that can be described by the word *saline*? Explain how this applies to sodium chloride.

Activity 2 Substances must be added to vaccines to make the disease-causing bacterium or virus they contain harmless. Added substances also keep the vaccine from spoiling or becoming less effective over time. Use the Internet to find out which substances are commonly added to vaccines for these reasons.

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6.1

Solutions and Other Mixtures

KEY TERMS
suspension
colloid
emulsion
solution
solute
solvent

OBJECTIVES

- Distinguish between homogeneous mixtures and heterogeneous mixtures.
- Compare and contrast the properties of solutions, colloids, and suspensions.
- Identify ways to separate different kinds of mixtures.

Any sample of matter is either a pure substance or a mixture of pure substances. Fruit salad is a mixture because it is a blend of different kinds of fruit. But some mixtures look like they are pure substances. For example, salt water looks the same as pure water. Air is a mixture of several different gases, but you can't tell that just by looking.

Heterogeneous Mixtures

A heterogeneous mixture, such as fruit salad, is not the same throughout. The quantity of each kind of fruit varies with each spoonful, as shown in **Figure 6-1.** Similarly, if you compared two shovelfuls of dirt from a garden, they would not be exactly the same. Each shovelful would have a different mixture of rock, sand, clay, and decayed matter.

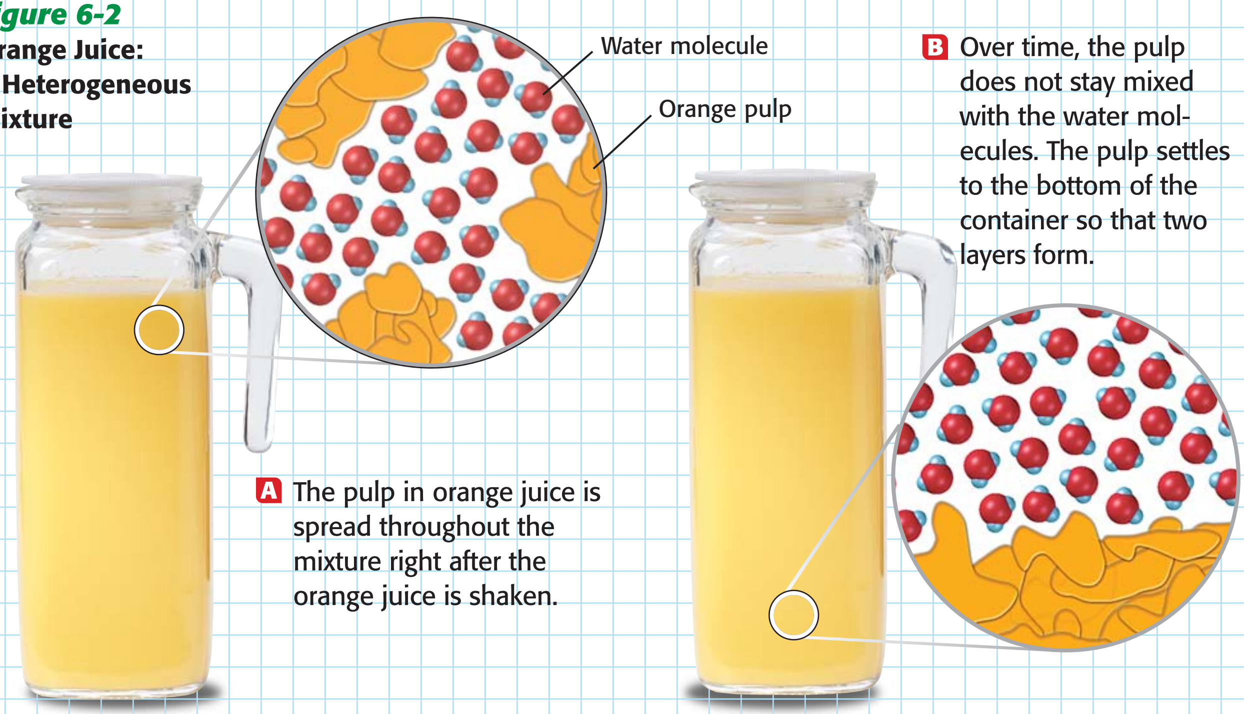
Particles in a suspension are large and eventually settle out

Have you ever forgotten to shake the orange juice carton before pouring yourself a glass of juice? The juice probably tasted watery. This is because most brands of orange juice are **suspensions** of orange pulp in orange juice, which is mostly water. If the carton is not shaken, the top layer of liquid in the carton is mostly water because all the pulp has settled to the bottom.

suspension a mixture that looks uniform when stirred or shaken that separates into different layers when it is no longer agitated

Figure 6-1
Fruit salad is a heterogeneous mixture. Each spoonful has a different composition of fruit because the fruits are not distributed evenly throughout the salad.

Figure 6-2
Orange Juice: A Heterogeneous Mixture



A The pulp in orange juice is spread throughout the mixture right after the orange juice is shaken.

B Over time, the pulp does not stay mixed with the water molecules. The pulp settles to the bottom of the container so that two layers form.

Settled juice is clearly a heterogeneous mixture because the liquid near the top of the container is not the same as the liquid near the bottom. Shaking the container mixes the pulp and water, as shown in **Figure 6-2A.** But the pulp pieces are big enough that they will eventually settle out again, as shown in **Figure 6-2B.** Particles in suspensions are usually larger than the tip of a sharpened pencil, which has a diameter of about 1000 nm.

Not all orange juices available in the grocery store contain pulp. That's because the pulp has been separated from the mixture. Particles in suspensions are usually large enough that they can be filtered out of the mixture. For example, a filter made of porous paper can be used to catch the suspended pulp in orange juice. That is, the pulp stays behind in the filter while tiny water molecules pass through the filter easily.

Particles in a colloid are smaller and do not settle out

Dessert gelatin is another heterogeneous mixture. It is a gel-like substance made of small pieces of solid protein spread throughout water. Gelatin is a **colloid.** There are two important differences between the particles in colloids and those in suspensions. The particles in colloids are much smaller than those in suspensions—ranging from only 1 to 100 nm in diameter. And because the particles in colloids are so small, they do not settle to the bottom of the mixture to form a different layer. Instead, the particles stay dispersed throughout the mixture.

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colloid a mixture of very tiny particles of pure substances that are dispersed in another substance but do not settle out of the substance

Figure 6-3
Because the spout of this special cup is near the bottom, the liquid in the bottom layer (which is denser) is poured out first.

Many familiar substances are colloids. Egg white, paint, and blood are colloids of solids in liquids. Whipped cream is made by dispersing a gas in a liquid, while marshmallows are made by dispersing a gas in a solid. Fog is made of small droplets of water dispersed in air, and smoke is made of very tiny solid particles dispersed in air.

Heterogeneous liquid-liquid mixtures

When oil is mixed with vinegar to make salad dressing, two layers form. That's because the two liquids are immiscible, meaning they don't mix. Eventually, the oil, which is less dense, floats on top of the vinegar, which is denser. You have to shake the mixture to be sure that the liquids mix so that you get a blend of both vinegar and oil on your salad.

One way to separate two immiscible liquids is to carefully pour the less dense liquid off the top. You can also separate immiscible liquids by using a special cup, like the one shown in **Figure 6-3.** Some health-conscious cooks, for instance, use this kind of cup to separate fat from meat juices. The desired meat juices settle to the bottom of the cup and are poured back onto the meat. The fat, which is less dense, stays behind in the cup.

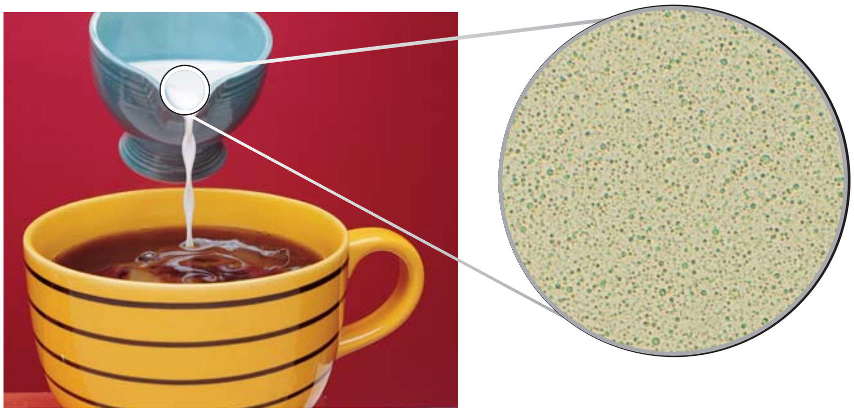
Some immiscible liquids can mix in emulsions

emulsion any mixture of immiscible liquids in which the liquids are spread throughout one another

Mayonnaise is a mixture of tiny droplets of oil suspended in vinegar. Unlike vinegar-and-oil salad dressings, which separate into two layers, the vinegar and oil in mayonnaise stay mixed. That's because mayonnaise has another ingredient that keeps the oil and vinegar together—egg yolk. Egg yolk coats the oil droplets, keeping them from joining to form a separate layer. Mayonnaise is an **emulsion,** a colloid in which liquids that normally do not mix are spread throughout each other.

Like other colloids, emulsions have particles so small that they may appear to be uniform. But a closer look shows that they are not. Cream has only one layer, so it looks like a single substance. Cream is really a mixture of oily fats called *lipids,* proteins, and carbohydrates dispersed in water. The lipid droplets are coated with a protein. The protein is an *emulsifier* that keeps the lipid droplets dispersed in the water so that they can spread throughout the entire mixture, as shown in **Figure 6-4.**

Figure 6-4
Cream looks like a single substance. But when cream is magnified, you can see that it is really an emulsion of droplets of fat, or lipids, dispersed in water.



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Quick ACTIVITY

Making Butter

As you have learned, cream is a lipid-in-water emulsion. Churning or shaking cream causes lipid droplets to stick to one another, forming butter. You can make your own butter by doing the following:

1. Pour 250 mL (about 1/2 pt) of heavy cream into an empty 500 mL (about 1 pt) container.
2. Add a clean marble, and seal the container tightly so that it does not leak.
3. Take turns shaking the container. When the cream becomes very thick, you will no longer hear the marble moving.
4. Open the container to look at the substance that formed. Record your observations.
5. If the butter is made of joined lipid droplets, what must make up most of the liquid that is left behind?

Homogeneous Mixtures

Homogeneous mixtures not only look uniform, they *are* uniform. Salt water is an example of a homogeneous mixture. If you add table salt to a glass of water and stir, the mixture soon looks like pure water. The mixture looks uniform even when you examine it under a microscope. That's because the components of the mixture are too small to be seen. The mixture looks like water, but it is really made of sodium ions and chloride ions surrounded by water molecules, as shown in **Figure 6-5A.**

When salt and water are mixed, no chemical reaction occurs. For this reason, it is easy to separate the two substances by evaporating, or boiling away, the water, as shown in **Figure 6-5B.** Once all the water has boiled away, you are left with only salt, as shown in **Figure 6-5C.**

PHYSICAL SCIENCE INTERACTIVE TUTOR

Disc One, Module 8:
Solutions
Use the Interactive Tutor to learn more about this topic.

Salt Water: A Homogeneous Mixture

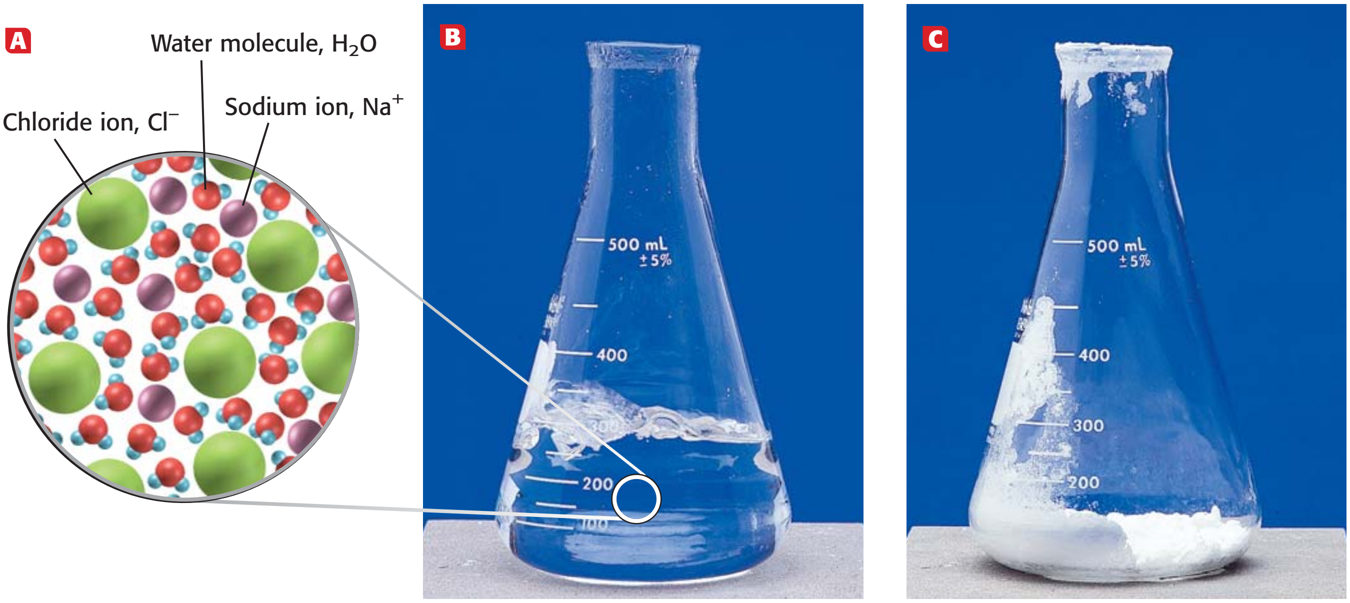

Figure 6-5
(A) Dissolving table salt in water makes a homogeneous mixture. The salt water has the same chemical makeup throughout. (B) If you heat the mixture to above 100°C, the water boils and begins to leave a salt residue on the sides of the container. (C) When all of the water has completely evaporated, you are left with only salt.

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Solutions are homogeneous mixtures

Figure 6-6 shows that when you add aquarium salt to water and stir, the solid seems to disappear. What really happens is the solid dissolves in water to form a **solution.** In this particular solution, aquarium salt is the **solute,** the substance that dissolves. Water is the **solvent,** the substance in which the solute dissolves. When a solute has dissolved completely in a solution, the dissolved particles are so small that you can't see them.

Like the water in the aquarium shown in **Figure 6-6,** many common solutions are solids dissolved in liquids. However, solutes and solvents can be in any state. For instance, vinegar is a solution of acetic acid, a liquid, dissolved in water, another liquid. And a tank of air used by a scuba diver can be thought of as a solution of oxygen and several other gases.

- **solution** a homogeneous mixture of two or more substances uniformly spread throughout a single phase
- **solute** the substance that dissolves in a solution
- **solvent** the substance that dissolves the solute to make a solution

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Miscible liquids mix to form solutions

Two or more liquids that form a single layer when mixed are said to be miscible. Sometimes when liquids mix, the resulting solution is useful. Examples are when water mixes with isopropanol to make a solution of rubbing alcohol and when acetic acid mixes with water to make vinegar. Other times, however, you might want to separate miscible liquids. For instance, chemists often have to separate miscible liquids when purifying substances in the laboratory. Because miscible liquids form solutions and do not separate into layers, they are not as easy to separate as immiscible liquids are. One way to separate miscible liquids is by a process called *distillation.*

Figure 6-6
To make a salt-water solution for her tropical fish, this girl is dissolving aquarium salt (a solute) in water (a solvent).

Separating miscible liquids is a challenging task. A distillation is the easiest way to separate some miscible liquids. A mixture of methanol and water could be separated by a distillation because the boiling points of the two liquids are sufficiently different. (Methanol boils at 64.5°C and water boils at 100.0°C.) To perform the distillation, you would first need to heat the entire mixture until it started boiling. The liquid with the lower boiling point (in this case, methanol) would vaporize first. Some of the water would also vaporize, but most of the water would stay behind.

If two miscible liquids have similar boiling points, it can be even harder to separate them by a distillation. Any time it is hard to separate the components of a mixture, a technique called *chromatography* can be useful.

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REAL WORLD APPLICATIONS

Chromatography Chromatography is often used to separate mixtures that can't be separated by simple methods. The figure at right shows how paper chromatography can be used to separate colored dyes in three different samples of black ink.

First ink marks are made on absorbent paper. Then the paper is put in a jar holding a small volume of solvent. The solvent travels upward through the paper, carrying the ink with it. The finished *chromatogram* reveals which dyes make up each of the inks.

Each dye has a different chemical structure. Dyes with structures more like that of the paper than that of the solvent stick to the paper and travel slower. Dyes with structures more like that of the solvent move upward with the solvent and therefore travel farther.

Applying Information

1. Does the blue dye in each ink sample have a structure more like that of the paper or the solvent? Why?
2. How would the result differ if the inks were made from a single dye instead of a mixture of several dyes?

SECTION 6.1 REVIEW

SUMMARY

- A heterogeneous mixture is a nonuniform blend of two or more substances.
- The particles in a suspension soon settle out of the mixture.
- The dispersed particles in a colloid are smaller and do not settle out.
- An emulsion is a colloid in which liquids that normally do not mix are spread throughout one another.
- A homogeneous mixture, or solution, is a uniform blend of two or more substances.
- In a solution, the solute is dissolved in the solvent.

CHECK YOUR UNDERSTANDING

1. **Classify** the following mixtures as homogeneous or heterogeneous:
   a. orange juice without pulp
   b. sweat
   c. cinnamon sugar
   d. dirt
2. **Explain** what would happen if coffee were brewed without a filter. What does the filter do?
3. **Describe** one reason smoke can irritate your eyes, while fog does not. (**Hint:** What is smoke a mixture of?)
4. **Identify** the solute and solvent in a solution containing silver nitrate, an ingredient in some hair dyes, and water.
5. **Arrange** the following mixtures in order of increasing particle size: muddy water (settles after a few hours), sugar water (does not settle), and sand in water (settles quickly).
6. **Explain** why a distillation would not separate a mixture of the miscible liquids formic acid, which boils at 100.7°C, and water, which boils at 100.0°C.
7. **Creative Thinking** Imagine as you are drinking lemonade outside, that some dirt blows into your glass. Write a plan for an experiment to separate the dirt from your lemonade. How could you separate the sugar and other solutes from the water?

WRITING SKILL

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6.2

Dissolving and Solubility

KEY TERMS

concentration
unsaturated solution
saturated solution
solubility
supersaturated solution
molarity

OBJECTIVES

- Describe how a substance dissolves in terms of its solubility, molecular motion, and solute-solvent interactions.
- Identify several factors that affect the rate at which a substance dissolves.
- Relate the structure of water to its ability to dissolve many different substances.
- Distinguish between saturated, unsaturated, and supersaturated solutions.

Suppose you and a friend are drinking iced tea. You add one spoonful of loose sugar to your glass of tea and stir. Soon all the sugar dissolves completely. Your friend adds a sugar cube to her tea. Even though your friend has been stirring for some time, a lump of sugar is still at the bottom of your friend's glass. Why does the sugar cube take longer to dissolve?

The Dissolving Process

According to the kinetic theory, the water molecules in each glass of tea are always moving. Some moving water molecules collide with sugar crystals. When this happens, energy is transferred to the sugar molecules at the surface of the crystal.

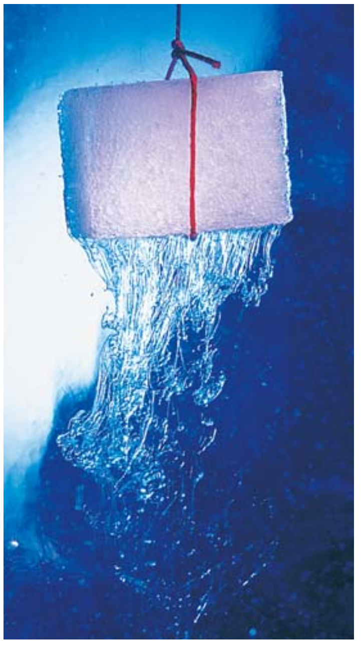

Figure 6-7
Sugar crystals dissolve in water when water molecules bump into sugar molecules at the surface of the crystals. These sugar molecules break away, dissolve, and spread throughout the solution.

Figure 6-7 shows that this energy, as well as the interaction between water and sugar molecules, causes sugar molecules at the surface of the crystal to break away from the rest of the sugar. These sugar molecules dissolve and move about randomly in the water.

Every time a layer of sugar molecules leaves the crystal, another layer of sugar molecules is uncovered. Sugar molecules break away from the crystal layer by layer in this way until the crystal completely dissolves.

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Solutes with a larger surface area dissolve faster

A substance in small pieces dissolves faster than the same substance in big pieces. When a solid is whole, most molecules are buried within it. Breaking the solid uncovers molecules along the break. The broken solid has more surface area, which leads to more solute-solvent collisions. Therefore, the solid dissolves faster.

Loose sugar has much more surface area than a sugar cube. That's why loose sugar dissolves faster. **Figure 6-8** shows how chewing a vitamin C tablet increases its surface area. This causes the vitamin to dissolve faster than it could if the vitamin were contained in a pill that was swallowed whole.

Stirring or shaking a solution helps the solute dissolve faster

If you pour sugar in a glass of water and let it sit without stirring, it will take a long time for the sugar to dissolve completely. That's because sugar is at the bottom of the glass surrounded by dissolved sugar molecules, as shown in **Figure 6-9A.** Dissolved sugar molecules will slowly *diffuse,* or spread out, throughout the entire solution. But until that happens, they keep water molecules from reaching the sugar that has not yet dissolved.

Stirring or shaking the solution moves the dissolved sugar away from the sugar crystals. Now more water molecules can interact with the solid, as shown in **Figure 6-9B,** so the sugar crystals dissolve faster.

Figure 6-8
Chewing a vitamin C tablet exposes molecules inside the tablet. More molecules can then collide with water molecules, so the tablet dissolves faster.

How Stirring Affects the Dissolving Process

Figure 6-9

A Without stirring, crystals of table sugar are surrounded by dissolved sugar molecules. Water molecules collide with these molecules instead of with the undissolved sugar.

B Stirring moves the dissolved sugar molecules out of the way, so more water molecules can collide with the undissolved sugar.

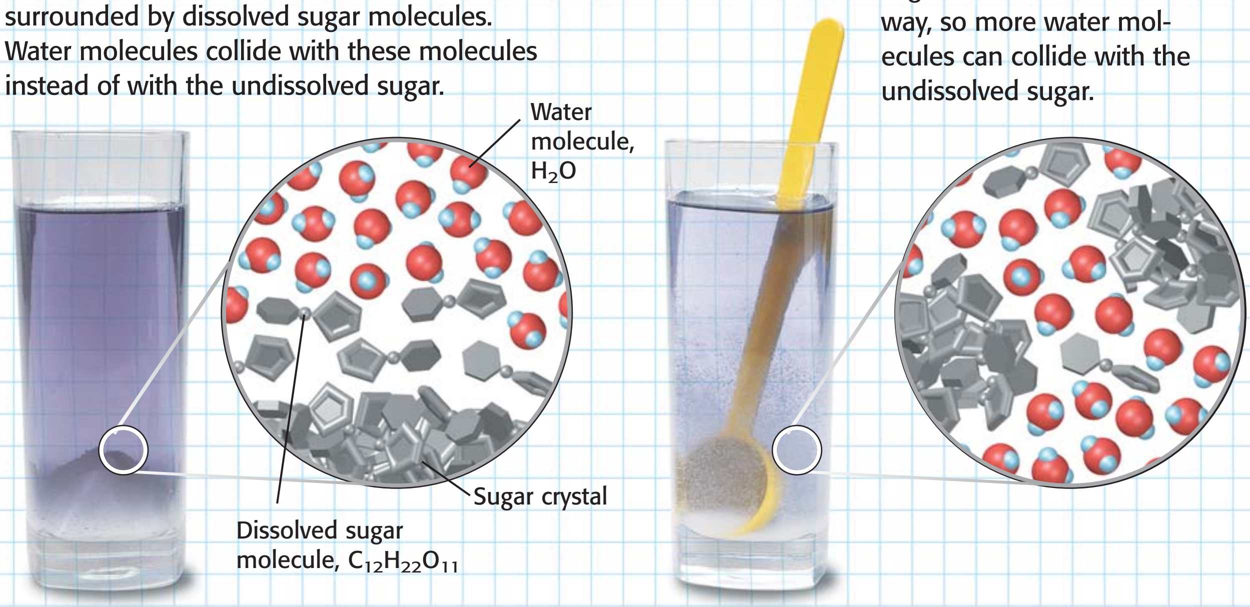

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Figure 6-10
Olive oil and water form two layers when they are mixed. That's because olive oil is *insoluble* in water.

Solutes dissolve faster when the solvent is hot

Sugar and other solutes dissolve faster in hot water than in cold water. Remember that as a substance is heated, its particles move faster. As a result, there are more collisions between particles. These collisions also transfer more energy.

Many people like to add salt to the water they boil to cook pasta. In hot water, salt crystals are hit more often by water molecules, and these water molecules have more energy. So it is more likely that these water molecules will strip off sodium ions and chloride ions when they hit salt crystals.

Not every substance dissolves

When you put table salt, or sodium chloride, in water and stir, it seems to disappear. Yet you know it is still there because the water tastes salty. Table salt seems to disappear because it dissolves in water. Table salt and other substances that dissolve in water are described as being *soluble* in water. The olive oil shown in **Figure 6-10** is an example of a substance that is *insoluble* in water, meaning that it does not dissolve. It is also possible to have substances that are only *partly soluble* in water.

Water: A Common Solvent

Two-thirds of Earth's surface is water. The liquids you drink are mostly water, and so is three-fourths of your body weight. There are many substances that can dissolve in water. For this reason, water is sometimes called the universal solvent.

The structure of water helps it dissolve charged particles

To understand what makes water such a good solvent, consider the structure of a single water molecule. Think also about the attractions between water molecules that you learned about in Chapter 4. You have already seen how the oxygen atom on one water molecule is attracted to a hydrogen atom on a neighboring water molecule. These attractions occur because of charges.

Water is not an ionic compound, but it is *polar.* This means the shared electrons of each water molecule are not evenly spread throughout the molecule. The oxygen atom attracts shared electrons more strongly than the hydrogen atoms in a water molecule. As a result, the oxygen atom has a partial negative charge, and each hydrogen atom has a partial positive charge, as shown in **Figure 6-11.** To show that a charge is partial, the lowercase Greek letter delta (δ) is used. You can see from **Figure 6-11** that a partial positive charge is written as δ+, and a partial negative charge is written as δ–.

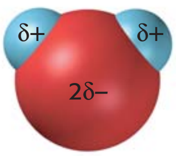
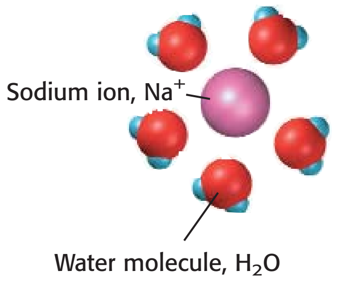
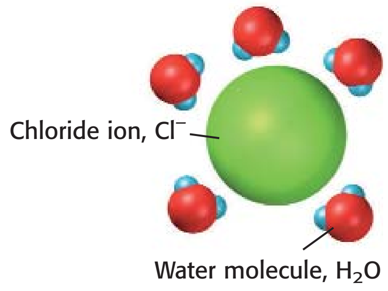


Figure 6-11
The oxygen atom in a water molecule is partially negative, and each hydrogen atom is partially positive. Note that the sum of these partial charges is equal to zero.

Figure 6-12



A When sodium chloride dissolves in water, positively charged sodium ions are attracted to the partially negative oxygen atoms of water.



B Negatively charged chloride ions are attracted to the partially positive hydrogen atoms of water.

Figure 6-12 shows why sodium chloride dissolves easily in water. Sodium ions are attracted to the partially negative oxygen atom, and chloride ions are attracted to the partially positive hydrogen atoms. This interaction between ions and water molecules pulls the ions away from the solid. Substances made of molecules that dissolve in water also have partial charges that interact with water molecules. However, these substances exist as single molecules floating in solution, not as ions, when they dissolve.

"Like dissolves like"

Water can dissolve many substances, but there are many others it can't dissolve. For example, olive oil doesn't dissolve in water, and neither does gasoline. When deciding whether it is likely one substance will dissolve in another substance, chemists often use the rule "like dissolves like."

Methanol is soluble in water because both liquids are polar. They both have partially charged atoms that are attracted to one another. Gasoline is not soluble in water because its components are *nonpolar,* meaning their molecules do not have partial charges on opposite ends, like water molecules have. Substances like gasoline are soluble in oils and in other nonpolar substances.

Quick ACTIVITY

"Like dissolves like"

Tincture of iodine is a solution of iodine in ethanol. It is used to clean cuts and scrapes so that they do not become infected. Iodine, I_2, is a somewhat *nonpolar* element. Ethanol, C_2H_5OH, is a somewhat *polar* compound. In this activity, you will determine whether water or ethanol is more polar.

1. Dip a cotton swab in tincture of iodine, and make two small spots on the palm of your hand. The ethanol will evaporate and make your palm feel cool. The spots that remain are iodine.
2. Dip a second cotton swab in water, and wash one of the iodine spots with it. What happens to the iodine spot?
3. Dip a third cotton swab in ethanol, and wash the other iodine spot with it. What happens to the iodine spot?
4. Did water or ethanol dissolve the iodine spot better? Is water more polar or less polar than ethanol? Write a paragraph explaining your reasoning.

WRITING SKILL

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Concentration

You can make a solution by dissolving sodium acetate in water. But how much sodium acetate do you need to add? And to what volume of water? Solutions can have different **concentrations,** depending on how much solute and solvent are present.

concentration the quantity of solute dissolved in a given quantity of solution

If you are not concerned about the exact concentration of a solution, you can express concentration less specifically. If a small quantity of solute is dissolved in a large volume of solvent, the resulting solution is said to be *dilute*. A *concentrated* solution, however, has a large quantity of dissolved solute.

Unsaturated solutions can dissolve more solute

An **unsaturated solution** of sodium acetate has many more water molecules than dissolved sodium ions and acetate ions, as shown in **Figure 6-13A.** A solution is unsaturated as long as it is able to dissolve more solute.

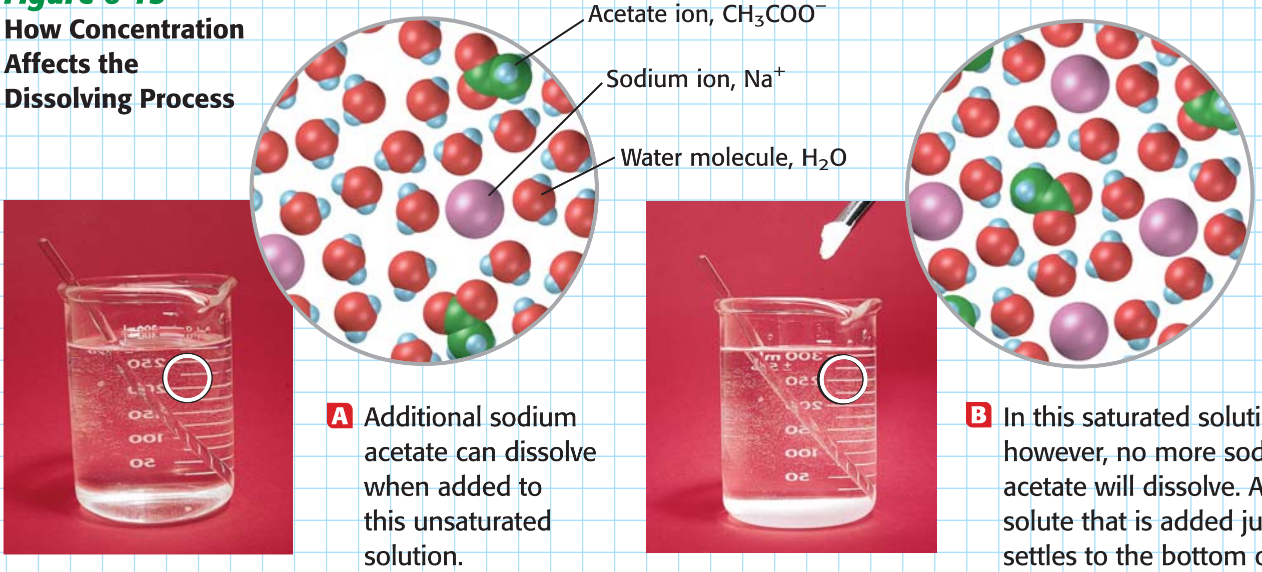
unsaturated solution a solution that is able to dissolve more solute

At some point, most solutions become saturated with solute

If you keep adding sodium acetate to the solution, the added sodium acetate dissolves until the solution becomes saturated, as shown in **Figure 6-13B.** A **saturated solution** is in equilibrium. This means that if any more solute dissolves, an equal amount comes out of solution. If you add more solute, it just settles to the bottom of the container. No matter how much you stir, no more sodium acetate will dissolve in a solution that is already saturated with solute.

saturated solution a solution that cannot dissolve any more solute at the given conditions

Figure 6-13
How Concentration Affects the Dissolving Process



A Additional sodium acetate can dissolve when added to this unsaturated solution.

B In this saturated solution, however, no more sodium acetate will dissolve. Any solute that is added just settles to the bottom of the beaker.

A saturated solution contains the greatest quantity of solute that will dissolve in a given quantity of solvent. Exactly how much solute will dissolve to make the solution saturated depends on the solute's **solubility** in the solvent as well as the solvent's temperature. At 20°C, you can dissolve a maximum of 203.9 g of table sugar in 100.0 g of water. At the same temperature, you can dissolve a maximum of 46.4 g of sodium acetate in 100.0 g of water. Although a much greater mass of table sugar will dissolve in water, the molar amounts of table sugar and sodium acetate that will dissolve in 100.0 g of water is nearly equal.

Not all solutions become saturated, though. Some substances can dissolve in each other in any proportion. A methanol-water solution, for example, never becomes saturated. Whether you add a small volume of methanol or a very large volume of methanol to water, it will always dissolve.

solubility the greatest quantity of a solute that will dissolve in a given quantity of solvent to produce a saturated solution

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Heating a saturated solution usually allows you to dissolve even more solute

The solubility of many solutes, such as sodium acetate, increases as the temperature of the solution increases. If you heat a solution that is already saturated with dissolved sodium acetate, even more sodium acetate can dissolve. If you keep adding sodium acetate, it will keep dissolving until the solution becomes saturated at the higher temperature.

supersaturated solution a solution holding more dissolved solute than is specified by its solubility at a given temperature

But something interesting happens when the solution cools down again. At the cooler temperature, this **supersaturated solution** holds more solute than it normally can. Supersaturated solutions are unstable systems because the solute's solubility is exceeded for a short time. Adding a small crystal of sodium acetate provides the surface that the excess solute needs to begin crystallizing, as shown in **Figure 6-14.** The solute keeps crystallizing out of the solution until the solution is saturated at the cooler temperature.

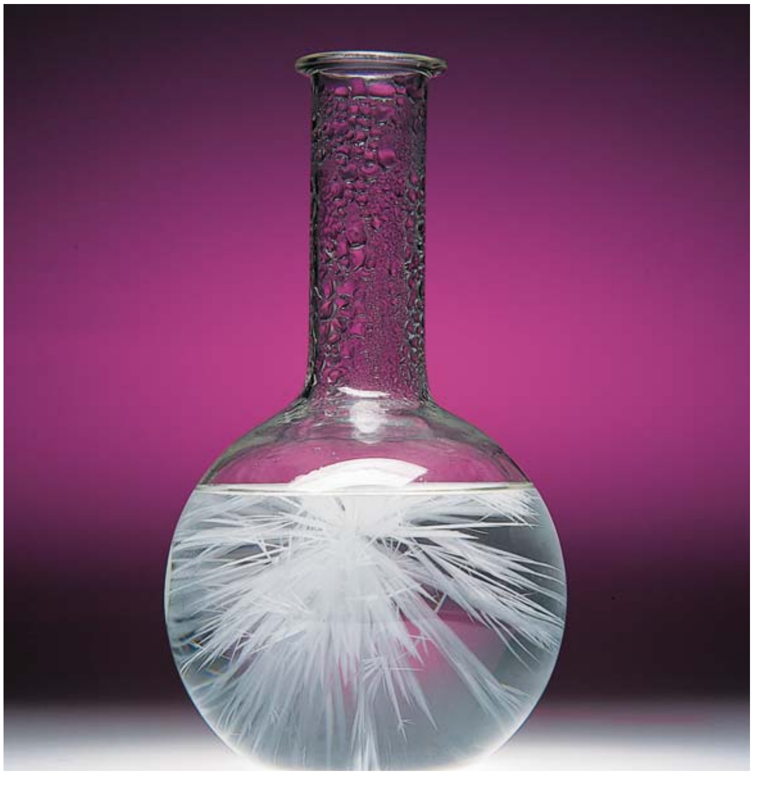


Figure 6-14
Adding a single crystal of sodium acetate to this supersaturated solution causes the excess sodium acetate to quickly crystallize out of the solution.

Measuring concentration precisely

Sometimes describing a solution as being unsaturated, saturated, or supersaturated is too general. Often you need to know exactly how much solute is dissolved in a solution. There are many different ways to express concentration. Which one is used depends on what the solution is being used for and how concentrated it is.

You have already seen that the solubility of a substance can be expressed as grams of solute per 100 g of solvent. Concentration can also be expressed as a mass percent, or grams of solute per 100 g of solution. A 5.0 percent solution of sodium chloride is made by dissolving 5.0 g of sodium chloride in 95 g of water. Concentration can also be expressed in units of **molarity.**

molarity a concentration unit of a solution that expresses moles of solute dissolved per liter of solution

$$\text{Molarity} = \frac{\text{moles of solute}}{\text{liters of solution}}, \text{ or } \text{M} = \frac{\text{mol}}{\text{L}}$$

A 1.0 M (pronounced "one *molar*") solution of sodium chloride contains 1.0 mol of dissolved NaCl for every 1.0 L of solution. Molarity is the preferred concentration unit for many chemists because it expresses the molar amount of solute present.

SECTION 6.2 REVIEW

SUMMARY

- The larger the surface area a solute has, the faster it will dissolve.
- Stirring or shaking the solution dissolves solutes faster.
- Heating a solvent also dissolves solutes faster.
- So many substances are soluble in water that it is sometimes called the universal solvent.
- An unsaturated solution can dissolve more solute.
- A saturated solution cannot dissolve any more solute.
- A solute's solubility is exceeded in a supersaturated solution.

CHECK YOUR UNDERSTANDING

1. **Decide** if hexane, C_6H_{14}, is likely to be soluble in water.
2. **Propose** a way to determine whether a salt-water solution is unsaturated, saturated, or supersaturated.
3. **Explain** why chewable medication is usually faster-acting in your body than the same medication enclosed in a pill.
4. **Describe** the steps you would take to make hot chocolate as quickly as possible using cold milk and a chocolate candy bar.
5. **Determine** whether your sweat would evaporate more quickly if there were 92 percent humidity or 37 percent humidity. (**Hint:** When there is 100 percent humidity, the air is totally saturated with dissolved water vapor.)
6. **Describe** why water can dissolve some ionic compounds, like NH_4Cl, as well as some nonionic compounds, like methanol.
7. **Determine** what mass of potassium iodide should be dissolved in 200 g of water to make a 3.0 percent solution.
8. **Critical Thinking** A home economics teacher instructs the class to continue adding table sugar to their homemade lemonade until the sugar stops dissolving. Write a paragraph describing how your lemonade would taste if you followed these directions exactly. What did the teacher really mean?

WRITING SKILL

Back

6.3

Acids, Bases, and pH

OBJECTIVES

- Compare and contrast acids and bases.
- Relate the pH of a solution to the concentration and strength of dissolved acid or base.
- Identify the products of neutralization reactions.

KEY TERMS

acid
indicator
base
pH
neutralization reaction
salt

Does the thought of eating a lemon make your mouth pucker? You know what to expect: that sour, piercing taste that can sometimes make you shudder. Eating a lime or a dill pickle may cause you to have a similar response.

What Are Acids?

Each of these foods tastes sour because of **acids.** Several fruits, including lemons and limes, contain citric acid. Dill pickles are soaked in vinegar, which contains acetic acid. Acids donate hydrogen ions, H^+, to form hydronium ions, H_3O^+, when they are dissolved in water. **Indicators,** such as litmus, can help you determine if a substance is an acid. Acids turn blue litmus paper red, as shown in **Figure 6-15.**

Acids in lemons and other foods are mixed with lots of water, so they are usually not harmful. But if you have ever gotten lemon juice in your eye accidentally, you know that it is painful. That's because all acids, even very dilute ones, can damage your eyes and other sensitive areas of your body. Concentrated acids, those that aren't mixed with much water, can burn your skin. To be safe, always protect yourself by wearing safety goggles, gloves, and a laboratory apron when working with acids in the laboratory. If possible, work with only very dilute acids.

acid a substance that donates hydrogen ions, H^+, to form hydronium ions, H_3O^+, when dissolved in water

indicator a compound that can reversibly change color in a solution, depending on the concentration of H_3O^+ ions

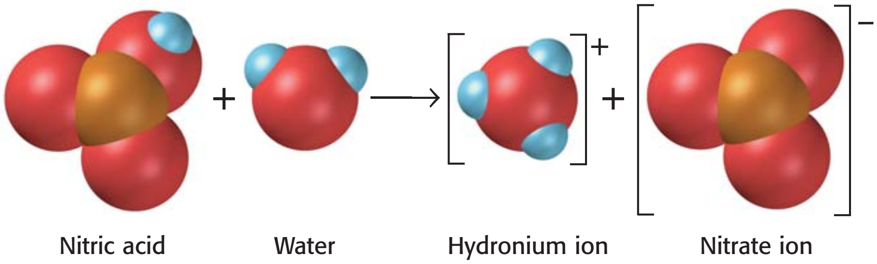
VOCABULARY Skills Tip

The word acid *originates from the Latin word* acidus, *meaning "sour."*

Figure 6-15
Lemons, limes, and dill pickles taste sour because of acids. Acids turn blue litmus paper red.

Some acid solutions form the maximum amount of charged ions

All acids can conduct electricity when dissolved in water because all acids form hydronium ions, H_3O^+, when they are dissolved in water. But some acid solutions conduct electricity better than others. Solutions of some acids, like nitric acid, conduct electricity well. Nitric acid, HNO_3, is a *strong acid*. Strong acids fully ionize when dissolved in water. This means their solutions have as many hydronium ions as the acid can possibly form. The following reaction takes place when nitric acid is added to water.



The single reaction arrow pointing to the right shows that nitric acid ionizes completely in water to form hydronium ions and nitrate ions. These ions move around in the solution and conduct electricity. Other strong acids behave similarly when dissolved in water. A solution of sulfuric acid in water, for instance, conducts electricity in car batteries.

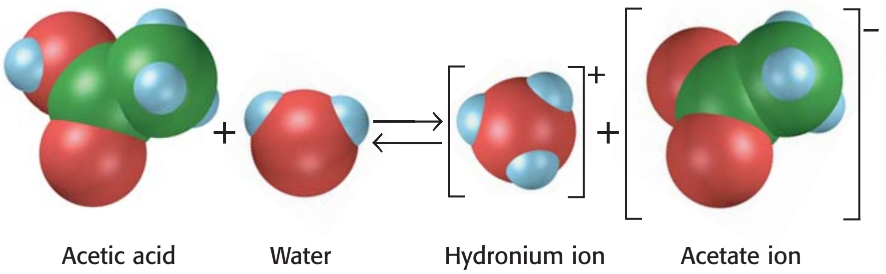
Figure 6-16

A Strong acids, like nitric acid, ionize completely and are therefore better conductors, as indicated by the brightly lit bulb.

B Weak acids, like acetic acid, only partially ionize. There are not as many ions in solution as there are for a strong acid, so the bulb is only dimly lit.

Other acids do not ionize completely

Solutions of *weak acids,* such as acetic acid, CH_3COOH, do not conduct electricity as well as nitric acid. When acetic acid is added to water, the following equilibrium takes place.



The reaction arrow pointing to the right shows that some acetic acid molecules combine with water molecules to form ions. The reaction arrow pointing to the left shows that not all of the acetic acid in the solution reacts to form ions. Because there are fewer ions (charges) in the solution, it does not conduct electricity as well as a solution of nitric acid, as shown in **Figure 6-16. Table 6-1** lists several common acids and their uses.

Table 6-1 **Some Common Acids**

Acid	Formula	Strength	Uses for dissolved acid
Hydrochloric acid (muriatic acid)	HCl	Strong	Cleaning and food processing; adjusting the pH of swimming pools
Sulfuric acid	H_2SO_4	Strong	Making fertilizers and other chemicals; fluid inside car batteries
Nitric acid	HNO_3	Strong	Making fertilizers and explosives
Acetic acid (ethanoic acid)	CH_3COOH	Weak	Making vinegar; manufacturing chemicals, plastics, and medicines
Formic acid	$HCOOH$	Weak	Dyeing textiles
Citric acid	$C_6H_8O_7$	Weak	Preparing flavorings, candies, and soft drinks

What Are Bases?

Like acids, all **bases** share common properties. Foods that contain bases taste bitter. Bases are also slippery. Like acidic solutions, basic solutions can conduct electricity and cause indicators to change color. Not all bases are exactly alike, though. Some bases contain hydroxide ions, OH^-, while others do not. But bases that do not will react with water molecules to form hydroxide ions. **Figure 6-17** shows some common household substances that contain bases. Bases turn red litmus paper blue.

Like acids, bases can be very dangerous if they are not diluted with water. To protect yourself when working with bases in the laboratory, always wear safety goggles, gloves, and a laboratory apron. If possible, work with very dilute bases instead of concentrated ones.

base a substance that either contains hydroxide ions, OH^-, or reacts with water to form hydroxide ions

Many common bases contain hydroxide ions

Potassium hydroxide, KOH, is a base found in some drain cleaners. Solutions of potassium hydroxide conduct electricity well, so potassium hydroxide must be a *strong base*. In water, potassium hydroxide dissociates completely to form ions, as shown below.

$$KOH \longrightarrow K^+ + OH^-$$

Figure 6-17
These household items all contain bases. Bases turn red litmus paper blue.

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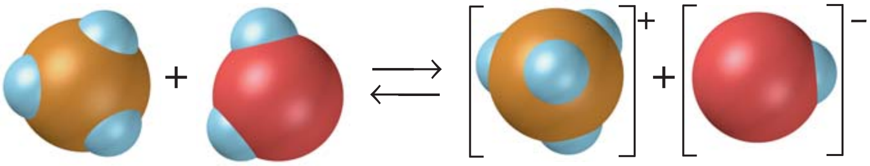
Other bases react with water to form hydroxide ions

As **Table 6-2** shows, ammonia is a base that does not contain hydroxide ions. When ammonia gas is dissolved in water, water acts like an acid and donates a hydrogen ion. This ion is accepted by ammonia. The result is a mixture of dissolved ammonia, water, ammonium ions, and hydroxide ions.



A solution of ammonia does not conduct electricity as well as a solution containing an equal concentration of potassium hydroxide. That's because the ammonia solution has fewer dissolved ions.

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TOPIC: pH
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KEYWORD: HK1064

VOCABULARY Skills Tip

The term pH *originates from the French words* pouvoir Hydrogène, *meaning "hydrogen power."*

pH a measure of the hydronium ion concentration in a solution

How Acidic Is an Acid?

You can tell if a solution is acidic, basic, or neutral by using litmus paper. But to determine if one solution is more acidic than another, you must measure the concentration of hydronium ions. The **pH** of a solution indicates its concentration of hydronium ions. The pH of a solution is often critical. For example, enzymes in your body work only in a very narrow pH range. And an abnormal pH of a person's blood can be a sign of health problems.

Table 6-2 **Some Common Bases**

Base	Formula	Strength	Uses for dissolved base
Potassium hydroxide (potash)	KOH	Strong	Manufacturing soap and some drain cleaners; bleaching
Sodium hydroxide (lye)	NaOH	Strong	Manufacturing soap, paper, textiles, and some drain cleaners
Calcium hydroxide (lime)	$Ca(OH)_2$	Strong	Making plaster, cement, and mortar
Ammonia	NH_3	Weak	Manufacturing fertilizers and many cleaners
Methylamine	CH_3NH_2	Weak	Manufacturing dyes and medicines
Pyridine	C_5H_5N	Weak	Manufacturing vitamins and medicines

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pH values correspond to the concentration of hydronium ions

pH is a measure of the hydronium ion concentration in a solution, but it also indicates the solution's hydroxide ion concentration. So a pH value can tell you how acidic or basic a solution is. pH can even tell you if a solution is neutral, or neither an acid nor a base.

Typically, the pH of solutions ranges from 0 to 14, as shown in **Figure 6-18.** Neutral solutions have a pH of 7. In neutral solutions, like pure water, the concentration of hydronium ions equals the concentration of hydroxide ions. Solutions with a pH of less than 7 are acidic. In acidic solutions, like apple juice, the concentration of hydronium ions is greater than the concentration of hydroxide ions. Solutions with a pH of greater than 7 are basic. In basic solutions, such as household ammonia, the concentration of hydroxide ions is greater than the concentration of hydronium ions.

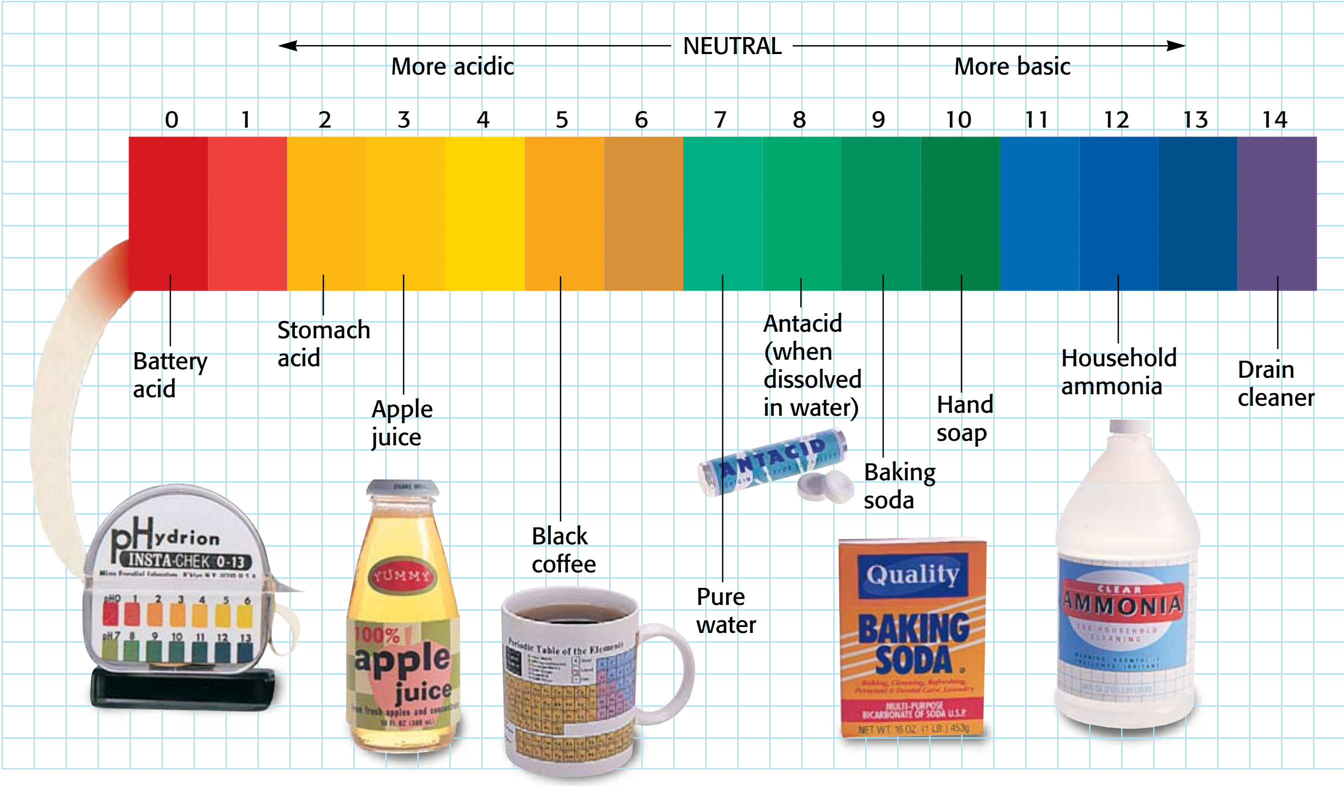
Did You Know?

Did you know that the concentration of hydronium ions and the concentration of hydroxide ions are related? In any solution made with water, the more hydronium ions there are (the more acidic the solution), the fewer hydroxide ions there are (the less basic the solution).

Small differences in pH values mean larger differences in hydronium ion concentration

Figure 6-18 compares the pH values of several common solutions. Notice how the pH value of apple juice differs from that of coffee by two pH units. Each unit of pH represents a factor of 10 in hydronium ion concentration. So apple juice is really 10^2, or 100 times, more acidic than coffee. Likewise, coffee is about 10^3, or 1000 times, more acidic than the antacid shown in **Figure 6-18.**

Figure 6-18
The pH of a substance is easily measured by comparing the color the substance turns a strip of pH paper with the color scale on the pH paper dispenser.



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Inquiry Lab

Which household substances are acids, which are bases, and which are neither?

Materials
- ✔ *baking powder*
- ✔ *baking soda*
- ✔ *bleach*
- ✔ *mayonnaise*
- ✔ *milk*
- ✔ *mineral water*
- ✔ *soft drinks*
- ✔ *tap water*
- ✔ *white vinegar*
- ✔ *dishwashing liquid*
- ✔ *laundry detergent*
- ✔ *pipet bulbs*
- ✔ *disposable glass pipets*
- ✔ *several 50 mL beakers*
- ✔ *blue litmus paper*
- ✔ *red litmus paper*

Procedure

SAFETY CAUTION Wear safety goggles, gloves, and a laboratory apron. Never pipet anything by mouth.

1. Prepare a sample of each substance you will test. If the substance is a liquid, pour about 5 mL of it into a small beaker. If the substance is a solid, place a small amount of it in a beaker, and add about 5 mL of water. Label each beaker clearly with the name of the substance that is in it.
2. Use a pipet to transfer a drop of liquid from one of the samples to red litmus paper. Then transfer another drop of liquid from the same sample to blue litmus paper. Record your observations.
3. Repeat step 2 for each sample. Be sure to use a clean pipet to transfer each sample.

Analysis

1. Which substances are acids? Which are bases? How did you determine this?
2. Which substances are neither acids nor bases? How did you determine this?

Neutralization Reactions

neutralization reaction a reaction in which hydronium ions from an acid and hydroxide ions from a base react to produce water molecules

A **neutralization reaction** is a reaction between hydronium ions and hydroxide ions to form water molecules. The resulting solution is more neutral than either of the reactants.

Strong acids and bases react to form water and a salt

A solution of a strong acid, like hydrochloric acid, will ionize completely, as shown below.

$$HCl + H_2O \longrightarrow H_3O^+ + Cl^-$$

Similarly, a solution of a strong base, like sodium hydroxide, dissociates completely, as shown below.

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

If the two solutions are of equal concentrations and equal volumes are combined, the following reaction takes place.

$$H_3O^+ + Cl^- + Na^+ + OH^- \longrightarrow Na^+ + Cl^- + 2H_2O$$

Notice how Na^+ and Cl^- are on both sides of this balanced equation. That's because they do not react. They are not changed at all in the reaction—it is as if they are on the sidelines, watching the reaction between H_3O^+ and OH^-.

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If you include only the substances that react, the equation can be written as follows.

$$H_3O^+ + OH^- \longrightarrow 2H_2O$$

This equation describes how most acids and bases react. Usually, when an acid reacts with a base, hydronium ions react with hydroxide ions to form water. The other ions—positive ions from the base and negative ions from the acid—form a **salt,** such as sodium chloride. Salts are ionic compounds that are often soluble in water. **Table 6-3** lists some common salts and some of the ways these salts are used.

salt an ionic compound composed of cations bonded to anions, other than oxide or hydroxide anions

Some acid-base reactions do not result in neutral solutions

Reactions between acids and bases do not always produce exactly neutral solutions. The pH of the solution depends on the amounts of acid and base that are combined. The pH also depends on whether the combined acid and base are strong or weak.

If a strong acid, like nitric acid, spills and reacts with an equal amount of a weak base, like sodium hydrogen carbonate from an antacid tablet, only some of the acid will be neutralized. The solution will still be acidic. However, if a strong acid reacts with *enough* of a weak base, the solution that results can be neutral or even basic.

A similar situation occurs when a strong base reacts with a weak acid. If the right ratio of amounts react, only some of the base will be neutralized. The solution will still be basic. But if a strong base reacts with *enough* of a weak acid, it's possible that the solution can be neutral or even acidic.

INTEGRATING

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Adding even small amounts of acids or bases can drastically change the pH of a system. Luckily, reactions take place in the human body to ensure that a proper pH is maintained. In your blood, hydrogen carbonate removes excess hydronium ions by reacting with them to form carbonic acid and water, as shown by the reaction below.

$$HCO_3^- + H_3O^+ \rightarrow H_2CO_3 + H_2O$$

Carbonic acid removes basic ions from your blood by reacting with them to form hydrogen carbonate ions and water, as shown by the following reaction.

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

Table 6-3 **Some Common Salts**

Salt	Formula	Uses
Aluminum sulfate	$Al_2(SO_4)_3$	Purifying water
Ammonium sulfate	$(NH_4)_2SO_4$	Fertilizing
Barium sulfate	$BaSO_4$	Medical diagnostic testing
Calcium chloride	$CaCl_2$	De-icing streets
Potassium chloride	KCl	Table-salt substitute
Silver bromide	AgBr	Developing photographic film
Sodium carbonate (washing soda)	Na_2CO_3	Manufacturing glass, detergents, and paper
Sodium hydrogen carbonate (baking soda)	$NaHCO_3$	Baking; manufacturing antacids and air fresheners

Avoiding dangerous reactions at home

Figure 6-19 shows that some household products should never be combined because they react to produce harmful substances. Ammonia and bleach react to produce a poisonous substance called chloramine, NH_2Cl. Combining vinegar and bleach produces chlorine gas, Cl_2, another poisonous substance. To be safe, don't combine household products and always check the warning labels.

Figure 6-19
Ammonia and bleach should never be combined and neither should vinegar and bleach. Both combinations result in reactions that produce poisonous substances.

SECTION 6.3 REVIEW

SUMMARY

- Acids are sour, corrosive substances that form hydronium ions when dissolved in water.
- Bases are bitter, slippery substances that either contain hydroxide ions or form them when dissolved in water.
- Indicators are substances that change color depending on whether a solution is acidic, basic, or neutral.
- The pH of a solution is a measure of its concentration of hydronium ions.
- Neutral solutions have a pH of 7, acidic solutions have a pH of less than 7, and basic solutions have a pH of greater than 7.
- A neutralization reaction occurs when hydronium ions and hydroxide ions react to form water molecules.

CHECK YOUR UNDERSTANDING

1. Classify the following substances as acidic, basic, or neutral:
  a. a soapy solution, pH = 9
  b. a sour liquid, pH = 5
  c. a solution with four times as many hydronium ions as hydroxide ions
  d. pure water (a liquid with an equal concentration of hydronium ions and hydroxide ions)

2. Arrange the following substances in order of increasing acidity: vinegar (pH = 2.8), gastric juices from inside your stomach (pH = 3.0), and a soft drink (pH = 3.4).

3. Complete the following sentence: A solution with a pH of 2 is ______ times more acidic than a solution with a pH of 6.

4. Write the balanced equation for the reaction of aluminum hydroxide, $Al(OH)_3$, a common antacid, with hydrochloric acid in your stomach.

5. Determine which acid and which base react to form the salt aluminum sulfate, $Al_2(SO_4)_3$.

6. Complete the following equations. Make sure that each equation is balanced properly.
  a. $KOH + HNO_3 \longrightarrow$
  b. $Ca(OH)_2 + H_2SO_4 \longrightarrow$
  c. $NaOH + HCl \longrightarrow$
  d. CH_3NH_2 (a base) $+ H_2O \rightleftarrows$

7. Decision Making Imagine you have made a solution that has a pH of 6.0 by dissolving NaOH and CH_3COOH in water. The solution needs to have a pH of 5.5. Should you add more acid or more base to achieve the desired pH?

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6.4

Acids and Bases in the Home

INTEGRATING TECHNOLOGY and Society

OBJECTIVES

- Recognize several acidic and basic substances commonly found in homes.
- Explain how soap is made and why it can remove dirt and grease.
- Describe the acidic or basic characteristics of other household items.

KEY TERMS

soap
detergent
disinfectant
bleach
antacid

As you have seen, you won't find acids and bases only in a laboratory. Many substances are acids and bases, including many items in your own home. Soaps, detergents, shampoos, antacids, vitamins, and even juices in your kitchen are just a few examples of household acids and bases.

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TOPIC: Acids and bases at home
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KEYWORD: HK1065

Cleaning Products

If you work in the garden without gloves or if you've been eating potato chips, no amount of water alone will remove the greasy film from your hands. That's because water doesn't mix with grease or oil. Unfortunately, most dirt that ends up on your skin and clothes has some grease or oil. So dirt cannot be removed with water alone. Something else is needed that can work with water to help it clean.

soap a cleaner that dissolves in both water and oil

Soaps allow oil and water to mix

Soaps can dissolve in both grease or oil and in water. Soaps are emulsifiers that let oil and water mix and keep them from separating. The fact that soap can make these two very different substances mix makes it a good cleaner. For example, when you wash your face with soap, like the girl in **Figure 6-20,** the oil on your face is suspended in soapy water. The water you rinse with carries away the soap and unwanted oil, leaving your face clean.

Figure 6-20
When you wash with soap, you create an emulsion of oil droplets spread throughout water.

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Connection to SOCIAL STUDIES

People have used soap for thousands of years. For instance, ancient Egyptians took baths regularly with soap made from animal fats or vegetable oils and basic solutions of alkali-metal compounds. According to Roman legend, people discovered that the water in the Tiber River near Mount Sapo was good for washing. Mount Sapo was used for elaborate animal-sacrifice rituals, and the combination of animal fat and the basic ash that washed down the mountain made the river soapy. Early-American pioneers made their soap in a similar way.

Making the Connection

1. The process of making soap is sometimes referred to as *saponification*. How does this word relate to the Roman soap legend?
2. American pioneers made lye soap from hog fat and ashes. Which substance provided the base needed to make the soap?

Soaps are made by reacting animal fats or vegetable oils with a solution of sodium hydroxide or potassium hydroxide. The products of the reaction are soap and an alcohol called glycerol. Soap is in the form of long hydrocarbon chains with a negatively charged group of atoms at one end of each chain. For every negatively charged end, there is a corresponding sodium or potassium cation.

Soap is able to remove grease and oil because the cations and the negatively charged ends of the chains ($—COO^-$) dissolve in water while the uncharged ends dissolve in oil, as shown in **Figure 6-21.** Soap acts as an emulsifier and surrounds the oil. This causes the droplets of oil to stay suspended in water. When you are washing your hands with soap, you naturally want to rub them together. Rubbing your hands together actually helps clean them. When you do this, you shift most of the emulsion of grease and water off your hands and into the sink. Rinsing your hands with clean water gets rid of any soap and grease that are left behind.

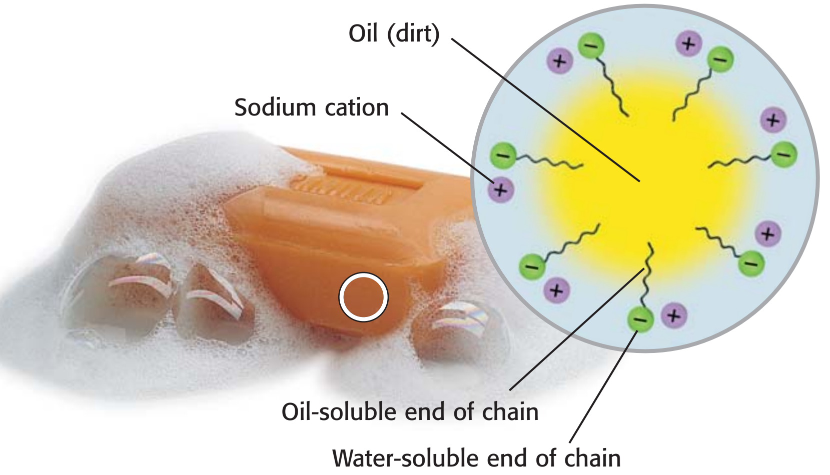
detergent a nonsoap water-soluble cleaner that can emulsify dirt and oil

Detergents are used to wash clothes and dishes

As useful as soap is for cleaning, it does not work well in water that is "hard," that is, water containing dissolved salts of the ions Mg^{2+}, Ca^{2+}, and Fe^{3+}. These ions react with soap to form an insoluble scum that settles out. This is especially a problem when you want to wash clothes and dishes. That's why clothes and dishes are washed with **detergents** instead of soap.

Like soaps, detergents are in the form of long chains that have a negatively charged end and an uncharged end. But the charged end of a detergent is a sulfonate group ($—SO_3^-$) instead of a carboxylate group ($—COO^-$). Detergents are also different from soaps because their chains are derived from petroleum products instead of from compounds that are found in animal fats. Detergents lather well in hard water and do not form a scum, so clothes and dishes washed with detergents are brighter and cleaner than they would be if they were washed with soap.

Figure 6-21
A droplet of oil can stay suspended in water because the charged ends of the soap dissolve in water and the uncharged ends dissolve in oil.



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Ammonia solutions are common household cleaners

Ammonia solutions, like the ones that are shown in **Figure 6-22,** are also very effective cleaners. Household ammonia is a solution of ammonia gas dissolved in water. Ammonia gas reacts with water to form a basic solution containing dissolved ammonia, water, ammonium ions, and hydroxide ions.

$$NH_3 + H_2O \rightleftharpoons NH_4^+ + OH^-$$

Hydroxide ions interact with greasy dirt, causing the grease to form an emulsion with the water. Scrubbing the area shifts this emulsion from the surface and cleans it.

Figure 6-22
The hydroxide ions present in ammonia solutions allow dirt and water to mix and be removed.

Disinfectants kill bacteria

A **disinfectant** is a substance that kills harmful bacteria and viruses. **Bleach,** a very good disinfectant, is a solution of sodium chlorite, $NaClO_2$, or sodium hypochlorite, NaOCl, in water.

Some hypochlorite ions, OCl^-, react with water to form hypochlorous acid, HOCl, and hydroxide ions.

$$OCl^- + H_2O \rightleftharpoons HOCl + OH^-$$

Hypochlorous acid gives bleach its disinfectant properties. Hydroxide ions that are formed in the reaction above make the solution basic. This is why bleach solutions often feel slippery.

You are probably more familiar with bleach because of its ability to remove colors and stains. Bleach does not actually remove the substance causing the stain. Instead, it removes the color of the unwanted stain by oxidizing the compound responsible. Most stains become colorless or white when they are oxidized.

disinfectant a substance that kills harmful bacteria or viruses

bleach a basic solution that can either be used as a disinfectant or to remove colors and stains

Quick ACTIVITY

Detergents

Detergents get their cleaning ability by helping water mix with substances that it normally does not mix with. In this activity, you will demonstrate this idea using a piece of wax paper, a drop of water, a straight pin, and liquid detergent.

1. Lay some wax paper on a flat surface, and put a drop of water on it. Does the water mix at all with the wax paper? How can you tell?
2. Gently touch the drop of water with the tip of the straight pin. What happens to the drop of water?
3. Now dip the tip of the straight pin in liquid detergent.
4. Gently touch the drop of water with the tip of the pin after it has been dipped in detergent. What happens to the drop of water? Why does the detergent have this effect?

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Inquiry Lab

What does an antacid do?

Materials
- ✔ plastic stirrer
- ✔ pipet bulbs
- ✔ vinegar
- ✔ 150–200 mL beakers (2)
- ✔ blue litmus paper
- ✔ disposable glass pipets
- ✔ spoon
- ✔ red litmus paper
- ✔ several varieties of antacid tablets
- ✔ wax paper

Procedure

SAFETY CAUTION Wear safety goggles, gloves, and a laboratory apron.

1. Pour 100 mL of water in a beaker. Add vinegar dropwise while stirring with the stirrer. Test the solution with litmus paper after each drop is added. Record the number of drops it takes for the solution to turn blue litmus paper bright red.
2. Use the back of a spoon to crush an antacid tablet on a small piece of wax paper. Pour 100 mL of water in the second beaker, and add the crushed antacid tablet. Stir the solution until the powder dissolves completely.
3. Use litmus paper to find out whether the solution is acidic, basic, or neutral. Record your results.
4. Now add vinegar dropwise to the antacid solution. Record the number of drops it takes the blue litmus paper to turn bright red. Compare this solution with the solution that has only vinegar and water. Compare the brand of antacid you tested with the brands of other groups.

Analysis

1. How does an antacid work to relieve the pain caused by excess stomach acid?
2. Of the brands that were tested, which brand worked the best? Explain your reasoning.

Other Household Acids and Bases

You probably have taken many of the acids and bases in your home for granted. For example, many of the clothes in your closet get their color from acidic dyes that are made of sodium salts containing the sulfonic group (—SO_3H) or carboxylic acid group (—COOH). And if you have ever had an upset stomach because of excess stomach acid, you might have taken an antacid tablet to feel better. The antacid was able to make you feel better because it is basic. Many other useful products throughout your home are also acids or bases.

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TOPIC: Antacids
GO TO: www.scilinks.org
KEYWORD: HK1066

Many health-care products are acids or bases

Ascorbic acid is another name for vitamin C, which your body needs to grow and repair itself. When you have a headache, you might take some aspirin. The chemical name for aspirin is acetylsalicylic acid. Both sodium hydrogen carbonate and magnesium hydroxide (milk of magnesia) can be used as **antacids.** Antacids are weak bases that you swallow to neutralize excess stomach acid. **Figure 6-23** on the next page shows how adding an antacid tablet to an acidic solution changes the pH of the solution. A similar reaction (without the color change) takes place in your stomach when you take an antacid.

antacid a weak base that neutralizes excess stomach acid

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Figure 6-23
Adding antacid tablets to an acidic solution makes the solution less acidic. This is indicated by the color change of the indicator present in the solution.

Shampoos also make use of acid-base properties

Shampoos can be made from soap. But if they are, they can leave a sticky buildup on your hair if you happen to live in an area that has hard water. However, shampoos made from detergents are able to remove dirt as well as most of the oil from your hair without leaving a buildup, even when they are used with hard water. Shampoo is not meant to remove all of the oil from your hair. Some oil is needed to give your hair shine and to keep it from becoming dry and brittle.

The appearance of your hair is greatly affected by the pH of the shampoo you use. Hair—which consists of strands of a protein called keratin—looks best when it is kept at either a slightly acidic pH or very close to neutral. If a shampoo is too basic, it can cause strands of hair to swell, causing them to have a dull, lifeless appearance. Shampoos are usually pH balanced, which means that they are made to be in a specific pH range. The pH of most shampoos is between 5 and 8.

Did You Know?

The protein keratin is also found in the outermost layer of cells of your epidermis, or outer layer of your skin. Keratin in these cells makes the skin tough and almost completely waterproof.

The horns, hoofs, claws, feathers, and scales of animals also consist mainly of keratin. Keratin helps keep these structures strong to protect the animal from the environment.

Acids and bases in the kitchen

Some cut fruits slowly turn brown when they are exposed to air, like the right side of the cut apple shown in **Figure 6-24.** This happens because certain molecules in the apple are oxidized. Both sides of the apple were cut at the same time, so why does the left side of the apple in **Figure 6-24** look like it was just cut? The left side was moistened with lemon juice shortly after it was cut. The citric acid in lemon juice keeps the apple from browning.

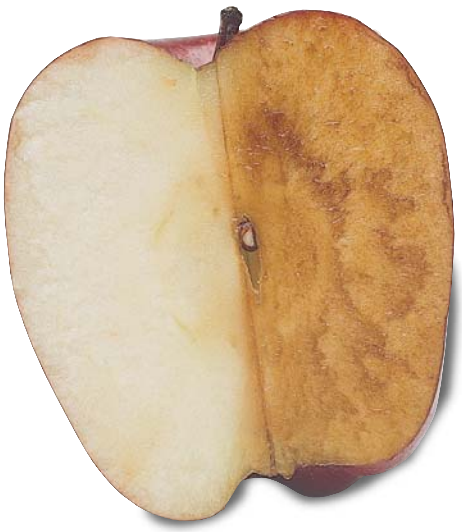

Figure 6-24
Coating the left side of this cut apple with an acidic substance, like lemon juice or pineapple juice, keeps it looking fresh longer.

Figure 6-25
If you add vinegar to milk, the acetic acid in vinegar causes the milk to curdle.

Acids have other uses in the kitchen as well. Acidic marinades made of vinegar or wine can be used to tenderize meats. Acids have the ability to do this because they can *denature* proteins in the meat. That is, the proteins unravel and lose their characteristic shapes. As a result, the meat becomes more tender.

Figure 6-25 shows that if you add vinegar to milk, the milk curdles. Although this reaction seems undesirable, a similar reaction occurs in the formation of yogurt. Bacteria convert lactose, a sugar in milk, into lactic acid. This acid changes the texture of milk and makes yogurt.

There are many bases in the kitchen as well. Baking soda, or sodium hydrogen carbonate, $NaHCO_3$, for instance, is used in cooking and also to absorb odors in the refrigerator. Baking powder is used to make light, fluffy batter for cakes and other foods. To unclog a drain in the sink, you might have used a drain cleaner containing potassium hydroxide, KOH, or sodium hydroxide, NaOH, sometimes called lye.

SECTION 6.4 REVIEW

SUMMARY

- Soaps are made by reacting fats or oils with a solution of NaOH or KOH.
- Soaps consist of long hydrocarbon chains ending with a negatively charged end ($-COO^-$) that dissolves in water. The uncharged end dissolves in grease or oil.
- Detergents are similar to soap, except that their chains have a different negatively charged end, ($-SO_3^-$).
- Disinfectants kill bacteria and viruses.
- Antacids neutralize excess stomach acid.
- Many foods contain acids or bases that react during food preparation.

CHECK YOUR UNDERSTANDING

1. **List** three acidic household substances and three basic household substances. How can you verify your answers?
2. **Describe** how soap can dissolve in both oil and water. How does soap work with water to remove oily dirt?
3. **Determine** what compound is responsible for the soap scum that develops in bathtubs where the water contains Fe^{3+} ions and the soap is sodium stearate, $NaC_{18}H_{35}O_2$.
4. **Explain** why the agitation of a washing machine helps a detergent clean your clothes. (**Hint:** Compare this agitation to your rubbing your hands together when you wash them.)
5. **Describe** why it is not necessary for bleach to actually remove the substance causing a stain.
6. **Predict** whether $CaCO_3$ is acidic, basic, or neutral. It is the active ingredient in some antacids.
7. **Explain** why soap scum forms in hard water that contains Mg^{2+} ions when a sodium stearate soap is used.
8. **Critical Thinking** Crayon companies recommend treating wax stains on clothes by spraying them with an oily lubricant, applying dishwashing liquid, and then washing them. Explain in a paragraph why this treatment would remove the stain. WRITING SKILL

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CHAPTER 6 REVIEW

Chapter Highlights

Before you begin, review the summaries of the key ideas of each section, found on pages 191, 198, 206, and 212. The key vocabulary terms are listed on pages 186, 192, 199, and 207.

UNDERSTANDING CONCEPTS

1. Which of the following is a homogeneous mixture?
- **a.** tossed salad
- **b.** soil
- **c.** a KCl solution
- **d.** vegetable soup

2. If the label on a bottle of medicine says "Shake well before using," the medicine is probably a ________.
- **a.** solution
- **b.** suspension
- **c.** colloid
- **d.** gel

3. Which of the following affects the solubility of a solute in a solvent?
- **a.** the surface area of the solute
- **b.** stirring the solution
- **c.** the temperature of the solvent
- **d.** All of the above

4. Suppose you add a teaspoon of table salt to a cool salt-water solution and stir until all of the salt dissolves. The solution you started with was ________.
- **a.** unsaturated
- **b.** supersaturated
- **c.** saturated
- **d.** concentrated

5. An acid forms which ions in solution?
- **a.** oxygen
- **b.** hydronium
- **c.** hydroxide
- **d.** sulfur

6. A base forms which ions in solution?
- **a.** oxygen
- **b.** hydronium
- **c.** hydroxide
- **d.** sulfur

7. A substance with a pH of 9 has
- **a.** the same number of H_3O^+ ions as it does OH^- ions.
- **b.** more H_3O^+ ions than OH^- ions.
- **c.** no H_3O^+ ions or OH^- ions.
- **d.** more OH^- ions than H_3O^+ ions.

8. When a solution of nitric acid is added to a solution of calcium hydroxide, the salt formed has the formula ________.
- **a.** H_2O
- **b.** CaH
- **c.** $Ca(NO_3)_2$
- **d.** None of the above

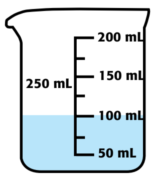
9. An antacid relieves an acid stomach because antacids are ________.
- **a.** acidic
- **b.** neutral
- **c.** basic
- **d.** dilute

10. Bleach removes stains by
- **a.** removing the color of the stain.
- **b.** covering the stain.
- **c.** removing the stain-causing substance.
- **d.** disinfecting the stain.

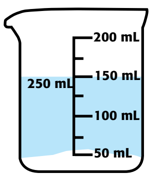
Using Vocabulary

11. A small amount of *solute* is added to two different solutions. Based on the figures below, which solution was *unsaturated*? Which solution was *saturated*?

a.



b.



12. Explain how the ionization of a *strong acid* differs from that of a *weak acid* in a solution. Give an example of a strong acid and a weak acid. Show what ions form when each is dissolved in water.

13. What *salt* is produced in the following neutralization reaction?

$$2H_3O^+ + 2Br^- + Ca^{2+} + 2OH^- \longrightarrow Ca^{2+} + 2Br^- + 4H_2O$$

14. Use the terms *pH* and *indicator* to describe a way to determine whether an unknown solution is acidic or basic.

15. How are *detergents* and *soaps* alike? How are they different?

CHAPTER 6 REVIEW

BUILDING MATH SKILLS

16. Graphing Make a solubility graph for $AgNO_3$ from the data in the table below. Plot the temperature on the *x*-axis. Plot solubility on the *y*-axis.

Temperature (°C)	Solubility of $AgNO_3$ (g of $AgNO_3$ /100 g of H_2O)
0	122
20	216
40	311
60	440
80	585
100	733

a. How does the solubility of $AgNO_3$ vary with the temperature of water?

b. Estimate the solubility of $AgNO_3$ at 35°C, at 55°C, and at 75°C.

c. At what temperature would the solubility of $AgNO_3$ be 680 g per 100 g of H_2O?

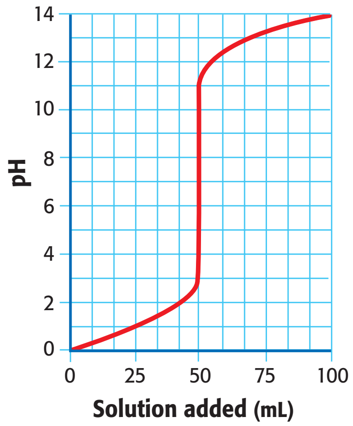
d. If 100 g of $AgNO_3$ were added to 100 g of H_2O at 10°C, would the solution be saturated or unsaturated?

THINKING CRITICALLY

17. Evaluating Data Based on the chart below, which solvents can be mixed with ether to form a single layer?

X = immiscible	Water	Methanol	Ether	Chloroform	Ethyl acetate
Water			X	X	X
Methanol					
Ether	X				
Chloroform	X				
Ethyl acetate	X				

18. Interpreting Graphics Study the graph shown at right. Is the solution being added acidic or basic? Explain how you determined your answer.



19. Applying Knowledge You have been investigating the nature of suspensions, colloids, and solutions and have made the following observations on three unknown samples. From your data, decide whether each sample is a solution, a suspension, or a colloid.

Sample	Clarity	Settles out?	Diameter of particles
1	Clear	No	Too small to be seen
2	Cloudy	Yes	1.5 mm
3	Clear	No	95 nm

20. Designing Systems COMPUTER SKILL Use what you have learned about how substances dissolve to make a diagram or a computer representation that shows how the ionic compound KBr dissolves in water.

21. Creative Thinking If you wish to change the pH of a pH-sensitive solution only very slightly, would it be better to add a strong acid or a weak acid? Explain why.

22. Problem Solving Insect bites hurt because the insect injects a toxin into the victim, often in the form of an acid. When an ant bites you, it injects you with formic acid. Suggest a treatment that might stop an ant bite from itching or hurting.

DEVELOPING LIFE/WORK SKILLS

23. Working Cooperatively The salt you use to flavor foods is usually mined from the ground. However, when mined, salt is often mixed with soil and minerals. Work with a partner to design a method to purify this crude material to yield pure salt. Write a specific plan that describes your method.

WRITING SKILL

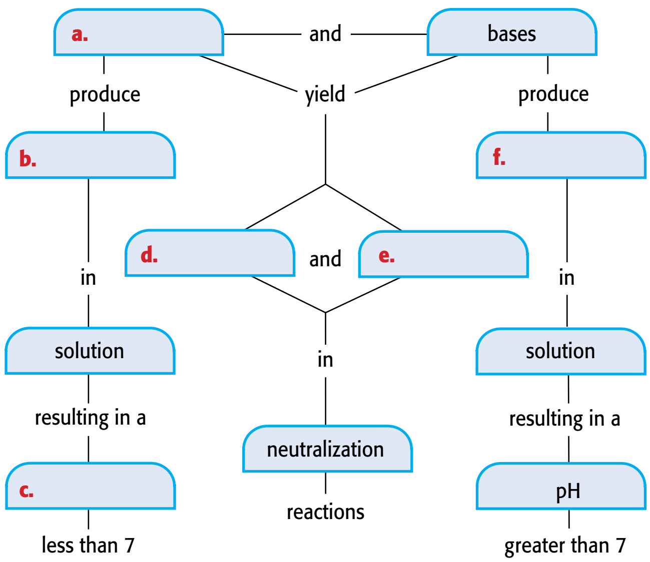
24. Communicating Effectively When there is an oil spill, emergency-response teams use the properties of oil and water along with solubility principles to clean spills and prevent them from spreading. Describe the research behind these techniques, and evaluate the impact this research has had on the environment.

25. Locating Information A reaction between baking soda, $NaHCO_3$, and a baking batter that is made of acidic ingredients produces CO_2 gas. The reaction makes the batter fluffier. Some recipes call for baking powder instead of baking soda. Find out what regular baking powder and double-acting baking powder are made of. Which is more likely to result in a light, fluffy cake? How does each substance differ from baking soda?

INTEGRATING CONCEPTS

26. Connection to History In the eighteenth century, the French chemist Antoine Lavoisier experimented with substances containing oxygen, like CO_2 and SO_2. He observed that these substances formed acidic solutions when dissolved in water. His observations led him to infer that for a solution to be acidic, it must contain oxygen. Provide evidence to disprove Lavoisier's conclusion.

27. Concept Mapping Copy the unfinished concept map below onto a sheet of paper. Complete the map by writing the correct word or phrase in the lettered boxes.



28. Connection to Health One method of taking medicine is known as transdermal infusion. As the name implies, medicine is absorbed into the body through the skin, after being placed in a package fastened to the body like a bandage. Medicines to prevent motion sickness and to treat some coronary conditions are sometimes given in this way. Identify and explore some of the applications of transdermal infusion and the research that made this technique possible. Write a two-page report that evaluates the impact this research has had on society.

internetconnect

SCILINKS NSTA

TOPIC: Transdermal patch medicines
GO TO: www.scilinks.org
KEYWORD: HK1067

Skill Builder Lab

Investigating How Temperature Affects Gas Solubility

Introduction

In general, a solid solute dissolves faster in a liquid solvent if the liquid is warm. In this lab, you will determine whether this is true of carbon dioxide, a gaseous solute, dissolved in a soft drink.

Objectives

- ***Compare*** the volume of carbon dioxide released from a warm soft drink with that released from a cold soft drink.
- ***Relate*** carbon dioxide's solubility in each soft drink to the temperature of each soft drink.

Materials

2 carbonated soft drinks in plastic bottles
2 small plastic bags
4 twist ties
thermometer
stopwatch
flexible metric tape measure
1 L beaker
crushed ice
paper towels

Safety Needs

safety goggles
gloves
laboratory apron

▶ Preparing for Your Experiment

1. Prepare a data table in your lab report similar to the one shown at right.

▶ Testing the Solubility of Carbon Dioxide in a Warm Soft Drink

SAFETY CAUTION Wear safety goggles, gloves, and a laboratory apron.

2. Obtain a bottle of carbonated soft drink that has been stored at room temperature, and carry it to your lab table. Try not to disturb the liquid.
3. Use a thermometer to measure the temperature in the laboratory. Record this temperature in your data table.
4. Remove the bottle's cap, and quickly place the open end of a deflated plastic bag over the bottle's opening. Seal the bag tightly around the bottle's neck with a twist tie. Begin timing with a stopwatch.
5. When the bag is almost fully inflated, stop the stopwatch. Very carefully remove the plastic bag from the bottle, making sure to keep the bag sealed so the carbon dioxide inside does not escape. Seal the bag tightly with another twist tie.
6. Gently mold the bag into the shape of a sphere. Measure the bag's circumference in centimeters by wrapping the tape measure around the largest part of the bag. Record the circumference in your data table.

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Soft Drink Data

	Temperature (°C)	Circumference of bag (cm)	Radius of bag (cm)	Volume of bag (cm^3)
Soft drink at room temp.				
Chilled soft drink				

▶ Testing the Solubility of Carbon Dioxide in a Cold Soft Drink

7. Obtain a second bottle of carbonated soft drink that has been chilled. Place the bottle in a 1 L beaker, and pack crushed ice around the bottle. Use paper towels to dry any water on the outside of the beaker, and then carefully move the beaker to your lab table.
8. Repeat step 4. Let the second plastic bag inflate for the same length of time that the first bag was allowed to inflate. Very carefully remove the bag from the bottle as you did before. Seal the plastic bag tightly with a twist tie.
9. Wait for the bag to warm to room temperature. While you are waiting, use the thermometer to measure the temperature of the cold soft drink. Record the temperature in your data table.
10. When the bag has warmed to room temperature, repeat step 6.

▶ Analyzing Your Results

1. Calculate the radius in centimeters of each inflated plastic bag by using the following equation. Record the results in your data table.

$$\text{radius (in cm)} = \frac{\text{circumference (in cm)}}{2\pi}$$

2. Calculate the volume in cubic centimeters of each inflated bag by using the following equation. Record the results in your data table.

$$\text{volume (in cm}^3\text{)} = \frac{4}{3}\pi \times [\text{radius (in cm)}]^3$$

3. Compare the volume of carbon dioxide released from the two soft drinks. Use your data to explain how the solubility of carbon dioxide in a soft drink is affected by temperature.

▶ Defending Your Conclusions

4. Suppose someone says that your conclusion is not valid because a soft drink contains many other solutes besides carbon dioxide. How could you verify that your conclusion is correct?