CHAPTER 21
Solutions

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Launch Lab
Crystal Garden

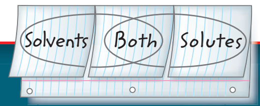
Solutions surround you in your daily life. The air that you breathe, the steel bridge that you drive across, and the apple juice that you drink for breakfast are all solutions. In this lab, you will use a solution to grow a garden of crystals.

For a lab worksheet, use your StudentWorks™ Plus Online.

Inquiry Launch Lab

FOLDABLES®

Make a three-tab Venn diagram. Label it as shown. Use it to organize your notes on solutions.



THEME FOCUS **Structures and Properties of Matter**

The structures of atoms, ions, and molecules determine whether or not two substances will form a solution.

BIG Idea A solution is a homogeneous mixture of a solute or solutes and a solvent or solvents.

Section 1 • How Solutions Form

Section 2 • Concentration and Solubility

Section 3 • Particles in Solution

Section 4 • Dissolving Without Water

Section 1

SC.912.L.18.12: Discuss the special properties of water that contribute to Earth's suitability as an environment for life: cohesive behavior, ability to moderate temperature, expansion upon freezing, and versatility as a solvent.

Reading Preview

Essential Questions

- How do substances dissolve in a liquid?
- How do solid solutions and gas solutions form?
- What factors affect the rates at which solids dissolve in liquids?

Review Vocabulary

polar molecule: a molecule with a slightly positive end and a slightly negative end as a result of electrons being shared unequally

New Vocabulary

solute
solvent
alloy

g Multilingual eGlossary

How Solutions Form

MAIN Idea A solution forms when a solute or solutes and a solvent or solvents become evenly mixed.

Real-World Reading Link Solutions are all around you. For example, air is a solution of gases, and the ocean is a solution of salt water. Many structures, such as buildings or bridges, are also solutions made from different metals. Solutions are an important part of life.

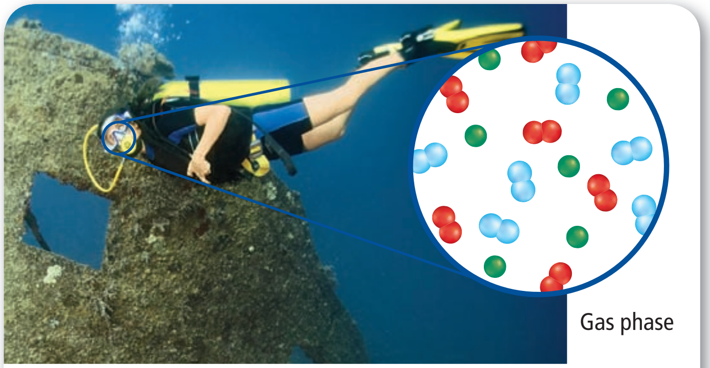
What is a solution?

Hummingbirds are fascinating creatures. They can hover for long periods while they sip nectar from flowers through their long beaks. To attract hummingbirds, many people use feeder bottles containing a red liquid, as shown in **Figure 1.** The liquid is a solution of sugar and red food coloring in water.

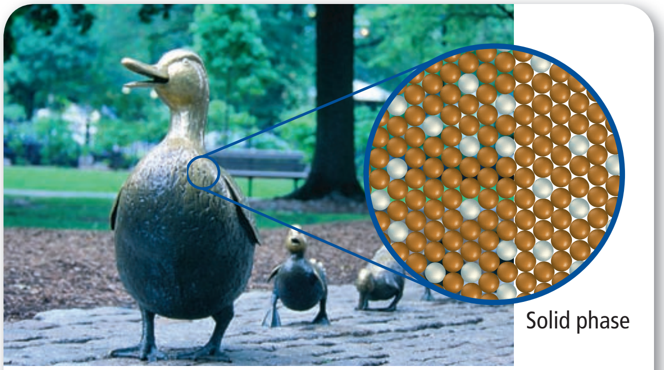
Suppose you are making some hummingbird food. When you add sugar to water and stir, the sugar crystals disappear. When you add a few drops of red food coloring and stir, the color spreads evenly throughout the sugar water. Why does this happen?

Hummingbird food is one of many solutions. A solution is a homogeneous mixture, which means it has the same composition throughout the mixture. The reason why you no longer see the sugar crystals and the reason why the red dye spreads out evenly is that they have formed a solution. The sugar molecules and the red dye mixed evenly among the water molecules.

Figure 1 Liquid solutions may contain gases, other liquids, and solids. For example, this hummingbird food contains sugar (solid), red food coloring (liquid), and oxygen and nitrogen (gases), all dissolved in water.



This diver breathes a solution of oxygen, nitrogen, and helium gases.



The bronze used to make this statue is a solid solution of copper and tin.

Figure 2 Solutions can also be mixtures of solids or gases. Gases naturally diffuse within a common container. But solids, such as bronze, must be in a molten state to combine into a solution.

Solutes and Solvents

To describe a solution, you can say that one substance is dissolved in another. The substance being dissolved in a solution is the **solute.** The substance in which a solute is dissolved is the **solvent.** When a solid or gas dissolves in a liquid, the solid or gas is the solute and the liquid is the solvent. Thus, in salt water, salt is the solute and water is the solvent. In carbonated soft drinks, carbon dioxide gas is one of the solutes and water is the solvent. When a liquid dissolves in another liquid, the substance that is present in the larger amount is typically called the solvent.

Reading Check **Explain** How do you know which substance is the solute in a solution?

Nonliquid solutions Solutions can also be gaseous or even solid. Examples of a gaseous solution and a solid solution are shown in **Figure 2.** Did you know that the air that you breathe is a solution? In fact, all mixtures of gases are solutions. Air is a solution of 78 percent nitrogen, 21 percent oxygen, and small amounts of other gases, such as argon, carbon dioxide, and water vapor.

The sterling silver and brass used in musical instruments are examples of solid solutions. Sterling silver contains 92.5 percent silver and 7.5 percent copper. Brass is a solution of copper and zinc metals. Solid solutions are known as alloys. An **alloy** is a mixture of elements that has metallic properties. Alloys are made by melting the solid solute and solvent together. Most coins, as shown in **Figure 3,** are alloys.

Inquiry **Virtual Lab**

Inquiry **Video Lab**

Foldables
Incorporate information from this section into your Foldable.

Vocabulary
Science Usage v. Common Usage
Solution
Science usage
a homogeneous mixture
Sugar water is a solution of solid sugar particles mixed with water.
Common usage
an action or process of solving a problem
The solution for getting the car from the mud was a tow truck.

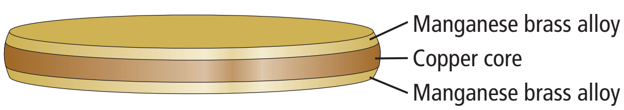
FIGURE 3

Visualizing Metal Alloys

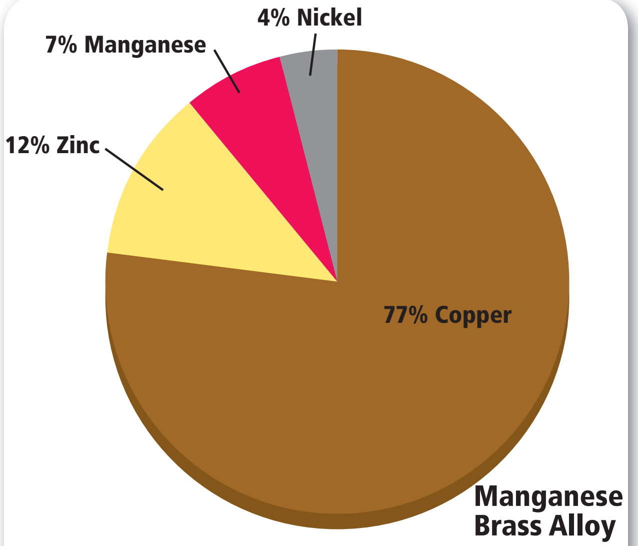
How do vending machines recognize whether the money being placed into them is the correct currency? They recognize coins by size, mass, and, sometimes, electrical conductivity.

The golden Sacagawea dollar was first issued in 2000 to replace the silver Susan B. Anthony dollar. It was the same size and mass as the Susan B. Anthony dollar, but the electrical conductivities were different.

An alloy's electrical conductivity is based on the composition of the alloy. Each alloy has its own specific electrical conductivity. If the Sacagawea dollar failed to match the conductivity of the Susan B. Anthony dollar, vending machines would have to be modified or replaced to take the Sacagawea dollar. By adding the right combination of zinc, manganese, and nickel to copper, the correct conductivity was achieved and the expensive task of replacing vending machines was avoided.



The Sacagawea dollar's copper core is half the coin's thickness. The outer layer is composed of the manganese brass alloy.



After testing thousands of coins for conductivity, a manganese-brass alloy was chosen for the Sacagawea dollar.

How Substances Dissolve

Fruity drinks made from powdered mixes, such as lemonade, are examples of solutions made by dissolving solids in liquids. Like the hummingbird food shown in **Figure 1,** they contain sugar as well as other substances, such as food coloring and additional flavors.

The dissolving of a solid in a liquid occurs at the surface of the solid. To understand how water solutions form, keep in mind two things that you have learned about water. Like the particles of any substance, water molecules are constantly moving, and water is a polar molecule.

Reading Check **Identify** where a solid actually dissolves when placed in a liquid.

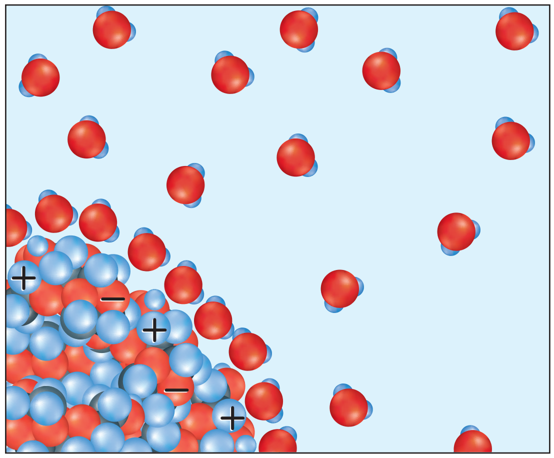
How it happens **Figure 4** shows the process of sugar dissolving in water. In step 1, the negative ends of water molecules are attracted to the positive ends of sugar crystals as water moves past the surface of the solid sugar. In step 2, the water molecules pull the sugar molecules into solution. Finally, in step 3, the water molecules and the sugar molecules mix evenly.

The process described in the three steps shown in **Figure 4** repeats as layer after layer of sugar molecules moves away from the crystal. The same three steps occur for any solid solute dissolving in a liquid solvent.

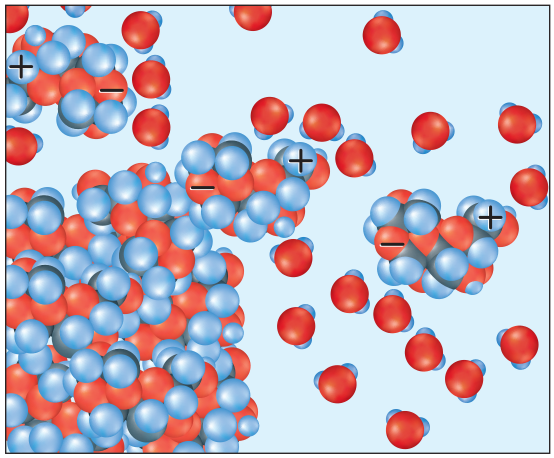
Dissolving liquids and gases A similar but more complex process takes place when liquids and gases dissolve. Liquid and gas particles move much more freely than particles of solids move. When gases dissolve in gases or when liquids and gases dissolve in liquids, particle movement eventually spreads solutes evenly throughout the solvent, resulting in a homogeneous mixture.

Dissolving solids in solids Solid particles do move a little, but this motion is not enough to spread particles evenly throughout a mixture. Solid metals are first melted and then mixed together while still molten. In the liquid state, the atoms can spread out evenly and will remain mixed after they have cooled.

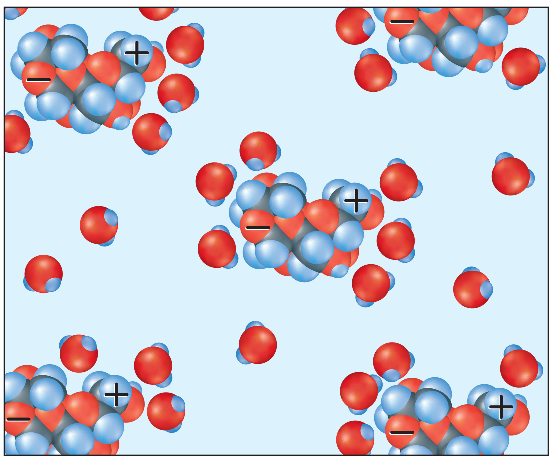
Figure 4 Dissolving sugar in water is a three-step process.



Step 1 At the surface of the sugar crystal, oppositely charged parts of the sugar and water molecules attract each other.



Step 2 Because the water molecules are moving in the liquid, they pull sugar molecules away from the crystal.



Step 3 Water molecules and sugar molecules continue to spread out until a homogeneous mixture forms.

MiniLab

Inquiry MiniLab

Observe the Effect of Surface Area

Procedure

1. Read the procedure and safety information, and complete the lab form.
2. Grind up two **sugar cubes.**
3. Place the ground sugar cubes into a **medium-sized glass,** and place two unground sugar cubes into a similar glass.
4. Add an equal amount of **water** at room temperature to each glass.
5. Do not disturb the glasses. Observe the amount of time it takes for the sugar to dissolve.

Analysis

1. **Compare** the times required to dissolve each sugar mixture.
2. **Conclude** What do you conclude about the dissolving rate and surface area?

Rate of Dissolving

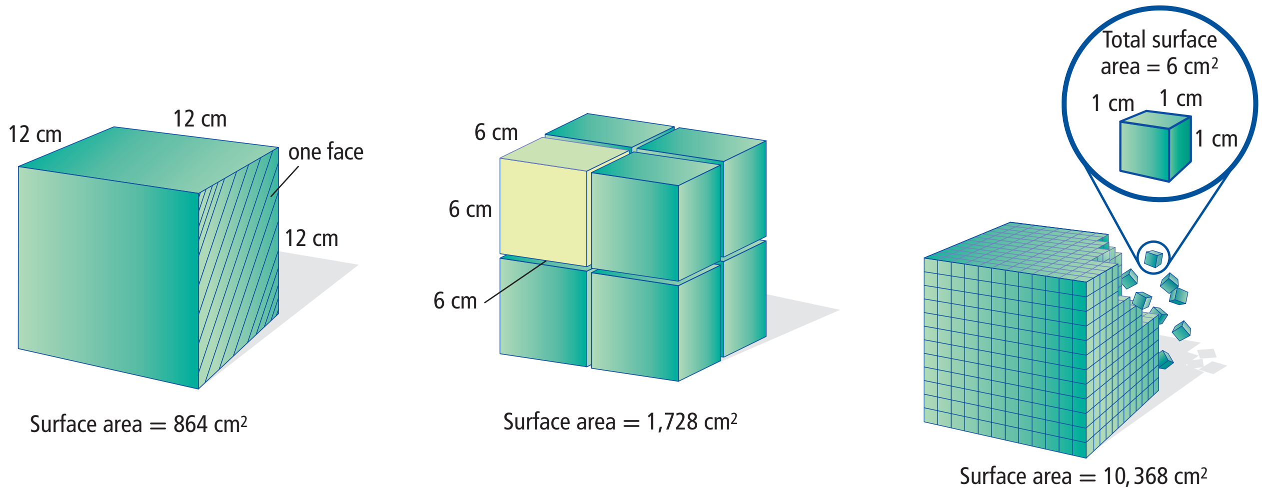
If two substances form a solution, they will do so at a measureable rate. Sometimes the rate at which a solute dissolves into a solvent is fast. Other times it is slow. There are several things that you can do to speed up the rate of dissolving. Stirring, increasing the surface area of the solute, and increasing the temperature of the solvent are three of the most effective techniques.

Stirring Think about how you make a drink from a powdered mix. After you add the mix to water, you stir it. How can stirring speed up the dissolving process? Stirring a solution speeds up dissolving because it moves the solvent around, bringing more solvent into contact with the solute. The solvent attracts the particles of solute, causing the solid solute to dissolve faster.

Surface area Another way to speed up the dissolving of a solid in a liquid is to increase the surface area of the solute. Suppose you want to sweeten your water with a 5-g crystal of rock candy. If you put the whole crystal into a glass of water, it might take several minutes to dissolve, even with stirring. However, if you first grind the rock candy into a powder, it will dissolve in the same amount of water in only a few seconds.

Why does breaking up a solid cause it to dissolve faster? Breaking the solid into smaller pieces greatly increases its surface area, as you can see in **Figure 5.** Because dissolving takes place at the surface of the solid, increasing the surface area allows more solvent to come into contact with more solid solute. Therefore, the speed of the dissolving process increases.

Figure 5 Surface area is the area of the exterior surface of an object, measured in square units. Increasing surface area increases the speed at which a solute is dissolved by a solvent.



A face of a cube is the outer surface that has four edges. A cube has six faces of equal area.

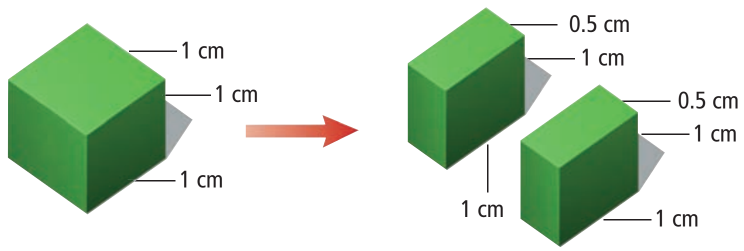
Pull apart the cube into eight smaller cubes of equal size. You now have a total of forty-eight faces.

If you divide the cube into smaller cubes that are 1 cm on a side, you will have 1,728 cubes and 10,368 faces.

EXAMPLE Problem 1

MA.912.S.1.2: Determine appropriate and consistent standards of measurement for the data to be collected in a survey or experiment.

Calculate Surface Area Suppose the length, height, and width of a cube are each 1 cm. If the cube is cut in half to form two rectangular pieces, what is the total surface area of the new pieces?



Identify the Unknown: Total surface area of the two new pieces

List Knowns:
length = l = 1 cm
height = h = 1 cm
width = w = 0.5 cm

Set Up the Problem:
The rectangular solids each have six faces.
Surface area front and back = $2(h \times w)$
Surface area left and right = $2(h \times l)$
Surface area top and bottom = $2(w \times l)$
Surface area of one piece = $2(h \times w) + 2(h \times l) + 2(w \times l)$
Total surface area = Number of pieces × Surface area of one piece

Solve the Problem:
Surface area of one piece =
$2(1\text{ cm} \times 0.5\text{ cm}) + 2(1\text{ cm} \times 1\text{ cm}) + 2(0.5\text{ cm} \times 1\text{ cm}) = 4\text{ cm}^2$
The total surface area of the two new pieces = $2(4\text{ cm}^2) = 8\text{ cm}^2$

Check the Answer:
Total surface area of the original cube = $6(w \times h) = 6(1\text{ cm} \times 1\text{ cm}) = 6\text{ cm}^2$
Dividing the cube in two increased the surface area, which is reasonable.

PRACTICE Problems

Find **Additional Practice Problems** in the back of your book.

1. The length, height, and width of a cube are each 3 cm. If the cube is cut in half to form two rectangular pieces, what is the total surface area of the new pieces?
2. If a cube that has a length, height, and width of 4 cm is broken down into 8 cubes of equal size, what is the surface area of the 8 new cubes?
3. **Challenge** A cube of salt with a length, height, and width of 5 cm each is attached along a face to another cube of salt with the same dimensions. How much surface area is lost by combining the cubes to form a rectangular solid?

Review
Additional Practice Problems

Figure 6 Hot water allows powdered chocolate mix to dissolve faster than cold water does. This means fewer solid clumps.

Temperature In addition to stirring and increasing the surface area of the solute, a third way to increase the rate at which most solids dissolve is to increase the temperature of the solvent. Think about making hot chocolate from a mix, as shown in **Figure 6.** The chocolate mix dissolves faster by mixing it with hot water instead of cold water. This is true of many solutions. Increasing the temperature of a solvent speeds up the movement of its particles. This temperature increase causes more solvent particles to come into contact with the solute. As a result, solute particles break loose and dissolve faster when the solvent is heated.

Controlling the process Think about how the three factors that you just learned affect the rate of dissolving. Can these factors combine to further increase the rate, or perhaps control the rate, of dissolving? Each technique of stirring, increasing the surface area, and heating, is known to increase the rate of dissolving by itself. When two or more techniques are combined, the rate of dissolving increases even more.

Consider a sugar cube placed in cold water. You know that the sugar cube will eventually dissolve. You can predict that heating the water will increase the rate by some amount. You can also predict that a combination of heating and stirring will further increase the rate. Finally, you can predict that increasing the surface area by crushing the cube combined with heating and stirring will result in the fastest rate of dissolving.

Section 1 Review

SC.912.L.18.12

Section Summary

- A solution is a homogeneous mixture.
- Solutions are composed of solutes and solvents.
- Stirring, surface area, and temperature all affect the rate of dissolving.

4. MAIN Idea **Summarize** possible ways in which phases of matter could combine to form a solution.
5. **Draw** a diagram that shows how a solid dissolves in a liquid.
6. **Describe** how stirring, surface area, and temperature affect the rate of dissolving.
7. **Think Critically** Amalgams are sometimes used in tooth fillings and are made of mercury. Explain why an amalgam is a solution.

Apply Math

8. **Find Surface Area** Calculate the surface area of a rectangular solid with dimensions $l = 2$ cm, $w = 1$ cm, and $h = 0.5$ cm.
9. **Calculate Percent Increase** If the length of the rectangle in question 8 is increased by 10%, by what percentage will the surface area increase?

Assessment Online Quiz

SC.912.L.18.12: Discuss the special properties of water that contribute to Earth's suitability as an environment for life: cohesive behavior, ability to moderate temperature, expansion upon freezing, and versatility as a solvent.

Reading Preview

Essential Questions

- How are the concentrations of solutions expressed?
- What is solubility?
- What are saturated, unsaturated, and supersaturated solutions?
- How do pressure and temperature affect the solubility of gases?

Review Vocabulary

solution: a homogeneous mixture that remains constantly and uniformly mixed and has particles that are so small that they cannot be seen with a microscope

New Vocabulary

concentration
solubility
saturated solution
unsaturated solution
supersaturated solution

Multilingual eGlossary

Concentration and Solubility

MAIN Idea In a given amount of solvent, concentration is the amount of solute actually dissolved and solubility is the maximum amount of solute that can dissolve.

Real-World Reading Link Lemonade tastes a particular way because of the specific amounts of the lemon juice and sugar in the drink. For example, if it is not sweet enough, you can add sugar.

Concentration

Suppose you add one teaspoon of lemon juice to a glass of water to make lemonade. Your friend adds four teaspoons of lemon juice to the same amount of water in another glass. You could say that your glass of lemonade is diluted and your friend's lemonade is concentrated because your friend's drink now has more lemon flavor than your drink has. A concentrated solution is one in which a large amount of solute is dissolved in the solvent. A dilute solution is one that has a small amount of solute in the solvent. These are relative concentrations.

Precise concentrations How much real fruit juice is in an average fruit drink? *Concentrated* and *diluted* are not precise terms. However, concentrations of solutions can be described precisely. The **concentration** of a solution is the amount of solute actually dissolved in a given amount of solvent.

One way to state concentration precisely is to give the percentage by volume of the solute. The percentage by volume of the juice in the orange drink shown in **Figure 7** is 10 percent. Adding 10 mL of solute to 90 mL of the solvent makes 100 mL of a ten percent solution. This means that for a volume of 100 mL of juice drink, there is a volume of 10 mL of juice (the solute) and 90 mL of water (the solvent).

$$\frac{10 \text{ mL juice}}{10 \text{ mL juice} + 90 \text{ mL water}} \times 100 = 10\% \text{ by volume of juice}$$

Figure 7 The concentrations of juice drinks often are given in percent by volume. Concentrations of juice drinks commonly range from 10 percent to 100 percent juice.

Identify ***the product that has the highest concentration of orange juice.***

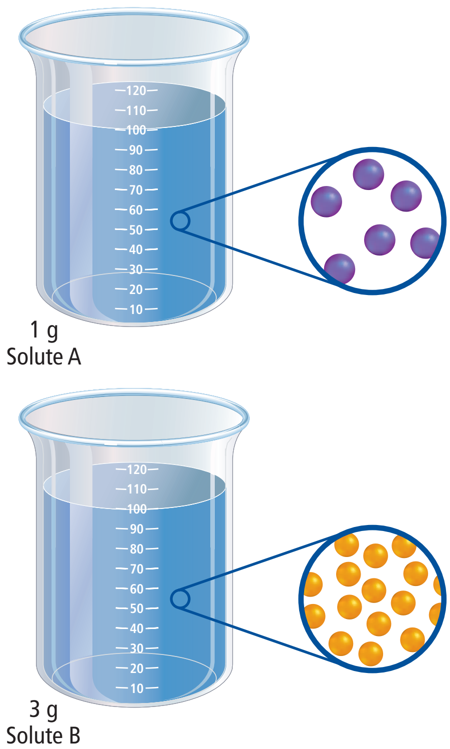


Figure 8 Three grams of solute B dissolve in 100 mL of water. In the same temperature and volume of water, only one gram of solute A dissolves. This means that solute B is more soluble in water.

Inquiry Virtual Labs

How much can dissolve?

You can stir several teaspoons of sugar into lemonade, and the sugar will dissolve. However, if you continue adding sugar, a point is eventually reached when no more sugar dissolves and the excess sugar sinks to the bottom of the glass. This indicates how soluble sugar is in water. **Solubility** (sol yuh BIH luh tee) is the maximum amount of a solute that can be dissolved in a given amount of solvent at a given temperature. Solubility of substances dissolved in water is often expressed as grams of solute per 100 g of water (g/100 g water).

Reading Check **Explain** What is solubility?

Comparing solubilities **Figure 8** shows two beakers with the same volume of water and two different solutes. In one beaker, one gram of Solute A dissolves completely, but additional solute does not dissolve and falls to the bottom of the beaker. In the other beaker, one gram of Solute B dissolves completely, and two more grams of Solute B also dissolve before additional solute begins to fall to the bottom of the beaker. If you assume that the temperature of the water is the same in both beakers, you can conclude that substance B is more soluble in water than substance A.

The solubilities of solutes in water vary. **Table 1** shows the solubilities of several substances in water at a temperature of 20°C. For solutes that are gases, such as hydrogen, oxygen, and carbon dioxide, the pressure must be given with the solubility, since the solubility can vary at different pressures.

Table 1 Solubility in Water at 20°C and Normal Atmospheric Pressure

State of Substance	Substance	Solubility in g/100 g of Water
Solid	salt (sodium chloride)	35.9
	baking soda (sodium bicarbonate)	9.6
	washing soda (sodium carbonate)	21.4
	lye (sodium hydroxide)	109.0
	table sugar (sucrose)	203.9
Gaseous	hydrogen	0.00017
	oxygen	0.005
	carbon dioxide	0.16

Types of Solutions

How much solute can dissolve in a given amount of solvent? That depends on a number of factors, including the solubility of the solute. Here, you will examine three types of solutions that are defined by the amount of a solute dissolved in a solvent.

Saturated solutions If you add 35 g of copper(II) sulfate ($CuSO_4$) to 100 g of water at 20°C, only 32 g will dissolve. You have a saturated solution because no more copper(II) sulfate can dissolve. A **saturated solution** is a solution that contains all of the solute that it can hold at a given temperature. However, if you heat the mixture to a higher temperature, more copper(II) sulfate dissolves.

Generally, as the temperature of a liquid solvent increases, the amount of solid solute that can dissolve in it also increases. **Table 2** shows the amounts of a few solutes that can dissolve in 100 g of water at different temperatures. Each would form a saturated solution. Some of these are also compounds shown on the graph in **Figure 9.**

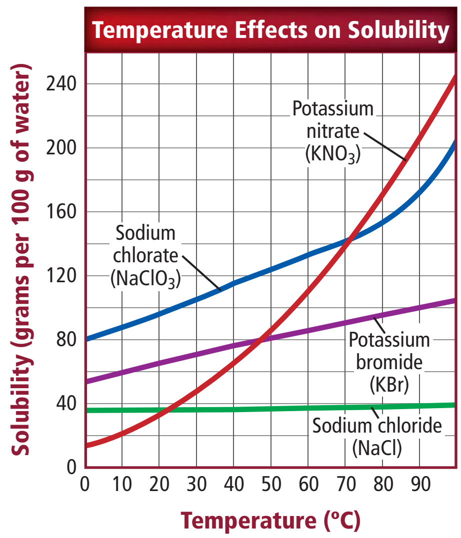
Solubility curves Each line on the graph from **Figure 9** is called a solubility curve for a particular substance. You can use a solubility curve to determine how much solute will dissolve at any temperature given on the graph. For example, about 79 g of potassium bromide (KBr) will form a saturated solution in 100 g of water at 50°C. How much sodium chloride (NaCl) will form a saturated solution with 100 g of water at the same temperature? You can also see that as temperature increases, so does the solubility of a substance.

Unsaturated solutions An **unsaturated solution** is any solution that can dissolve more solute at a particular temperature. Often times, when a saturated solution is heated to a higher temperature, it becomes unsaturated and is therefore able to dissolve more solute. The term *unsaturated* is not a precise term. If you look at **Table 2,** you will see that 35.9 g of sodium chloride (NaCl) forms a saturated solution in 100 g of water with a temperature of 20°C. However, an unsaturated solution of sodium chloride could be any amount less than 35.9 g in 100 g of water with a temperature of 20°C.

Table 2 Solubility of Compounds in g/100 g of Water

Compound	0°C	20°C	100°C
Copper(II) sulfate	23.1	32.0	114
Potassium bromide	53.6	65.3	104
Potassium chloride	28.0	34.0	56.3
Potassium nitrate	13.9	31.6	245
Sodium chlorate	79.6	95.9	204
Sodium chloride	35.7	35.9	39.2
Sucrose (sugar)	179.2	203.9	487.2

Figure 9 The effect of temperature on the solubility of four different compounds is shown in this solubility curve.



A seed crystal of sodium acetate is added to a supersaturated solution of sodium acetate.

Excess solute immediately forms a solid.

A solid continues to form until the solution is saturated.

Figure 10 A supersaturated solution is unstable.

Explain ***why supersaturated solutions are unstable.***

Supersaturated solutions If you make a saturated solution of potassium nitrate (KNO_3) at 100°C and then let it cool to 20°C, part of the solute comes out of solution. At the lower temperature, the solvent cannot hold as much solute. Most other saturated solutions behave in a similar way when cooled.

However, if you cool a saturated solution of sodium acetate ($NaC_2H_3O_2$) from 100°C to 20°C without disturbing it, no solute comes out of solution. At this point, the solution is supersaturated. A **supersaturated solution** is one that contains more solute than a saturated solution at the same temperature. Supersaturated solutions are unstable. **Figure 10** shows that when a seed crystal of sodium acetate is dropped into the supersaturated solution, excess sodium acetate comes out of solution.

Solution Energy

The formations of some solutions are exothermic—they give off energy to the surrounding environment. One example is reusable heat packs. The heat packs contain a supersaturated solution of sodium acetate ($NaC_2H_3O_2$). The solution warms when Na^+ and $C_2H_3O_2^-$ ions interact with water molecules.

On the other hand, some substances must draw energy from the surroundings to dissolve. During this endothermic process, the solution becomes colder. Cold packs made of ammonium nitrate (NH_4NO_3) and water operate in this way. When the inner bag is broken, water mixes with ammonium nitrate. The interaction between ammonium nitrate and water draws energy from the surroundings, which causes the pack to cool.

Solubility of Gases

If you shake an opened bottle of a carbonated soft drink, it bubbles up and might squirt out. Shaking, stirring, or pouring a solution of a gas exposes more gas particles to the surface, where they escape from the liquid and come out of solution.

Figure 11 These carbonated soft drinks are bottled under pressure to keep carbon dioxide in solution. Opening the bottles reduces the pressure on the surface of the gas-liquid solution and carbon dioxide bubbles out of solution.

Pressure effects Carbonated soft drinks are bottled so that the pressure inside of the bottle is greater than the pressure outside of the bottle. This increases the amount of carbon dioxide dissolved in the liquid. When you open the bottle, the pressure inside of the bottle decreases and the carbon dioxide gas mixed in the soft drink escapes from the soft drink and bubbles out, as shown in **Figure 11.**

Temperature effects Another way to increase the amount of gas that dissolves in a liquid is to cool the liquid. This is just the opposite of what you do to increase the amounts of most solids dissolved in a liquid. For example, even more carbon dioxide will bubble out of a warm soft drink than a cold soft drink.

Section 2 Review

SC.912.L.18.12

Section Summary

- Solubility curves help predict how much solute can dissolve at a particular temperature.
- Saturated, unsaturated, and supersaturated solutions are defined by how much solute can dissolve in a solvent.
- Solutions absorb or give off energy as they form.
- Temperature and pressure affect how much gas dissolves in a liquid.

10. MAIN Idea **Contrast** What is the difference between solubility and concentration?
11. **Compare and contrast** the difference between relative and precise concentrations. Give examples.
12. **Explain** Do all solutes dissolve to the same extent in the same solvent? How do you know?
13. **Identify** the type of solution that you have if solute continues to dissolve as you add more.
14. **Think Critically** Explain how keeping a carbonated beverage capped and refrigerated helps keep it from going flat.

Apply Math

15. **Calculate** By volume, orange drink is ten percent each of orange juice and corn syrup. A 1.5-L can of the drink costs $0.95. A 1.5-L can of orange juice is $1.49, and 1.5 L of corn syrup is $1.69. Per serving, does it cost less to make your own orange drink or to buy it?

Assessment Online Quiz

Section 3

SC.912.P.8.2: Differentiate between physical and chemical properties and physical and chemical changes of matter. **SC.912.L.18.12:** Discuss the special properties of water that contribute to Earth's suitability as an environment for life: cohesive behavior, ability to moderate temperature, expansion upon freezing, and versatility as a solvent. **ALSO COVERS: MA.912.S.3.2**

Reading Preview

Essential Questions

- Why do some solutions conduct electricity?
- What are two ways that some solutes form ions in solution?
- How do solutes affect the freezing and boiling points of solvents?

Review Vocabulary

ion: charged particle that has greater or fewer electrons than protons

New Vocabulary

electrolyte
nonelectrolyte
ionization
dissociation

Multilingual eGlossary

Particles in Solution

MAIN Idea Dissolved particles can both lower the freezing point and raise the boiling point of a solvent.

Real-World Reading Link If you have ever made homemade ice cream, you know that one of the ingredients is salt. It might have struck you as strange that most of it was added to the ice, not the actual ice cream mixture. Salt helps to freeze the ice cream.

Ion Formation in Solution

Did you know that there are charged particles in your body that conduct electricity? In fact, you could not live without them. Some help nerve cells transmit messages. Each time that you blink your eyes or wave your hand, nerves control how muscles respond. Recall that these charged particles are called ions. Compounds that produce solutions of ions in water are known as **electrolytes.**

Solutions containing electrolytes conduct electricity. Some substances, such as sodium chloride, are strong electrolytes because they are entirely in the form of ions in solution. Strong electrolytes conduct a strong current. Other substances, such as acetic acid in vinegar, remain mainly in the form of molecules when they dissolve. They produce few ions, conduct a weak current, and they are called weak electrolytes. Substances that form no ions in water and do not conduct electricity are called **nonelectrolytes.** Fats and sugars are examples of nonelectrolytes.

Ionization Solutions of electrolytes form in two ways. One way applies to molecular solutions, such as hydrogen chloride in water. The molecules of hydrogen chloride are composed of neutral atoms. In order to form ions, the molecules must be broken apart so that the atoms take on a charge. The process in which molecular compounds dissolve in water and form charged particles is called **ionization.** The process is shown in **Figure 12,** using hydrogen chloride (HCl) as a model.

Concepts in Motion
Animation

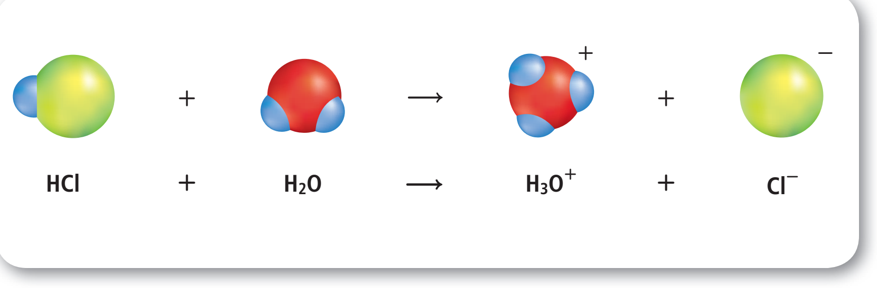


Figure 12 Both hydrogen chloride (HCl) and water (H_2O) are polar molecules. Water surrounds the hydrogen chloride molecules and pulls them apart, forming positive hydrogen ions (H^+) and negative chloride ions (Cl^-). The water molecules attract the hydrogen ions and form hydronium ions (H_3O^+).

Dissociation The second way that solutions of electrolytes form is the separation of ions in ionic compounds. The ions already exist in the ionic compound. Polar water molecules surround the ionic compound and pull apart the compound into its individual ions. **Dissociation** is the process in which positive and negative ions of an ionic solid mix with the solvent to form a solution.

Reading Check **Name** the two ways that solutions of electrolytes form.

A model of a sodium chloride (NaCl) crystal is shown in **Figure 13.** In the crystal, each positive sodium ion (Na^+) is attracted to six negative chloride ions (Cl^-). Each of the negative chloride ions is attracted to six positive sodium ions, and these attractions create a continuous pattern that exists throughout the crystalline structure.

When placed in water, the crystalline structure breaks apart. Remember that water molecules are polar, which means that the positive ends of the water molecules—the hydrogen atoms in a water molecule—are attracted to the negative chloride ions. Likewise, the negative end of the water molecule—the oxygen atom—is attracted to the positive sodium ions.

In **Figure 14,** water molecules approach the sodium ions (Na^+) and chloride ions (Cl^-) in the crystal. The water molecules break apart the crystalline structure by pulling the ions away and surrounding them in solution. The sodium and chloride ions have dissociated. The solution now consists of sodium and chloride ions mixed with water. The ions move freely through the solution and are capable of conducting an electric current.

Reading Check **Compare and Contrast** What are the differences and similarities between dissociation and ionization?

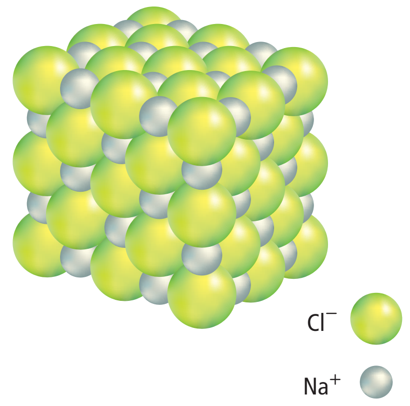
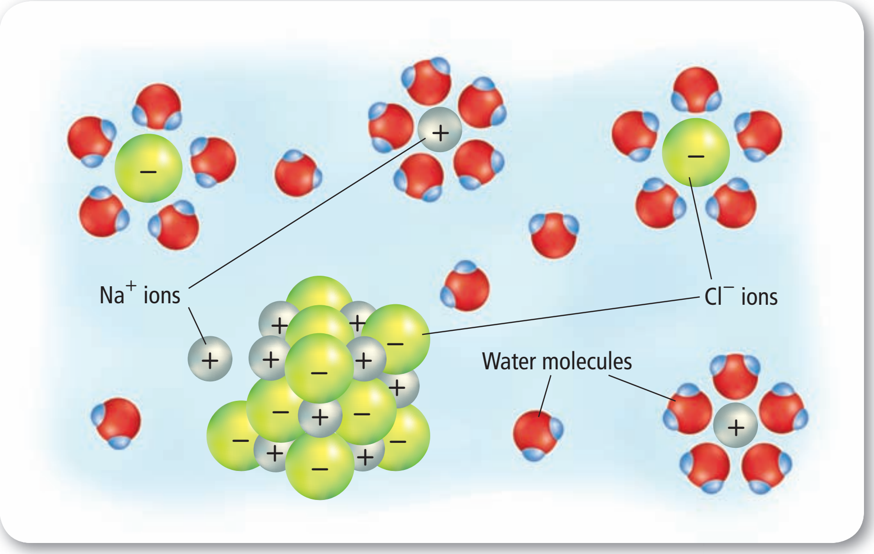


Figure 13 This is a model of a sodium chloride crystal. Each chloride ion is surrounded by six sodium ions and vice versa.



Concepts in Motion
Animation

Figure 14 Sodium chloride (NaCl) is an ionic compound, and water is a polar molecule. Sodium chloride dissociates as water molecules attract and pull the sodium and chloride ions from the crystal. Water molecules then surround and separate the Na^+ and Cl^- ions.

Explain ***Why will sodium chloride in solution conduct electricity?***

VOCABULARY

ACADEMIC VOCABULARY

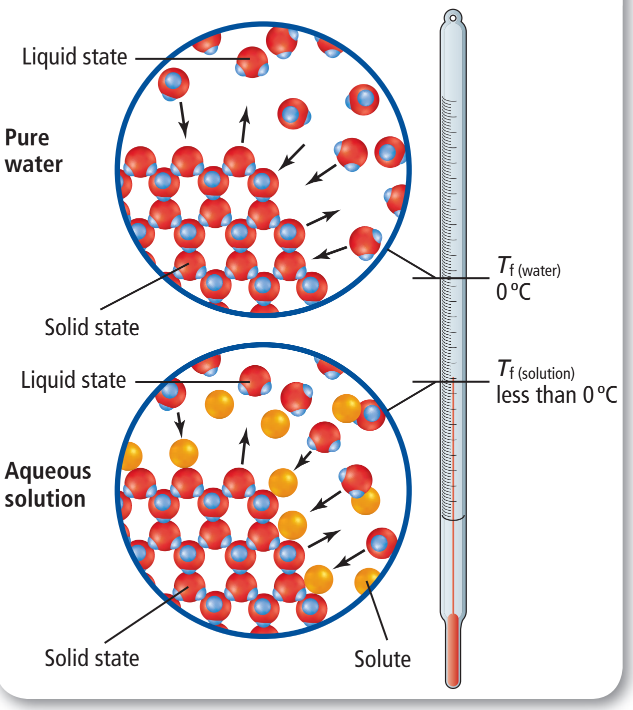
Affect

to produce a material influence upon or alteration in

The rain affected their plans for a picnic.

■ **Figure 15** Freezing is the change from the liquid to the solid state. If a solute is added, it can prevent the liquid from forming an orderly solid at its usual freezing point.

Explain ***how adding a solute affects the freezing point of a solution.***



Effects of Solute Particles

All solute particles—polar and nonpolar, electrolyte and nonelectrolyte—affect the physical properties of the solvent. These effects can be useful. For example, adding antifreeze to water in a car radiator lowers the freezing point of the radiator fluid. Salt added to the ice and water mixture in an ice cream maker lowers the freezing point of the solution, and the ice cream freezes faster. The effect that a solute has on a solvent depends on the number of solute particles in solution and not on the chemical nature of the particles.

Lowering freezing point Adding a solute, such as antifreeze, to a solvent lowers the freezing point of the solvent. The amount that the freezing point lowers depends upon the concentration of the solute particles that you add.

As a substance freezes and changes state from a liquid to a solid, the particles arrange themselves in an orderly pattern. A solute interferes with the formation of this pattern, making it harder for the solvent to freeze, as shown in **Figure 15.** To overcome this, the temperature of the solvent must decrease to freeze the solution.

Animal antifreeze Animals that live in extremely cold climates have their own internal antifreeze. Caribou, for example, contain substances in the lower sections of their legs that prevent freezing in subzero temperatures. The caribou can stand for long periods of time in snow with no harm to their legs.

Fish living in polar waters also have a natural chemical antifreeze called glycoprotein (gli koh PROH teen) in their bodies. Glycoprotein prevents ice crystals from forming in moist tissues in fish.

Raising boiling point Surprisingly, antifreeze also raises the boiling point of the radiator fluid. How can it do this? Solute particles interfere with the solvent particles as they transition from liquid to gas at the surface of the solution. This lowers the vapor pressure. As a result, more energy is needed for the solvent to escape from the liquid surface. The boiling point of the solution will be higher than the boiling point of pure solvent. The amount the boiling point is raised depends upon the concentration of solute present.

Car radiators The beaker in **Figure 16** on the left represents a car radiator when it contains water only—no antifreeze. Some of the water molecules on the surface will vaporize and change to the gaseous state. The number of water molecules that vaporize depends upon the temperature of the liquid water. As temperature increases, water molecules move more quickly and more molecules vaporize. Finally, when the pressure of the water vapor equals atmospheric pressure, the water begins to boil.

Figure 16 on the right shows the result of adding antifreeze to water. Particles of solute are evenly distributed throughout the solution, including at the surface. Now fewer water molecules can reach the surface and vaporize, making the vapor pressure of the solution lower than that of the pure solvent. This means that it will require a higher temperature to make the water boil. Antifreeze increases the boiling point of the water in a vehicle's radiator and helps prevent overheating.

Reading Check **Describe** How does antifreeze affect the vapor pressure of a pure solvent?

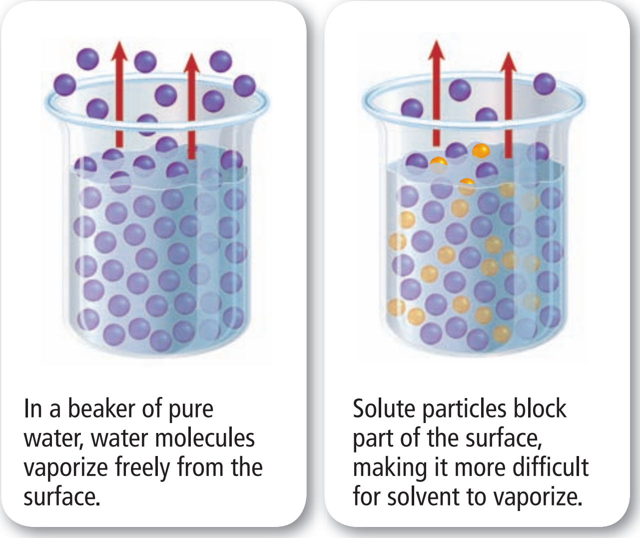


Figure 16 Solute particles raise the boiling point of a solution.

Describe ***how antifreeze in a car can help prevent both freezing and overheating.***

Section 3 Review

SC.912.P.8.2, SC.912.L.18.12, MA.912.S.3.2

Section Summary

- Ionization and dissociation are two ways to form ions in solution.
- Solute particles lower the freezing point of a solution.
- Solute particles raise the boiling point of a solution.

16. MAIN Idea **Explain** how the concentration of a solute in a solution influences its boiling point and freezing point.
17. **Identify** what kinds of solute particles are present in water solutions of electrolytes and nonelectrolytes.
18. **Determine** whether ionization or dissociation has taken place if calcium phosphate ($Ca_3(PO_4)_2$) breaks into Ca^{2+} and PO_4^{3-}.
19. **Think Critically** People often put salt on ice that forms on sidewalks and driveways during the wintertime. The salt helps melt the ice, forming a saltwater solution. Explain why this solution resists refreezing.

Apply Math

20. **Graph** Use the data points (0, 12), (10, 8), (20, 4), and (30, 0) to graph the effect of a solute on the freezing point of a solvent. Label the *x*-axis *Solute (g)* and the *y*-axis *Freezing point (degrees Celsius)*. Find the slope of the line that you graph.

Assessment Online Quiz

LAB Boiling Points of Solutions

MA.912.S.3.2: Collect, organize, and analyze data sets, determine the best format for the data and present visual summaries from the following: bar graphs, line graphs, stem and leaf plots, circle graphs, histograms, box and whisker plots, scatter plots, and cumulative frequency (ogive) graphs.

Objective

- **Determine** how adding salt to water affects the boiling point of water.

Background: Adding salt to water and adding antifreeze to a car radiator have a common result—increasing the boiling point.

Question: *How much can the boiling point of a solution be changed?*

Preparation

Materials

distilled water (400 mL)
Celsius thermometer
table salt (NaCl) (72 g)
ring stand
hot plate
250-mL beaker

Safety Precautions

Procedure

1. Read the procedure and safety information, and complete the lab form.
2. Copy the data table shown below. Bring 100 mL of distilled water to a gentle boil in a 250-mL beaker. Record the temperature in degrees Celsius. Do not touch the hot plate surface.

Effects of Solute on Boiling Point

Grams of NaCl Solute	Boiling Point (°C)
0	
12	
24	
36	

3. Dissolve 12 g of NaCl in 100 mL of distilled water. Bring this solution to a gentle boil, and record its boiling point in the table.
4. Add 12 g more of NaCl to bring the total NaCl in solution to 24 g. Record the solution's boiling point in the table.
5. Repeat step 4, for a total of 36 g NaCl in solution, and record the boiling point in the table.
6. Make a graph of your results. Place grams of NaCl on the x-axis, and place boiling point on the y-axis.

Conclude and Apply

1. **Summarize** the results of steps 2–5.
2. **Explain** the differences between the boiling points of pure water and a saltwater solution.
3. **Predict** the effect of doubling the amount of water instead of the amount of NaCl in step 4.
4. **Determine** the value for the boiling point temperatures of 6 g, 18 g, and 30 g of NaCl in 100 mL of water as read from your graph.
5. **Predict** what would happen if you continued to add more salt. Would your graph continue in the same pattern or eventually level off? Design an experiment to test your prediction.

COMMUNICATE YOUR DATA

Determine Average your class's data and redraw the graph in procedure step 6 using the average data. As a class, discuss whether the average data is more accurate than the individual data.

Section 4

SC.912.L.16.10: Evaluate the impact of biotechnology on the individual, society and the environment, including medical and ethical issues. **SC.912.L.18.12:** Discuss the special properties of water that contribute to Earth's suitability as an environment for life: cohesive behavior, ability to moderate temperature, expansion upon freezing, and versatility as a solvent. **ALSO COVERS: SC.912.P.8.2**

Reading Preview

Essential Questions

- What solutes do not dissolve well in water?
- How does polarity affect solubility?
- How does soap work?

Review Vocabulary

solvent: the substance in which the solute dissolves

Multilingual eGlossary

Dissolving Without Water

MAIN Idea Polarity determines which solvent will dissolve a substance.

Real-World Reading Link Do you take vitamins? Some vitamins stay in your body and accumulate, and others quickly leave your body. What is the difference? The length of time that they will remain is determined by whether the vitamins dissolve in fat or in water.

When Water Will Not Work

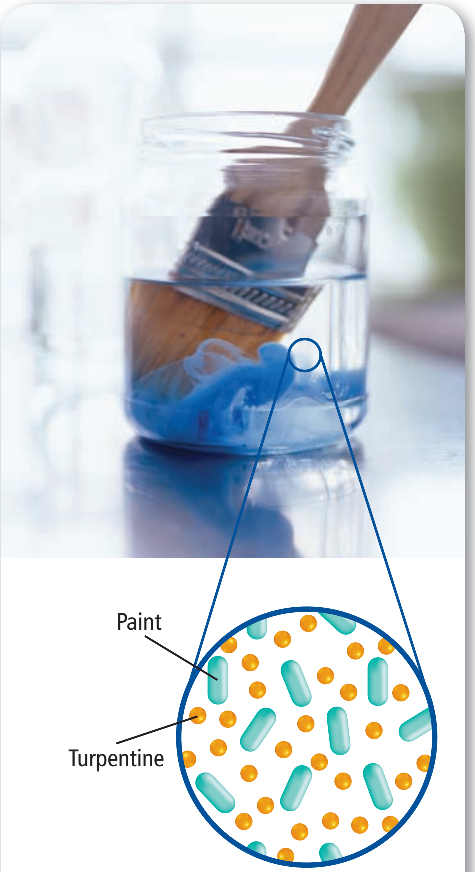
Water often is referred to as the universal solvent because it can dissolve so many substances. However, there are some substances, such as oil, that cannot dissolve in water. Why?

As you learned in the first section, water molecules have positive and negative areas that allow them to attract polar or ionic solutes. Recall that polar molecules have positive areas and negative areas. However, nonpolar molecules have no separated positive and negative areas. Because of this, nonpolar molecules are not attracted to ionic or polar substances, such as water.

Nonpolar solutes Nonpolar molecules do not dissolve in water or only dissolve a very small amount. For example, the oil-contaminated water shown in **Figure 17** shows how the oil, which consists of nonpolar molecules, does not mix with seawater, a polar solution of water, salt, and nutrients.

Oils contain large molecules made of carbon and hydrogen atoms, which are called hydrocarbons. In hydrocarbons, carbon and hydrogen atoms share electrons in a nearly equal manner. The nonpolar oil molecules are not attracted to the polar water molecules in the ocean and will not dissolve.

Figure 17 Oil is composed of nonpolar molecules, and water molecules are polar. Oil does not mix with water and remains on the surface of the water.



■ **Figure 18** Turpentine, a nonpolar solvent, mixes with oil-based paints as a thinner and can also be used as a brush cleaner.

Nonpolar solvents Some substances around your house may be useful as nonpolar solvents. For example, mineral oil can dissolve candle wax from glass or metal candleholders. Mineral oil and wax are nonpolar substances. Oily peanut butter, a nonpolar solvent, is sometimes used to remove bubble gum, also a nonpolar substance, from hair.

Many nonpolar solvents are connected with specific jobs. Oil-based paints contain pigments that are dissolved in oil. In order to thin or remove such paints, a nonpolar solvent must be used. People who paint pictures using oil-based paints probably use the solvent turpentine. It comes from the sap of a pine tree. **Figure 18** shows how well turpentine dissolves nonpolar paint.

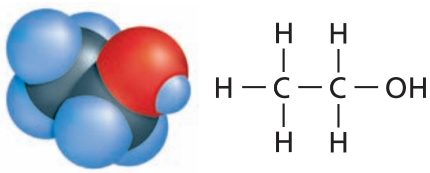
Dry cleaners also use nonpolar solvents. The word *dry* refers to the fact that no water is used in the process. Because molecules of a nonpolar solute can easily slip in among molecules of a nonpolar solvent, dry cleaning removes oil and grease stains.

Drawbacks of nonpolar solvents Although nonpolar solvents have many uses, they have some drawbacks, too. First, many nonpolar solvents are flammable. Also, some solvents are extremely toxic. These solvents are hazardous if they come into contact with skin or if their vapors are inhaled. For these reasons, you must always be careful when handling these substances and never use them in an enclosed area. Good ventilation is critical because nonpolar solvents tend to evaporate more readily than water. Even small amounts can produce high concentrations of harmful vapor in the air.

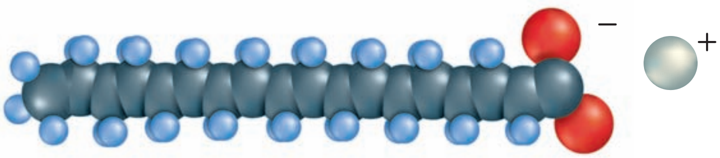
Versatile Molecules

Some substances are versatile because they have a nonpolar end and a polar end. For example, **Figure 19** shows that the alcohol ethanol has a polar and a nonpolar end. In addition, sodium stearate has a polar and a nonpolar end. As a result, ethanol and sodium stearate can dissolve polar and nonpolar substances. Sodium stearate is an important ingredient in soap.

■ **Figure 19** Ethanol and sodium stearate are examples of molecules that have both polar and nonpolar ends.



Ethanol (C_2H_5OH) has a polar –OH group and a nonpolar –C_2H_5 group.



The long end the hydrocarbon chain for sodium stearate is nonpolar. One end of the molecule is ionic.

How soap works The oils on human skin and hair keep them from drying out, but the oils can also attract and hold dirt. The oily dirt is a nonpolar mixture, so washing with water alone will not clean away the dirt. This is why soap is needed.

Soaps are substances that have polar and nonpolar properties. Soaps are salts of fatty acids. Fatty acids are long, hydrocarbon molecules with a nonpolar end and a carboxylic acid group –COOH at the other end. When a soap is made, the hydrogen atom of the acid group is removed, leaving a negative charge behind to form an ionic bond with a positive ion of sodium or potassium. For example, when Na^+ bonds with $–COO^-$, the salt, sodium stearate shown in **Figure 19** is made.

Reading Check **Summarize** Why is soap required to clean oily dirt?

The ionic end of soap dissolves in water, and the long hydrocarbon portion dissolves in oily dirt. In this way, the dirt is removed from your skin, hair, or a fabric, suspended in the wash water, and washed away, as shown in **Figure 20.**

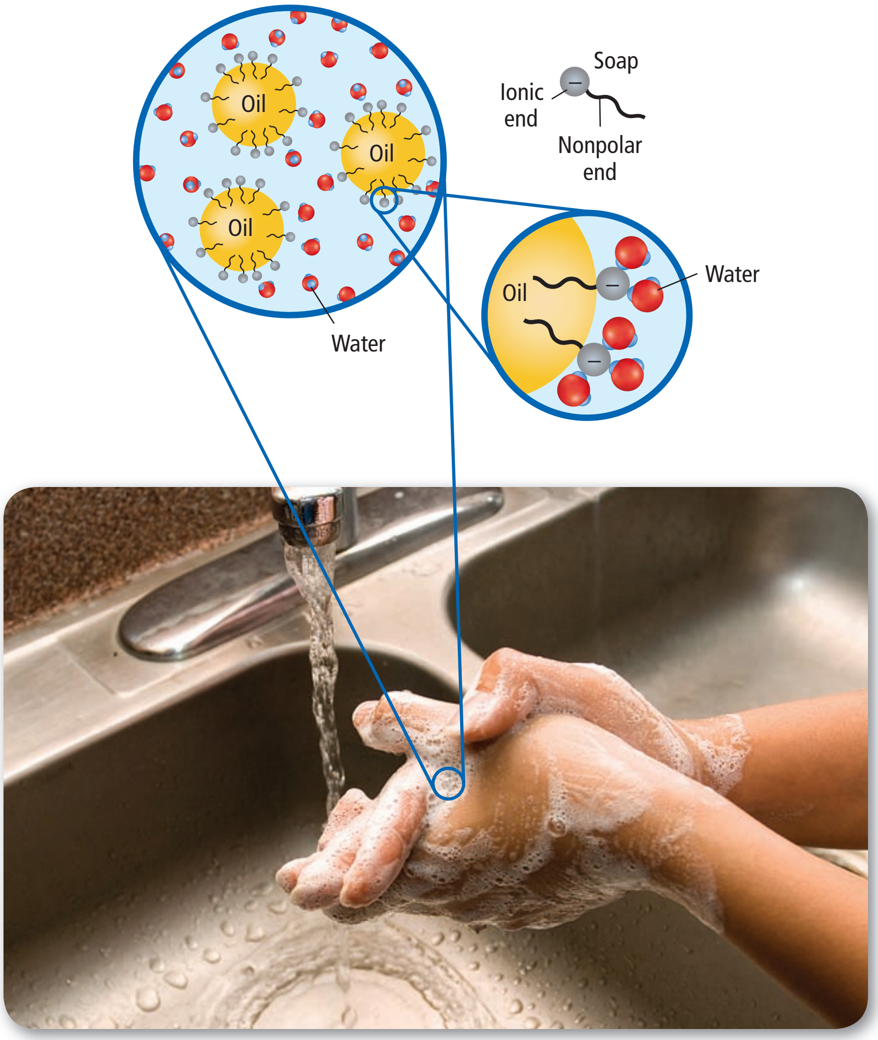


Figure 20 Soap cleans because its nonpolar hydrocarbon part dissolves in oily dirt and its ionic part interacts strongly with water. The soap carries the oily dirt along as you use the water to rinse.

MiniLab

Inquiry MiniLab

Observe Clinging Molecules

Procedure

WARNING: ***Rubbing alcohol is flammable.***

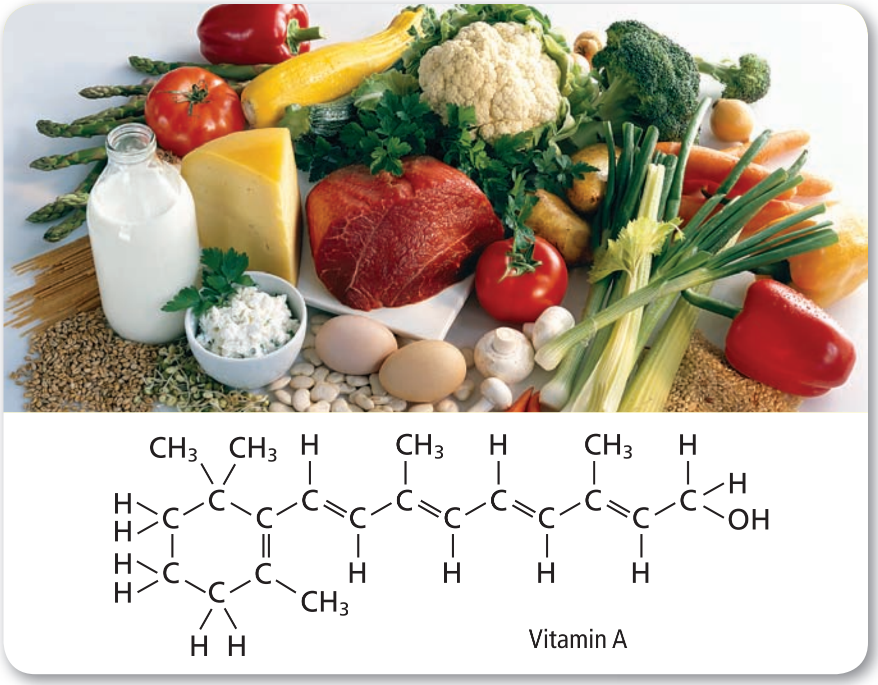
1. Read the procedure and safety information, and complete the lab form.
2. Lay **two clean pennies** side by side and heads up on a **paper towel.**
3. Slowly place drops of **water** from a **dropper** onto the head of one penny. Count each drop, and continue until the accumulated water spills off the edge of the penny.
4. With adult supervision, repeat step 3 using **rubbing alcohol** (a solution of approximately 70 percent isopropyl alcohol) and the other penny.

Analysis

1. **Identify** Which penny held the most drops before liquid spilled over the edge?
2. **Determine** How polar do you think isopropyl alcohol (C_3H_7OH) is compared to water?
3. **Conclude** How do the results of the investigation support the concept of polarity and the attraction between molecules?

SC.912.L.18.12: Discuss the special properties of water that contribute to Earth's suitability as an environment for life: cohesive behavior, ability to moderate temperature, expansion upon freezing, and versatility as a solvent.

■ **Figure 21** The structural formula of vitamin A shows a long hydrocarbon chain that makes it nonpolar. Foods such as liver, lettuce, cheese, eggs, carrots, sweet potatoes, and milk are good sources of this fat-soluble vitamin. Vitamins D, E, and K are also fat-soluble vitamins.



Polarity and Vitamins

Taking the right types of vitamins in the correct doses is important to your health. Some of the vitamins that you need, such as vitamin A, as shown in **Figure 21,** are nonpolar and dissolve in fat, which is another nonpolar substance. Because fat and fat-soluble vitamins do not wash away with the water that is present in the cells throughout your body, the excess vitamins can accumulate in your tissues. Fat-soluble vitamins are toxic in high concentrations, so taking large doses that are not recommended by your physician can be dangerous.

Other vitamins, such as vitamins B and C, are polar molecules, meaning they are water soluble. When you look at the structure of vitamin C, as shown in **Figure 22,** you will see that it has several carbon-to-carbon bonds. This might make you think that it is nonpolar. But, if you look again, you will see that it also has several oxygen-to-hydrogen bonds that resemble those found in water. This makes vitamin C polar.

■ **Figure 22** Although vitamin C has carbon-to-carbon bonds, it is water soluble because it also has polar groups. Foods that are good sources of vitamin C help heal wounds and help the body absorb iron.

Explain ***Compare the number of oxygen atoms in vitamin C with the number in vitamin A in Figure 21. What effect does oxygen have in these two molecules?***

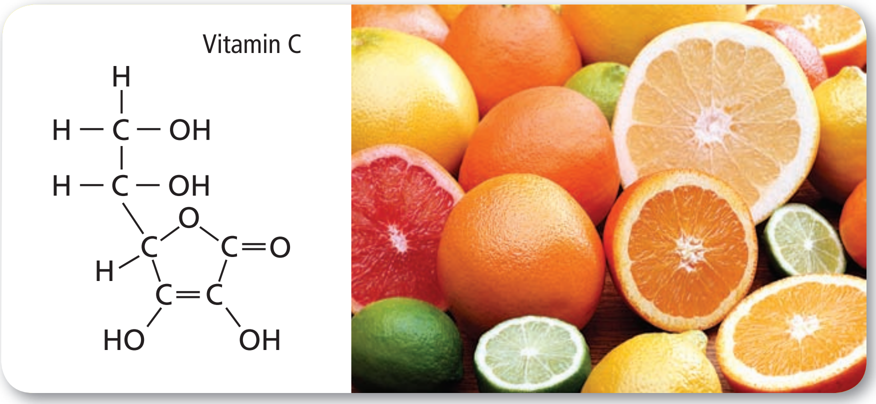


Table 3	Sources of Vitamin C	
Food	**Serving Size**	**Amount of Vitamin C (mg)**
Orange juice, fresh	1 cup	124
Green peppers, raw	$\frac{1}{2}$ cup	96
Broccoli, raw	$\frac{1}{2}$ cup	70
Cantaloupe	$\frac{1}{4}$ melon	70
Strawberries	$\frac{1}{2}$ cup	42

Polar vitamins dissolve readily in the water that is present in your body. These vitamins do not accumulate in tissue because any excess vitamin is washed away. For this reason, you must replace water-soluble vitamins more quickly than fat-soluble vitamins by eating enough of the foods that contain them or by taking vitamin supplements. **Table 3** shows a variety of sources of vitamin C. In general, the best way to stay healthy is to eat a variety of healthy foods. Such a diet will supply the vitamins that you need with no risk of overdoses.

Reading Check **Restate** Why is it necessary to replace water-soluble vitamins more quickly than fat-soluble vitamins?

VOCABULARY
WORD ORIGIN
Polar
comes from the Latin *polus* meaning *pole*
Polar solvents can dissolve polar solutes.

Section 4 Review

SC.912.L.16.10, SC.912.L.18.12

Section Summary

- Polar solvents dissolve polar solutes, and nonpolar solvents dissolve nonpolar solutes.
- Nonpolar solvents have many household and industrial uses.
- Some molecules have both polar and nonpolar parts and are versatile solvents.

21. MAIN Idea **Explain** how a polar solvent dissolves a polar solute and how a nonpolar solvent dissolves a nonpolar solute.
22. **Describe** polar and nonpolar molecules.
23. **Explain** how one solute can dissolve in both polar and nonpolar solvents.
24. **Draw** a diagram to explain how soap cleans your hands.
25. **Think Critically** What might happen to your skin if you washed too often?

Apply Math

26. **Calculate** If 60 mg of vitamin C in a multivitamin provides only 75 percent of the recommended daily dosage for children, how much is recommended?
27. **Interpret** To get the recommended dose of vitamin C, approximately how much fresh orange juice must you drink? (Refer to Table 3.)

Assessment Online Quiz

LAB Saturated Solutions

SC.912.L.18.12: Discuss the special properties of water that contribute to Earth's suitability as an environment for life: cohesive behavior, ability to moderate temperature, expansion upon freezing, and versatility as a solvent.

Objective

- **Observe** the effects of temperature on the amount of solute that dissolves.

Background: Two major factors to consider when you are dissolving a solute in water are temperature and the ratio of solute to solvent. What happens to a solution as the temperature changes? To be able to draw conclusions about the effect of temperature, you must keep other variables constant. For example, you must be sure to stir each solution in a similar manner.

Question: *How does solubility change as temperature is increased?*

Preparation

Materials

water at room temperature
large test tubes
Celsius thermometer
table sugar
copper wire stirrer, bent into a spiral, as shown in the photo above, right
test-tube holder
graduated cylinder (25 mL)
beaker (250 mL) with 150 mL of water
electric hot plate
test-tube rack
ring stand and clamp
balance

Safety Precautions

WARNING: *Do not touch the test tubes or the hot plate surface when the hot plate is turned on or is cooling down. When heating a solution in a test tube, keep it pointed away from yourself and from others. Do not remove goggles until clean up, including washing hands, is completed.*

Procedure

1. Read the procedure and safety information, and complete the lab form.
2. Copy the data table below.
3. Place 20 mL of water in a test tube.
4. Add 30 g of sugar to the same test tube in step 3.
5. Stir the solution. Does the sugar dissolve?

Data Table

Temperature (°C)	Total Grams of Sugar Dissolved

Inquiry Lab

6. If it dissolves completely, add another 5 g of sugar to the test tube. Does it dissolve?
7. Continue adding 5 g amounts of sugar at a time until no more sugar dissolves.
8. Now place a beaker with 150-mL of water in it on the hot plate. Carefully hang the thermometer from the ring stand so that the bulb is immersed about halfway into the beaker, making sure that the bulb does not touch the sides or bottom. Record the starting temperature.
9. Using a test-tube holder, place the test tube into the water.
10. Turn on the hot plate. Gradually increase the temperature of the hot plate, while stirring the solution in the tube until all of the sugar dissolves.
11. Note the temperature at which all of the sugar dissolves.
12. Add another 5 g of sugar, and continue stirring. Note the temperature at which this additional sugar dissolves.
13. Continue in this manner until you have six data points. Turn off the hot plate. Note the total amount of sugar that has dissolved.

Analyze Your Data

1. **Graph** Analyze your data by constructing a line graph. Place grams of sugar per 100 g of water on the *y*-axis, and place temperature in degrees Celsius on the *x*-axis. Because you used only 20 mL of water, multiply the number of grams of sugar by five.
2. **Interpret** Using your graph, estimate the solubility of sugar at 100°C and at 0°C, the boiling and freezing points of water, respectively.

Conclude and Apply

1. **Determine** How did the saturation change as the temperature was increased?
2. **Evaluate** Compare your results with those given in **Table 2.** Calculate the percent error of your results for the solubility of sugar at 0°C, 20°C, and 100°C.
3. **Analysis** What might have caused the percent errors calculated in question 2?

COMMUNICATE YOUR DATA

Evaluate Many, but not all, solutes can form supersaturated solutions with water. Work with your class to develop a test to evaluate whether sugar can form a supersaturated solution in water.

SCIENCE & HISTORY

SC.912.P.8.2: Differentiate between physical and chemical properties and physical and chemical changes of matter.

Hidden Nobel Prize Medals

On April 9, 1940, chemist George de Hevesy faced a dilemma. Outside his laboratory in Copenhagen, Denmark, Nazi forces were occupying the city. Inside, he held in his hand two Nobel Prize medals for physics, belonging to Max von Laue and James Franck, German scientists who had protested Nazi policies. They had left their medals, which resembled the medal shown in **Figure 1,** in Copenhagen for safekeeping.

Dissolving gold De Hevesy decided that the only way to make sure the Nazis would not seize the medals was to hide them in plain sight. Gold is not a very reactive element. One of the only chemicals that can accomplish the task is aqua regia, a mixture of nitric acid and hydrochloric acid. De Hevesy reacted the Nobel Prize medals with aqua regia, put the resulting solution in a jar, and stored it on a shelf with other liquid solutions.

Figure 1 Nobel Prizes are awarded in several categories including chemistry, medicine, physics, literature, economics, and peace.

Figure 2 The precipitate lead iodide is formed when lead nitrate reacts with sodium iodide.

Although the Nazis searched the laboratory, they left the solution undisturbed. After the end of World War II, the gold was extracted from the solution and sent to the Royal Swedish Academy of Sciences, the group that awards Nobel Prizes. Franck and von Laue later received newly cast medals to replace the ones that de Hevesy had dissolved.

The process of precipitation In the Nobel Prize medal example, the gold and aqua regia reacted to form substances that dissolve in water. Together, they formed a solution. The gold was extracted from the solution by a process called precipitation, as shown in **Figure 2.** Precipitation occurs when a reaction in a solution forms a solid product, called a precipitate, that does not dissolve in the solvent. De Hevesy's gold formed a precipitate that could be filtered from the liquid, cleaned, dried, and molded into the replacement medals.

WebQuest **Create** **Suppose you are a journalist present the day that Franck and von Laue received their recast Nobel Prize medals. Write a news article describing the scene and the interview that would take place with the scientists.**

Chapter 21 Study Guide

THEME FOCUS Structures and Properties of Matter

Solutions form as interactions between solute and solvent particles cause them to become mixed. The solutions can be described in terms of solubility and concentration.

BIG Idea A solution is a homogeneous mixture of a solute or solutes and a solvent or solvents.

Section 1 How Solutions Form

alloy (p. 647)
solute (p. 647)
solvent (p. 647)

MAIN Idea **A solution forms when a solute or solutes and a solvent or solvents become evenly mixed.**

- A solution is a homogeneous mixture.
- Solutions are composed of solutes and solvents.
- Stirring, surface area, and temperature all affect the rate of dissolving.

Section 2 Concentration and Solubility

concentration (p. 653)
saturated solution (p. 655)
solubility (p. 654)
supersaturated solution (p. 656)
unsaturated solution (p. 655)

MAIN Idea **In a given amount of solvent, concentration is the amount of solute actually dissolved and solubility is the maximum amount of solute that can dissolve.**

- Solubility curves help predict how much solute can dissolve at a particular temperature.
- Saturated, unsaturated, and supersaturated solutions are defined by how much solute can dissolve in a solvent.
- Solutions absorb or give off energy as they form.
- Temperature and pressure affect how much gas dissolves in a liquid.

Section 3 Particles in Solution

dissociation (p. 659)
electrolyte (p. 658)
ionization (p. 658)
nonelectrolyte (p. 658)

MAIN Idea **Dissolved particles can both lower the freezing point and raise the boiling point of a solvent.**

- Ionization and dissociation are two ways to form ions in solution.
- Solute particles lower the freezing point of a solution.
- Solute particles raise the boiling point of a solution.

Section 4 Dissolving Without Water

MAIN Idea **Polarity determines which solvent will dissolve a substance.**

- Polar solvents dissolve polar solutes, and nonpolar solvents dissolve nonpolar solutes.
- Nonpolar solvents have many household and industrial uses.
- Some molecules have both polar and nonpolar parts and are versatile solvents.

Review Vocabulary eGames

SC.912.P.8.2, SC.912.L.18.12, LA.910.2.2.3

Use Vocabulary

Complete each sentence with the correct term from the Study Guide.

28. In lemonade, sugar is a(n) _________ and water is the _________.

29. When ionic compounds undergo _________, they dissolve in water and form charged particles.

30. If more of substance B dissolves in water than substance A, then substance B has a higher _________ than substance A.

31. The amount of solute dissolved in a given amount of solvent is the _________.

32. More solute can dissolve in a(n) _________.

33. Nonpolar solutes in a solution are called _________.

Check Concepts

34. Which of the following is NOT a solution?
- **A)** glass of flat soda
- **B)** air in a scuba tank
- **C)** bronze alloy
- **D)** mud in a water tank

35. BIG Idea What term is NOT appropriate to use when describing solutions?
- **A)** heterogeneous
- **B)** homogeneous
- **C)** liquid
- **D)** solid

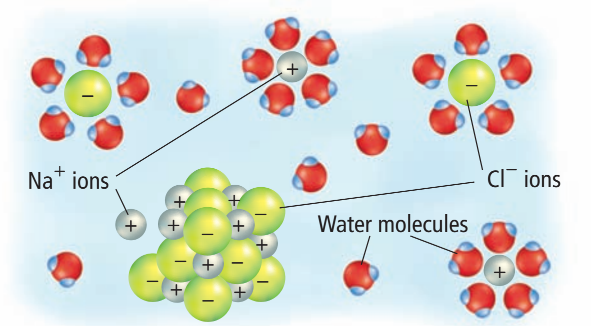
36. When iodine is dissolved in alcohol, what term is used to describe the alcohol?
- **A)** alloy
- **B)** solvent
- **C)** solution
- **D)** solute

37. What word is used to describe a mixture that is 85 percent copper and 15 percent tin?
- **A)** alloy
- **B)** solvent
- **C)** saturated
- **D)** solute

38. Solvents, such as paint thinner and gasoline, evaporate more readily than water because they are what type of compounds?
- **A)** ionic
- **B)** nonpolar
- **C)** dilute
- **D)** polar

39. What can a polar solvent dissolve?
- **A)** any solute
- **B)** a polar solute
- **C)** a nonpolar solute
- **D)** no solute

Use the figure below to answer question 40.



40. What process is the sodium chloride in the figure undergoing?
- **A)** dissociation
- **B)** electrolysis
- **C)** ionization
- **D)** saturation

41. What can you increase to make a gas more soluble in a liquid?
- **A)** particle size
- **B)** pressure
- **C)** stirring
- **D)** temperature

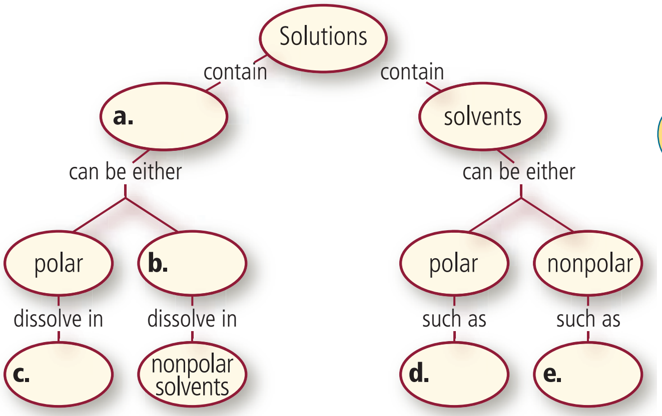
42. THEME FOCUS If a solute crystallizes out of a solution when a seed crystal is added, what kind of solution is it?
- **A)** unsaturated
- **B)** saturated
- **C)** supersaturated
- **D)** dilute

Assessment Online Test Practice

Interpret Graphics

43. Copy and complete the concept map on solutions.

Concepts in Motion **Interactive Concept Map**



Use the table below to answer question 44.

Limits of Solubility

Compound	Type of Solution	Amount of Solute Added to 100 g of Water at 20°C
$CuSO_4$	a.	32.0 g
KCl	b.	36.0 g
KNO_3	c.	31.6 g
$NaClO_3$	d.	92.9 g

44. Using the data in **Table 2**, complete the table above. Use the terms *saturated, unsaturated,* and *supersaturated* to describe the type of solution.

Think Critically

45. Hypothesize Why might potatoes cook more quickly in salt water than in pure water?

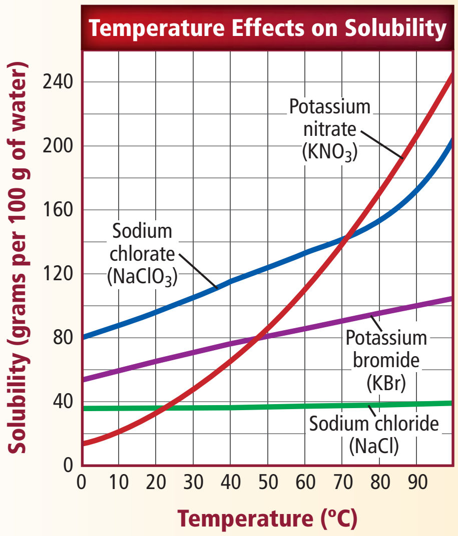
46. Explain What happens when an ionic compound such as copper(II) sulfate ($CuSO_4$) dissolves in water?

47. Describe Why is the term *dilute* not precise?

48. Explain Why is the statement, "Water is the solvent in a solution," not always true?

Apply Math

Use the graph below to answer question 49.



49. Interpret Data Determine the temperature at which a solution of 80 g potassium nitrate (KNO_3) in 100 mL of water is saturated.

50. Use Numbers How would you make a 25 percent solution by volume of apple juice?

51. Make and Use Graphs Using **Table 2,** make a graph of solubility versus temperature for copper(II) sulfate ($CuSO_4$) and potassium chloride (KCl). How would you make a saturated solution of each substance at 80°C?

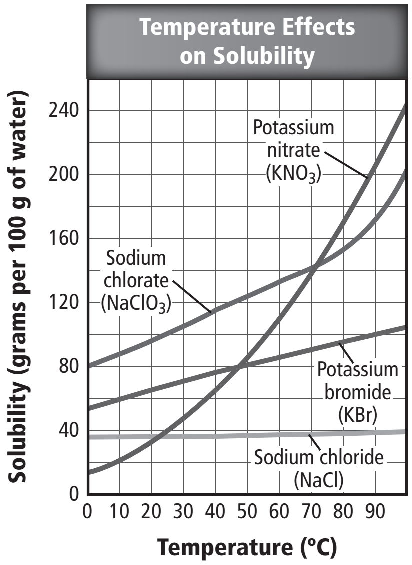
Assessment **Online Test Practice**

Standardized Test Practice

Multiple Choice

Record your answers on the answer sheet provided by your teacher or on a sheet of paper.

Use the graph below to answer questions 1–3.



1. How much potassium nitrate (KNO_3) will you have to add to 100 g of water at 40°C to prepare a saturated solution? SC.912.L.18.12
- **A.** 60 g
- **B.** 70 g
- **C.** 100 g
- **D.** 240 g

2. If 25 g of sodium chlorate ($NaClO_3$) are dissolved in 100 g of water at 70°C, how would you describe the solution? SC.912.L.18.12
- **A.** concentrated
- **B.** supersaturated
- **C.** saturated
- **D.** unsaturated

3. Which of the following will make a saturated solution if added to 100 g of water?
- **A.** 20 g of NaCl if the water is 50°C
- **B.** 100 g of KBr if the water is 90°C
- **C.** 80 g of $NaClO_3$ if the water is 30°C
- **D.** 60 g of KNO_3 if the water is 100°C

SC.912.L.18.12

4. Which of the following statements about solubility is true as the temperature increases?
- **A.** The solubility of both gases and solids increases. SC.912.L.18.12
- **B.** The solubility of both gases and solids decreases.
- **C.** The solubility of gases increases, and the solubility of solids decreases.
- **D.** The solubility of gases decreases, and the solubility of solids increases.

Use the table below to answer question 5.

Solubility of Substances in Water at 20°C

Substance	Solubility in g/100 g of Water
Sodium bicarbonate	9.6
Sodium carbonate	21.4
Sodium hydroxide	109.0
Sucrose	203.9

5. Which of the following is the most soluble in water at 20°C? SC.912.L.18.12
- **A.** sodium hydroxide
- **B.** sucrose
- **C.** sodium bicarbonate
- **D.** sodium carbonate

6. Which of the following statements about solute surface area is true? SC.912.L.18.12
- **A.** Grinding increases the surface area of the solute and slows down dissolving.
- **B.** Grinding increases the surface area of the solute and speeds up dissolving.
- **C.** Grinding decreases the surface area of the solute and slows down dissolving.
- **D.** Grinding decreases the surface area of the solute and speeds up dissolving.

Short Response

Record your answers on the answer sheet provided by your teacher or on a sheet of paper.

7. When you take clothing to the dry cleaner, it is important to identify any stains that are on the clothing. Why does the dry cleaner need this information? SC.912.L.18.12

Use the figure below to answer question 8.

8. The drawing above shows carbon dioxide gas dissolved in water. Assuming temperature and volume are equal, which bottle could contain more dissolved CO_2? Explain. SC.912.L.18.12

9. Why does shaking or pouring a carbonated drink cause gas to come out of solution? SC.912.L.18.12

10. The solubility of potassium chloride in water is 34 g per 100 g of water at 20°C. A warm solution containing 100 g of potassium chloride in 200 g of water is cooled to 20°C. How many grams of potassium chloride will come out of solution? (Assume the solution is not supersaturated.) SC.912.L.18.12

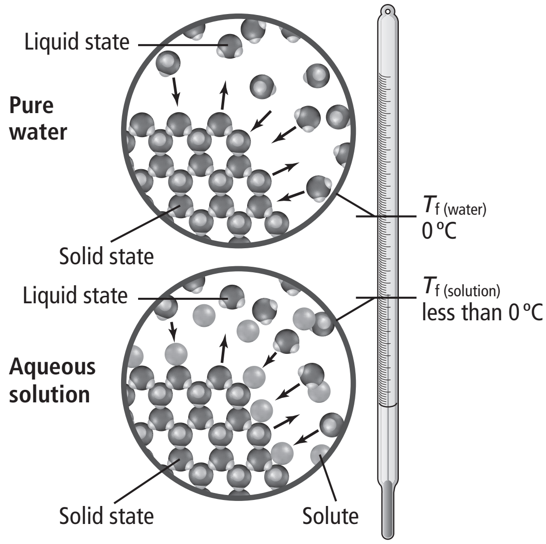
11. Why is salt mixed with ice in an ice cream maker? SC.912.L.18.12

Extended Response

Record your answers on a sheet of paper.

12. Why can carp, catfish, and other fish with low-oxygen needs live in warmer waters than trout, which need more oxygen to survive? SC.912.L.18.12

Use the figure below to answer question 13.



13. Explain what the figure shows. Describe this process. SC.912.L.18.12

14. You are given a clear-water solution containing potassium nitrate. How could you determine whether the solution is unsaturated, saturated, or supersaturated? SC.912.L.18.12

15. A solution conducts electricity. What do you know about the solution? SC.912.L.18.12

16. Why does antifreeze also raise the boiling point of water? SC.912.L.18.12

NEED EXTRA HELP?																
If You Missed Question . . .	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Review Section . . .	2	2	2	1, 2	2	1	4	2	2	2	3	2	3	2	3	3