SECTION

B

A LOOK AT WATER AND ITS CONTAMINANTS

As the preceding article indicates, scientists attribute the cause of the fish kill to something dissolved or suspended in the Snake River. What might those substances be? How can the search for the cause be narrowed further? Knowledge of the properties of water (and of substances that might be found in it) will aid in this task. To understand these properties, you will be introduced to matter at the particulate level. You will also begin to learn the language of chemistry and to use it to communicate with your classmates as you investigate the fish kill.

B.1 PHYSICAL PROPERTIES OF WATER

Water is a common substance—so common that it is usually taken for granted. You drink it, wash with it, swim in it, and sometimes grumble when it falls from the sky. But are you aware that water is one of the rarest and most unusual substances in the universe? As planetary space probes have gathered data, scientists have learned that the great abundance of water on Earth is unmatched by any planet or moon in our solar system. Earth is usually half-enveloped by water-laden clouds, as you can see in Figure 12. In addition, more than 70% of Earth's surface is covered by oceans having an average depth of more than three kilometers (two miles).

Kilo- (k) is the metric prefix meaning 1000. One kilometer (km) = 1000 meters (m).

Figure 12 *Earth as seen from space. What states of water can be observed in this winter scene?*

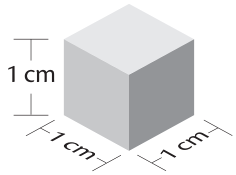


Figure 13 *One cubic centimeter (shown actual size).*

0 °C = 32 °F

Water is a form of matter. As you may recall from previous science courses, matter is anything that occupies space and has mass. All solids, liquids, and gases are classified as matter. Matter can be distinguished by its characteristic properties. Water has many important **physical properties,** properties that can be observed and measured without changing the chemical makeup of the substance. One physical property of matter is **density,** which is a measure of the mass of a material in a given volume. The density of water as a liquid is easy to remember. Because one milliliter (mL) of water has a mass of 1.00 g, the density of water is 1.00 g/mL. One milliliter of volume is exactly equal to one cubic centimeter (1 cm^3), which is pictured in Figure 13. Thus the density of water can also be reported as 1.00 g/cm^3. Another physical property of matter is freezing point. The freezing point of water is 0 °C at normal pressure. Can you think of other physical properties of water?

Water is the only ordinary liquid found naturally in our environment. Because so many substances dissolve readily in water, quite a few liquids are actually water solutions. Such water-based solutions are often called **aqueous solutions.** Even water that seems pure is never entirely so. Surface water contains dissolved minerals as well as other substances. Distilled water used in steam irons and car batteries contains dissolved gases from the atmosphere, as does rainwater.

Pure water is clear, colorless, odorless, and tasteless. The characteristic taste and slight odor of some tap-water samples are caused by substances dissolved in the water. You can confirm this by boiling and then refrigerating a sample of distilled water. When you compare its taste with the taste of chilled tap water, you may notice that "pure" distilled water tastes flat.

Water's physical properties, along with its chemical properties, distinguish it from other substances. In the following activity, you will compare the density of water with the density of some other common materials.

DENSITY

Building Skills 2

Most likely, you are already familiar with such physical properties of water as density, boiling point, and melting point. Use your experiences with water and other materials to answer the following questions concerning density.

1. In the foul-water laboratory activity (page 8), you observed that coffee grounds settled to the bottom of the water sample, whereas oil "floated" on top. Explain this observation in relation to the relative densities of coffee grounds, water, and oil.
2. How does the density of ice compare with that of liquid water? (*Hint:* Use your everyday experiences to answer this question.) What would happen to rivers and lakes (and fish) in cooler climates if the relative densities of ice and liquid water were reversed?
3. Suppose you were given a small cube of copper metal. What measurements would you need to make to determine its density? How would you make these measurements in the laboratory?

B.2 MIXTURES AND SOLUTIONS

How do you know when liquid water is not sufficiently pure? How can substances in water be separated and identified? Answers to these questions will be helpful in understanding and possibly solving the fish-kill mystery. But first you must learn how to recognize various types of mixtures.

When two or more substances combine yet retain their individual properties, the result is called a **mixture.** The foul water that you purified earlier is an example of a mixture because it contained coffee grounds, garlic powder, oil, and salt. As you discovered, the components of a mixture can be separated by physical means such as filtration and adsorption.

When you first examined your foul-water sample, did it look uniform throughout? Most likely, the coffee grounds had settled to the bottom and were not distributed evenly throughout the liquid. The foul water is an example of a **heterogeneous mixture** because its composition is not the same, or uniform, throughout. One type of heterogeneous mixture is called a **suspension** because the particles are large enough to settle out and can be separated by using a filter. Water plus coffee grounds and water plus small pepper particles are examples of suspensions.

A heterogeneous mixture's composition varies.

If the particles are smaller than those in a suspension, they may not settle out and thus may cause the water to appear cloudy. Recall what happened when your teacher shined a light through your sample of purified water. The scattering of the light, known as the Tyndall effect (see Figure 7, page 12), indicated that small, solid particles were still present in the water. This type of mixture is known as a **colloid.**

CD-ROM WWW. **Modeling Matter: Attraction Between Water Molecules**

A more familiar example of a colloid is milk, which contains small butterfat particles dispersed in water. These colloidal butterfat particles are not visible to the unaided eye; the mixture appears uniform throughout. Thus milk can be classified as homogeneous, which leads to the familiar term *homogenized milk.* Under high magnification, however, individual butterfat globules can be observed floating in the water. Milk no longer appears homogeneous. See Figure 14.

Particles smaller than colloidal particles also may be present in a mixture. When small amounts of table salt are mixed with water, as in your foul-water sample, the salt **dissolves** in the water. That is, the salt crystals separate into particles so small that they cannot be seen even at high

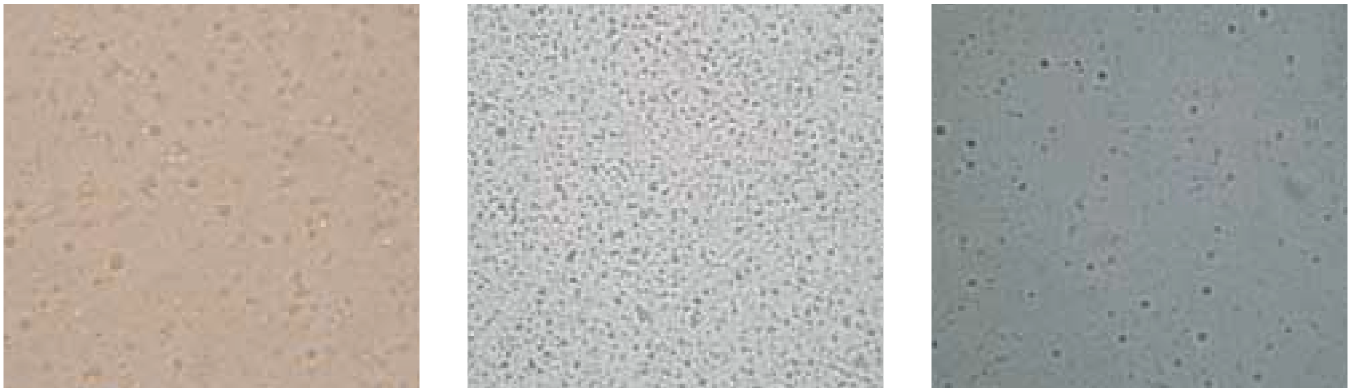


Figure 14 *Fat globules can be seen under magnification, so that milk no longer looks homogeneous.* Left: *Whole milk under 1000X magnification.* Center: *Whole milk under 400X magnification.* Right: *Non-fat milk under 400X magnification.*

magnification. Nor do the particles exhibit the Tyndall effect when a light beam is passed through the mixture. These particles become uniformly mingled with the particles of water, producing a **homogeneous mixture,** or a mixture that is uniform throughout. All **solutions** are homogeneous mixtures. In a salt solution, the salt is the **solute** (the dissolved substance) and the water is the **solvent** (the dissolving agent). All solutions consist of one or more solutes and a solvent.

Molecular Views of Water CD-ROM www.

Evidence that something was still dissolved in your purified water sample came from the results of the conductivity test. The positive result (the bulb lit up) indicated that electrically charged particles were dissolved in the mixture.

B.3 MOLECULAR VIEW OF WATER

So far in this investigation of water, you have focused on properties observable with your unaided senses. In doing so, have you wondered why water's freezing point is 0 °C or why certain substances such as salt dissolve in water? To understand why water has its particular properties, you must investigate it at the level of its atoms and molecules.

A compound can be broken down chemically into two or more simpler substances—either elements or new compounds. By definition, an element cannot be broken down into any simpler substances.

All matter is composed of **atoms.** Atoms are often called the building blocks of matter. Matter that is made up of only one kind of atom is known as an **element.** For example, oxygen is considered an element because it is composed of only oxygen atoms. Because hydrogen gas contains only hydrogen atoms, it too is an element. Approximately 90 different elements are found in nature, each having its own unique type of atom and identifying properties.

What type of matter is water? Is it an element? A mixture? As you most likely know, water contains atoms of two elements—oxygen and hydrogen. Thus water cannot be classified as an element. And, because its properties are different from those of oxygen and hydrogen, water cannot be classified as a mixture either.

Instead, water is an example of a **compound**—a substance composed of atoms of two or more elements linked together chemically in fixed proportions. To date, chemists have identified more than 18 million compounds. Compounds are represented by chemical formulas. In addition to water (H_2O), some other compounds and formulas with which you may be familiar include table salt (NaCl), ammonia (NH_3), baking soda ($NaHCO_3$), and chalk ($CaCO_3$).

Each element and compound is considered a **pure substance** because each has a uniform and definite composition as well as distinct properties. The smallest unit of a pure substance that retains the properties of that substance is a **molecule.** Atoms of a molecule are held together by **chemical bonds.** You can think of chemical bonds as the "glue" that holds atoms of a molecule together. One molecule of water is composed of two hydrogen atoms bonded to one oxygen atom, hence H_2O. An ammonia molecule (NH_3) contains three hydrogen atoms bonded to a nitrogen atom. Figure 15 shows representations of some atoms and molecules.

The following activity will give you a chance to apply an atomic and molecular view to a variety of common observations.

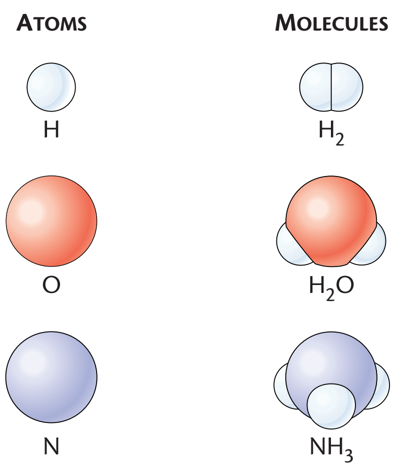


Figure 15 *On the left: hydrogen (H), oxygen (O), and nitrogen (N) atoms. On the right: hydrogen (H_2), water (H_2O), and ammonia (NH_3) molecules. Note the relative sizes of the atoms. Models similar to these are used throughout the textbook to depict atoms and molecules.*

MODELING MATTER

PICTURES IN THE MIND

You live in a macroscopic world—a world filled with large-scale, readily observed things. As you experience the properties and behavior of bulk materials, you probably give little thought to the particulate world of atoms and molecules. If you wrap leftover cake in aluminum foil, it is unlikely that you think about how the individual aluminum atoms are arranged in the wrapping material. It is also unlikely that you consider what the mixture of molecules that make up air looks like as you breathe. And you seldom wonder about the behavior of atoms and molecules when you see water boiling or iron nails rusting.

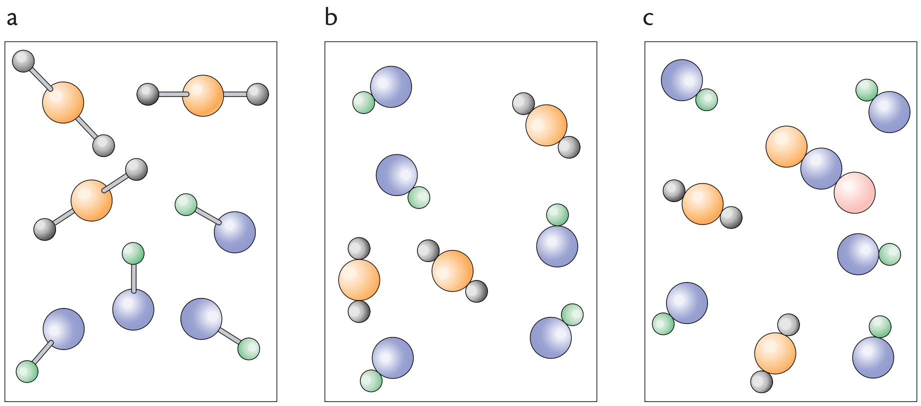
Having a sense of how individual atoms and molecules might look and behave in elements, compounds, and mixtures can help you explain everyday phenomena. This activity will give you practice in observing, interpreting, evaluating, and creating visual models of matter at the particulate level.

To introduce you to these visualizations, consider this example: Suppose you want to draw a model of a homogeneous mixture of two gaseous compounds. You know that a homogeneous mixture is uniform throughout, so the two compounds should be intermingled and evenly distributed. You also know that compounds are composed of atoms of two or more different elements linked together by chemical bonds.

Suppose a molecule of one of the compounds contains two different atoms. To represent this molecule, you could draw two differently shaded or labeled circles to denote atoms of the two elements and a line connecting the atoms to denote a bond.

Suppose the other compound is composed of molecules that each contain three atoms, and that two of the atoms are of the same element. You now need to choose the order in which the atoms should be connected: the unique atom (Y) could be in the middle, X–Y–X, or on the end, X–X–Y. As long as you draw this imaginary compound in the same way every time, it does not matter which way you do it for this activity. However, the way in which atoms are connected in real compounds does, in fact, make a difference; X–Y–X is a different molecule from X–X–Y.

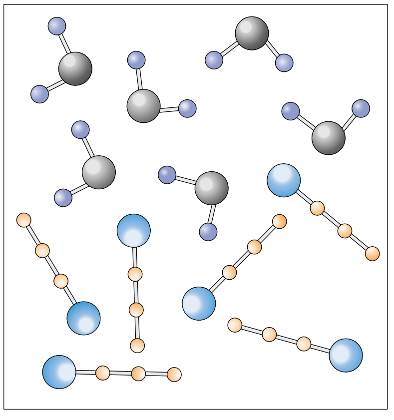
Examine the three models (a, b, and c) in the illustration. Which best represents a homogeneous mixture of the two compounds just described? You are correct if you said that b is the best visual model. The two types of molecules are uniformly mixed, and the atoms are shaded to indicate that they represent different elements. In a, the mixture is not homogeneous because the molecules are not uniformly mixed. Model c contains three different compounds instead of two. Notice that in a, bonded atoms in each molecule are connected by lines. In b and c, bonded atoms just touch each other. Both



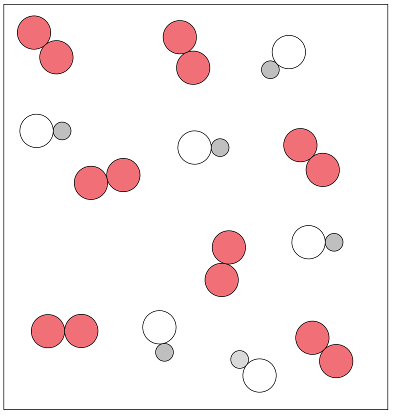
representations are used by chemists; either one is acceptable in this activity.

Now it is your turn to create and evaluate various visual models of matter.

1. Draw a model of a homogeneous mixture composed of three different gaseous elements. Describe the key features of your drawing.
2. What kind of matter does the following model represent? Explain your answer.



3. Draw a model of each of the following samples of matter. Write a description of key features of each model.
   a. a mixture of gaseous elements X and Z
   b. a two-atom compound of X and Z
   c. a four-atom compound of X and Z
   d. a solution composed of a solvent that is a two-atom compound of L and R, and a solute that is a compound composed of two atoms of D and one atom of T
4. One at a time, compare each visual model that you created in Question 3 with those of your classmates.
   a. Although the models may look a little different, does each set depict the same type of sample? Comment on any similarities and differences.
   b. Do the differences help or hinder your ability to visualize the type of matter being depicted?
5. The element iodine (I) has a greater density in the solid state than in the gaseous state. Draw models that depict and account for this difference at the atomic level. Iodine exists as a two-atom molecule.
6. A student in a chemistry class at Riverwood High School was asked to draw a model of a mixture composed of an element and a compound. Comment on the usefulness of the student's drawing.



7. You have been interpreting and creating two-dimensional models of three-dimensional molecules.
   a. What are the limitations of two-dimensional representations?
   b. How can two-dimensional drawings be enhanced to show the features of three-dimensional atoms and molecules?
   c. Describe how you could make three-dimensional models from everyday materials.
8. a. How useful are models to you in visualizing matter at the particulate level?
   b. What characteristics do good models of matter have?

As you continue to study chemistry, you will encounter visual models of matter similar to those in this activity. When you see them, think about their usefulness as well as their possible limitations.

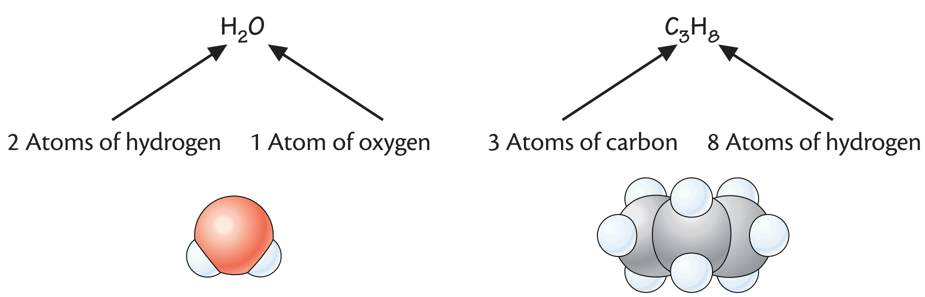
B.4 SYMBOLS, FORMULAS, AND EQUATIONS

An international "chemical language" for use in oral and written communication has been developed to represent atoms, elements, and compounds. The "letters" in this language's alphabet are **chemical symbols,** which are understood by scientists throughout the world. Each element is assigned a chemical symbol. Only the first letter of the symbol is capitalized; all other letters are lowercase. For example, C is the symbol for the element carbon and Ca is the symbol for the element calcium. Symbols for some common elements are listed in Figure 16.

All known elements are organized into the Periodic Table of the Elements, which is one of the most useful tools of chemists. As you continue your study of chemistry, you will learn more about this important table. For now, become familiar with this tool by locating each element listed in Figure 16 on the Periodic Table found on the inside back cover of this textbook. How many of these elements have you heard of before?

"Words" in the language of chemistry are composed of "letters" (elements) from the Periodic Table. Each "word" is a **chemical formula,** which represents a different chemical substance. In the chemical formula of a substance, a chemical symbol represents each element present. A **subscript** (a number written below the normal line of letters) indicates how many atoms of each element just to the left of the number are in one molecule or unit of the substance.

For example, as you already know, the chemical formula for water is H_2O. The subscript 2 indicates that each water molecule contains two hydrogen atoms. Each water molecule also contains one oxygen atom. However, the subscript 1 is understood and is therefore not included in a chemical formula. Here is another example. The chemical formula for propane, a compound commonly used as a fuel, is C_3H_8. What elements are present in propane, and how many atoms of each are there? You are correct if you said each propane molecule consists of three atoms of carbon and eight atoms of hydrogen.



If formulas are the "words" in the language of chemistry, then **chemical equations** are the "sentences." Each chemical equation summarizes the details of a particular chemical reaction. **Chemical reactions** entail the breaking and forming of chemical bonds, causing atoms to become rearranged into new substances. These new substances have different properties from those of the original material(s).

Common Elements

Name	Symbol
Aluminum	Al
Bromine	Br
Calcium	Ca
Carbon	C
Chlorine	Cl
Cobalt	Co
Copper	Cu
Gold	Au
Hydrogen	H
Iodine	I
Iron	Fe
Lead	Pb
Magnesium	Mg
Mercury	Hg
Nickel	Ni
Nitrogen	N
Oxygen	O
Phosphorus	P
Potassium	K
Silver	Ag
Sodium	Na
Sulfur	S
Tin	Sn

Figure 16 *Common elements.*

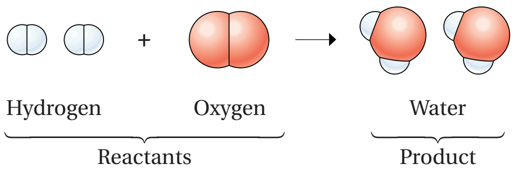
Elements That Exist as Diatomic Molecules	
Element	**Formula**
Hydrogen	H_2
Nitrogen	N_2
Oxygen	O_2
Fluorine	F_2
Chlorine	Cl_2
Bromine	Br_2
Iodine	I_2

Figure 17 *These elements occur naturally as diatomic molecules.*

"GEN-U-INE DIATOMICS" can serve as a good memory device for all diatomic elements. The names of the diatomic elements end in either GEN or INE, and U better remember them!

The chemical equation for the formation of water

$$2\ H_2 + O_2 \longrightarrow 2\ H_2O$$



shows that two hydrogen molecules (2 H_2) and one oxygen molecule (O_2) react to produce (→) two molecules of water (2 H_2O). The original (starting) substances in a chemical reaction are called the **reactants;** their formulas are always written on the left side of the arrow. The new substance or substances formed from the rearrangement of the reactant atoms are called **products;** their formulas are always written on the right side of the arrow. Note that this equation, like all chemical equations, is balanced—the total number of each type of atom (four H atoms and two O atoms) is the same for both reactants and products.

Perhaps you noticed that in the chemical equation for the formation of water the reactants hydrogen and oxygen are written with subscripts of 2 (H_2 and O_2). Do all elements have subscripts? Most uncombined elements in chemical equations are represented as single atoms (Cu, Fe, Na, and Mg, for example). A handful of elements are **diatomic molecules;** they exist as two bonded atoms of the same element. Oxygen and hydrogen are two examples of diatomic molecules. Figure 17 lists all the elements that exist as diatomic molecules at normal conditions. It will be helpful for you to remember these elements. Find the diatomic elements in the Periodic Table. Where are they located?

WORKING WITH SYMBOLS, FORMULAS, AND EQUATIONS

Building Skills 3

1. a. Name the element represented by each symbol below.

i. P   v. Br
ii. Ni   vi. K
iii. Cu   vii. Na
iv. Co   viii. Fe

b. Which elements in Question 1a have symbols corresponding to their English names?

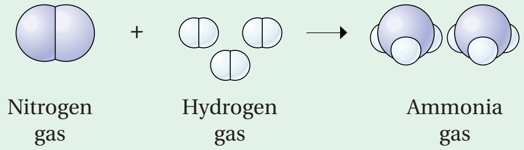
c. Which is more likely to be the same throughout the world—the element's symbol or its name?

2. For each formula, name the elements present and give the number of atoms of each element.

a. H_2O_2 — Hydrogen peroxide (antiseptic)
b. $CaCl_2$ — Calcium chloride (de-icer for sidewalks)
c. $NaHCO_3$ — Sodium hydrogen carbonate (baking soda)
d. H_2SO_4 — Sulfuric acid (battery acid)

Look at the information available in a chemical equation:

$$N_2 \quad + \quad 3\ H_2 \longrightarrow 2\ NH_3$$



First, complete an "atom inventory" of this chemical equation:

$$\begin{array}{ccccc} N_2 & + & 3\ H_2 & \longrightarrow & 2\ NH_3 \\ \text{2 N atoms} & + & \text{6 H atoms} & = & \text{2 N atoms and 6 H atoms} \end{array}$$

Note that the total number of atoms of N (nitrogen) and H (hydrogen) remains unchanged during this chemical reaction.

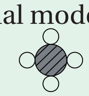
Next, interpret the equation in terms of molecules:

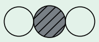
$$\begin{array}{ccccc} N_2 & + & 3\ H_2 & \longrightarrow & 2\ NH_3 \\ \text{1 } N_2 \text{ molecule} & & \text{3 } H_2 \text{ molecules} & \longrightarrow & \text{2 } NH_3 \text{ molecules} \end{array}$$

Note that one molecule of N_2 reacts with three molecules of H_2 to produce two molecules of the compound NH_3, called ammonia. Also note that molecules of nitrogen (N_2) and hydrogen (H_2) are diatomic, whereas the ammonia molecule is composed of four atoms—one nitrogen atom and three hydrogen atoms.

3. The following chemical equation represents the burning of methane, CH_4, to form water and carbon dioxide:

$$CH_4 + 2\ O_2 \longrightarrow CO_2 + 2\ H_2O$$

a. Write a sentence describing the equation in terms of molecules.
b. Identify each molecule as either a compound or an element.
c. Complete an atom inventory for the equation.
d. Provide a visual model ("picture in your mind") of the chemical reaction. Let  represent CH_4.

Let  represent CO_2.

Use the model of an H_2O molecule in Figure 15 (page 26) to draw a representation of H_2O similar to that of CH_4 and CO_2 shown here.

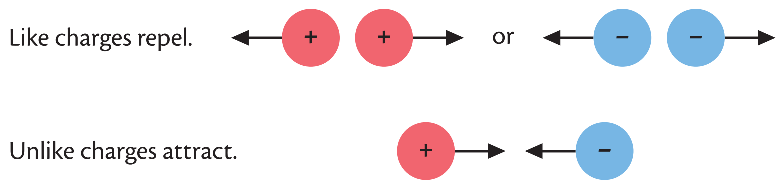
Household ammonia is made by dissolving gaseous ammonia in water.

B.5 THE ELECTRICAL NATURE OF MATTER

Previously, you were introduced to the concept of atoms and molecules. How do the atoms in molecules "stick" together to form bonds? Are atoms made up of even smaller particles? The answers to these questions require an understanding of the electrical properties of matter.

You have already experienced the electrical nature of matter, most probably without realizing it! Clothes often display "static cling" when they are taken from the dryer. The pieces of apparel stick firmly together and can be separated only with effort. The shock that you sometimes receive after walking across a rug and touching a metal doorknob is another reminder of matter's electrical nature. And if two inflated balloons are rubbed against your hair, both balloons will attract your hair but repel each other, a phenomenon best seen when the humidity is low.

The electrical properties of matter can be summarized as follows:



What are these positive and negative charges? How do they relate to the idea of atoms and molecules? The following points will be useful in answering these questions.

- Every electrically neutral (uncharged) atom contains equal numbers of positively charged particles called **protons** and negatively charged particles called **electrons.** In addition, most atoms contain one or more electrically neutral particles called **neutrons.**
- Positive–negative attractions between the protons in one atom and the electrons in another atom provide the "glue" that holds atoms together. This glue is the chemical bond that you read about on page 26.

States of Matter CD-ROM WWW.

These basic ideas will be used in later sections and in upcoming units to explain the properties of substances, the process of dissolving, and chemical bonding. Right now you will combine these ideas with your knowledge of atoms, chemical symbols, and chemical names to learn about a class of compounds that generally dissolve to some extent in water. It is possible that one or more of these compounds could be the cause of the fish kill.

B.6 IONS AND IONIC COMPOUNDS

Na	Electrically neutral sodium atom
Na^+	Sodium ion
Cl	Electrically neutral chlorine atom
Cl^-	Chloride ion
Na^+Cl^-	Sodium chloride (table salt)

Earlier in this unit (page 26), you learned about molecules. Molecules make up one type of compound. Another type of compound is composed of **ions,** which are charged atoms. Atoms can gain or lose electrons to form negative or positive ions, respectively. **Ionic compounds** are composed of positive and negative ions. An ionic compound has no net electrical charge; it is neutral because the positive and negative charges offset each other. The most familiar example of an ionic compound is table salt, sodium chloride (NaCl).

In solid ionic compounds, such as table salt, the ions are held together in crystals by attractions among the negative and positive charges. When an ionic compound dissolves in water, its individual ions separate from one another and disperse in the water. The designation (aq) following the symbol for an ion, as in $Na^+(aq)$, means that the ions are in water (aqueous) solution.

When an atom gains one or more electrons (which have negative charge), the resulting negatively charged ion is called an **anion.** A positively charged ion, called a **cation,** results from an atom losing one or more electrons. An ion can be a single atom, such as a sodium ion (Na^+) or a chloride ion (Cl^-), or a group of bonded atoms, such as an ammonium ion (NH_4^+) or a nitrate ion (NO_3^-). An ion consisting of a group of bonded atoms is called a **polyatomic** (many-atom) **ion.** Figure 18 lists the formulas and names of common cations and anions.

Common Ions

Cations

1+ Charge		2+ Charge		3+ Charge	
Formula	**Name**	**Formula**	**Name**	**Formula**	**Name**
H^+	Hydrogen	Mg^{2+}	Magnesium	Al^{3+}	Aluminum
Na^+	Sodium	Ca^{2+}	Calcium	Fe^{3+}	Iron(III)*
K^+	Potassium	Ba^{2+}	Barium		
Cu^+	Copper(I)*	Zn^{2+}	Zinc		
Ag^+	Silver	Cd^{2+}	Cadmium		
NH_4^+	Ammonium	Hg^{2+}	Mercury(II)*		
		Cu^{2+}	Copper(II)*		
		Pb^{2+}	Lead(II)*		
		Fe^{2+}	Iron(II)*		

Anions

1− Charge		2− Charge		3− Charge	
Formula	**Name**	**Formula**	**Name**	**Formula**	**Name**
F^-	Fluoride	O^{2-}	Oxide	PO_4^{3-}	Phosphate
Cl^-	Chloride	S^{2-}	Sulfide		
Br^-	Bromide	SO_4^{2-}	Sulfate		
I^-	Iodide	SO_3^{2-}	Sulfite		
NO_3^-	Nitrate	CO_3^{2-}	Carbonate		
NO_2^-	Nitrite				
OH^-	Hydroxide				
HCO_3^-	Hydrogen carbonate (bicarbonate)				

*Some metals form ions that have one charge under certain conditions and a different charge under different conditions. To specify the charge for these metal ions, Roman numerals are used in parentheses after the metal's name.

Figure 18 *Common ions.*

Solid sodium chloride, NaCl(s), consists of equal numbers of positive sodium ions (Na^+) and negative chloride ions (Cl^-) arranged in three-dimensional networks called crystals. See Figure 19. The ionic compound calcium chloride, $CaCl_2$, presents a similar picture. However, unlike sodium ions, calcium ions (Ca^{2+}) each have a charge of 2+.

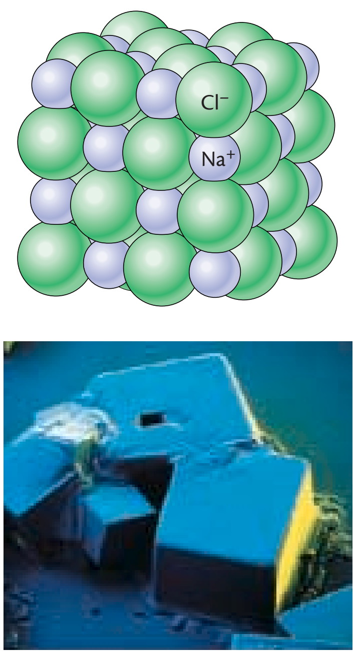


Figure 19 *Space-filling model of a sodium chloride (NaCl) crystal and a photo of magnified sodium chloride crystals.*

The formula for sodium chloride is not ClNa (Rule 1); nor is it Na_2Cl_2 or Na_3Cl_3 (Rule 2).

The "Cl_2" in $CaCl_2$ represents two Cl^- anions—not a diatomic molecule of chlorine.

You can easily write formulas for ionic compounds by following two simple rules.

1. Write the cation first, then the anion.
2. The correct formula contains the fewest positive and negative ions needed to make the total electrical charge zero.

Why are the numbers of chloride ions different in sodium chloride (NaCl) and calcium chloride ($CaCl_2$)? In sodium chloride, the ion charges are 1+ and 1−. Because one ion of each type results in a total charge of zero, the formula for sodium chloride must be NaCl.

When cation and anion charges do not add up to zero, ions of either type must be added until the charges cancel. In calcium chloride, one calcium ion (Ca^{2+}) has a charge of 2+. Each chloride ion (Cl^-) has a charge of 1−; two Cl^- ions are needed to equal a charge of 2−. Thus two chloride ions (2 Cl^-) are needed for each calcium ion (Ca^{2+}). The subscript 2 written after chlorine's symbol in the formula indicates this. The formula for calcium chloride is $CaCl_2$. Using these rules, what is the formula for aluminum sulfide, an ionic compound made up of aluminum cations (Al^{3+}) and sulfide anions (S^{2-})?

Formulas for compounds containing polyatomic ions, such as Na_2CO_3 (sodium carbonate), follow these same basic rules. However, if more than one polyatomic ion is needed to bring the total charge to zero, the formula for the polyatomic ion is enclosed in parentheses before the needed subscript is added. Ammonium sulfate is composed of ammonium (NH_4^+) and sulfate (SO_4^{2-}) ions. Two ammonium cations with a total charge of 2+ are needed to match the 2− charge of the sulfate anion. Thus the formula for ammonium sulfate is $(NH_4)_2SO_4$.

The written name of an ionic compound is composed of two parts. The cation is named first, then the anion. As Figure 18 (page 33) suggests, many cations have the same name as their original elements. Anions composed of a single atom, however, have the last few letters of the element's name changed to the suffix *-ide*. For example, the anion formed from fluorine (F) is fluor*ide* (F^-). Thus KF is named potassium fluoride. The following activity will provide practice in naming and writing formulas for ionic compounds according to the universal language of chemistry.

IONIC COMPOUNDS

Building Skills 4

Prepare a data table similar to the one shown here that identifies the composition of each ionic compound described in Statements 2 through 7.

DATA TABLE

	Cation	Anion	Formula	Name
1.	K^+	Cl^-	KCl	Potassium chloride
	(Complete this chart for substances 2 through 7.)			
7.				

Refer to Figure 18 on page 33 as needed to complete this activity. Potassium chloride, the primary ingredient in table-salt substitutes used by people on low-sodium diets, has been done as an example in the sample data table.

2. $CaSO_4$ is a component of plaster.
3. A substance composed of Ca^{2+} and PO_4^{3-} ions is found in some brands of phosphorus-containing fertilizer. This substance is also a major component of bones and teeth.
4. Ammonium nitrate, a rich source of nitrogen, is often used in fertilizer mixtures.
5. $Al_2(SO_4)_3$ is a compound that can be used to help purify water.
6. Magnesium hydroxide is called milk of magnesia when it is mixed with water.
7. Limestone and marble are two common forms of the compound calcium carbonate.

B.7 WATER TESTING

Laboratory Activity

Introduction

How can chemists detect and identify certain ions in water solutions? This activity will allow you to use a method that chemists, including those investigating the Riverwood fish kill, use to detect the presence of specific ions in water solutions.

The tests that you will perform in this activity are **confirming tests.** That is, a positive test confirms that the ion in question is present. In each confirming test, you will look for a change in solution color or for the appearance of an insoluble material called a **precipitate.** A negative test (no color or precipitate) does not necessarily mean that the ion in question is absent. The ion may simply be present in such a small amount that the test result may not be observed. Technologies are available to detect these very small amounts, however.

These tests are classified as qualitative tests, ones that identify the presence or absence of a particular substance in a sample. In contrast, quantitative tests determine the amount of a specific substance present in a sample. Both types of tests would most likely be used in determining the cause of the Snake River fish kill.

You will test for the presence of iron(III) (Fe^{3+}) and calcium (Ca^{2+}) cations, as well as chloride (Cl^-) and sulfate (SO_4^{2-}) anions. Although you are familiar with the names and symbols for Ca^{2+}, Cl^-, and SO_4^{2-}, the name for Fe^{3+} may look strange to you. Some elements can form cations with different charges. Iron atoms can lose either two electrons to form Fe^{2+} cations or three electrons to form Fe^{3+} cations. Thus the name "iron cation" is not descriptive enough; it does not distinguish between Fe^{2+} and Fe^{3+}. For this reason, Roman numerals are added to the name to indicate the charge on the ion. Examples of other cations that must include Roman numerals in their names are copper(I) and copper(II), and cobalt(II) and cobalt(III).

There are two types of iron cations: Fe^{2+} is designated Fe(II); Fe^{3+} is Fe(III).

You will perform each confirming test on several different water samples. The first solution will be a **reference solution**—one that contains the ion of interest. The second will be a **control**—a sample known not to contain the ion. The control in this activity is distilled water. The other solutions will be tap-water and natural-water samples that you or your teacher collected. These solutions may or may not contain the ion. To determine whether these solutions contain the ion, you will need to compare the results with your reference and control samples.

In your laboratory notebook, prepare four data tables (one for each ion) similar to the one shown. Add rows if you are testing more than one natural-water sample. Be certain to identify the source of each natural-water sample.

DATA TABLE: (Specify ion)

Solution	Observations (color, precipitate, etc.)	Result (Is ion present?)
Reference		
Control		
Tap water		
Natural water from (source)		

The following suggestions will help guide your ion analysis.

1. If the ion is in tap or natural water, it will probably be present in a smaller amount than in the same volume of reference solution. Thus the quantity of precipitate or color produced in the tap or natural water sample will be less than in the reference solution.
2. When completing an ion test, mix the contents of the well thoroughly, using a toothpick or small glass stirring rod. Do not use the same toothpick or stirring rod in other samples without first rinsing it and wiping it dry.
3. In a confirming test based on color change, so few color-producing ions may be present that it is difficult to determine if the reaction actually took place. Here are two ways to decide whether the expected color is actually present:
   - Place a sheet of white paper behind or under the wellplate to make any color more visible.
   - Compare the color of the control (distilled water) test with that of the sample. Distilled water does not contain any of the ions tested. So even a faint color in the tap or natural water confirms that the ion is present.
4. In a confirming test based on the formation of a precipitate, you may be uncertain whether a solid precipitate is present even after thoroughly mixing the solutions. Placing the wellplate on a black or dark surface often makes a precipitate more visible.

Procedure

The test procedures for each ion follow. If the ion of interest is present, a chemical reaction will take place, producing either a colored solution or a precipitate. The chemical equations are given for each ion.

> Only ions that take part in the reaction are included in this type of equation.

Calcium Ion (Ca^{2+}) Test

$Ca^{2+}(aq)$	$+$	$CO_3^{2-}(aq)$	$\longrightarrow$	$CaCO_3(s)$
calcium ion carbonate		carbonate ion		calciu

Follow these steps for each sample (Ca^{2+} reference, control, tap water, natural water):

1. Place 20 drops into a well of a 24-well wellplate.
2. Add three drops of sodium carbonate (Na_2CO_3) test solution to the well.
3. Record your observations, including the color and whether a precipitate formed.
4. Determine whether the ion is present and record your results.
5. Repeat for the remaining solutions.
6. Discard the contents of the wellplate as directed by your teacher.

Iron(III) Ion (Fe^{3+}) Test

$Fe^{3+}(aq)$	$+$	$SCN^{-}(aq)$	$\longrightarrow$	$[FeSCN]^{2+}(aq)$
iron(III) ion		thiocyanate ion		iron(III) thiocyanate ion

Follow these steps for each sample (Fe^{3+} reference, control, tap water, natural water):

1. Place 20 drops into a well of a 24-well wellplate.
2. Add one or two drops of potassium thiocyanate (KSCN) test solution to the well.
3. Record your observations, including the color and whether a precipitate formed.
4. Determine whether the ion is present and record your results.
5. Repeat for the remaining solutions.
6. Discard the contents of the wellplate as directed by your teacher.

Chloride Ion (Cl^-) Test

$Cl^{-}(aq)$	$+$	$Ag^{+}(aq)$	$\longrightarrow$	$AgCl(s)$
chloride ion		silver ion		silver chloride

Follow the same procedure as that for the Fe^{3+} ion, with the following changes:

- Use the Cl^- reference solution.
- In Step 2, add three drops of silver nitrate ($AgNO_3$) test solution instead of potassium thiocyanate (KSCN) test solution.

Sulfate Ion (SO_4^{2-}) Test

$$SO_4^{2-}(aq) + Ba^{2+}(aq) \longrightarrow BaSO_4(s)$$

sulfate ion   barium ion   barium sulfate

Follow the same procedure as that for the Fe^{3+} ion, with the following changes:

- Use the SO_4^{2-} reference solution.
- In Step 2, add three drops of barium chloride ($BaCl_2$) test solution instead of potassium thiocyanate (KSCN).

Questions

1. a. Why was a control used in each test?
   b. Why was distilled water chosen as the control?
2. Describe some difficulties associated with the use of qualitative tests.
3. These tests cannot absolutely confirm the absence of an ion. Why?
4. How might your observations have changed if you had not cleaned your wells or stirring rods thoroughly between each test?

B.8 PURE AND IMPURE WATER

Now that you have learned about water's properties and about some of the substances that can dissolve in water, you are ready to return to the problem of Riverwood's fish kill. Recall that various Riverwood residents had different ideas about the cause of the problem. For example, longtime resident Harmon Lewis was sure the cause was pollution of the river water. Which substances are regarded as pollutants, and which are harmless when dissolved in water?

What is the difference between clean and pure water?

Families in most U.S. cities and towns receive an abundant supply of clean, but not absolutely pure, water at an extremely low cost. You can check the water cost in your own area: If you use municipal water, your family's water bill will contain the current water cost per gallon. Divide that value by 3.8 (there are 3.8 liters in one gallon) to compute the current cost for one liter of water.

It is useless to insist on absolutely pure water. The cost of processing water to make it completely pure would be prohibitively high. And, even if costs were not a problem, it would still be impossible to have absolutely pure water. The atmospheric gases nitrogen (N_2), oxygen (O_2), and carbon dioxide (CO_2) will always dissolve in the water to some extent.

B.9 THE RIVERWOOD WATER MYSTERY

Making Decisions

Your teacher will divide the class into several different groups of students. Each group will complete this decision-making activity. Afterward, the entire class will compare and discuss the answers obtained by each group.

At the beginning of this unit, you read newspaper articles describing the Riverwood fish kill and the reactions of several citizens to it. Among those interviewed were Harmon Lewis, a longtime resident of Riverwood, and Dr. Margaret Brooke, a water-systems scientist. These two people had very different reactions to the fish kill. An angry Harmon Lewis was certain that human activity—probably some sort of pollution—had caused the fish kill. Dr. Brooke refused to even speculate about the cause of the fish kill until she had conducted some tests.

Which of these two positions comes closer to your own reaction at this point? Complete the following activities to investigate the issue further.

1. Reread the fish-kill newspaper reports located at the beginning of Sections A and B. List all facts (not opinions) concerning the fish kill found in these articles. Scientists often refer to facts as data. **Data** are objective pieces of information. They do not include interpretation.
2. List at least five factual questions that you would want answered before you could decide on possible causes of the fish kill. Some typical questions might be: Do barges or commercial boats travel on the Snake River? Were any shipping accidents on the river reported recently?
3. Look over your two lists—one of facts and the other of questions.
   a. At this point, which possible fish-kill causes can you rule out as unlikely? Why?
   b. Can you suggest a probable cause? Be as specific as possible.

Later in this unit you will have an opportunity to test the reasoning that you used in answering these questions.

B.10 WHAT ARE THE POSSIBILITIES?

The activities that you just completed (gathering data, seeking patterns or regularities among the data, suggesting possible explanations or reasons to account for the data) are typical of the approaches scientists take in attempting to solve problems. Such scientific methods are a combination of systematic, step-by-step procedures and logic, as well as occasional hunches and guesses.

A fundamental yet difficult part of scientists' work is knowing what questions to ask. You have listed some questions that might be posed concerning the cause of the fish kill. Such questions help focus a scientist's thinking. Often a large problem can be reduced to several smaller problems or questions, each of which is more easily managed and solved.

The number of possible causes for the fish kill is large. Scientists investigating this problem must find ways to eliminate some causes and zero in on more promising ones. They try to either disprove all but one cause or produce conclusive proof in support of a specific cause.

As you recall, water analyst Brooke studied possible causes of the Snake River fish kill. She concluded that if the actual cause were water related, it would have to be due to something dissolved or suspended in the water.

CD-ROM WWW. Questions & Answers

In Section C, you will examine several categories of water-soluble substances and consider how they might be implicated in the fish kill. The mystery of the Riverwood fish kill will be confronted at last!

CHEMISTRY AT WORK

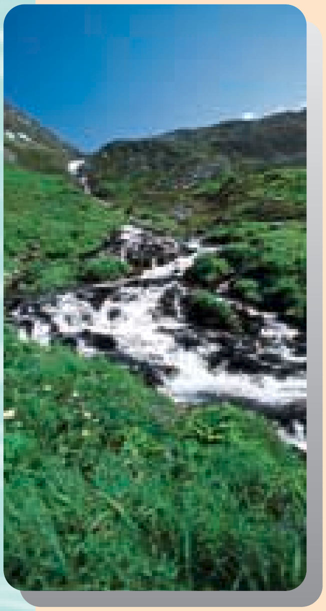
Environmental Cleanup: It's a Dirty Job . . . But That's the Point

Wayne Crayton spends his summers touring exotic islands in the Aleutian Islands chain off the coast of Alaska. But it's not just an adventure that he's embarked on. It's also his job.

As an Environmental Contaminants Specialist with the United States Army Corps of Engineers, Alaska District, Wayne investigates areas that were formerly used as military bases and fueling stations. Wayne and his teammates review and assess the damage (if there is any) that contaminants have done to key areas used by wildlife. Based on their findings, they then develop plans to fix the problems.

Wayne and his teammates recommend procedures for removing and treating contaminated soil and other material.

As part of its investigation planning, Wayne's team reviews information to determine what they're likely to find at a given site. For example, historical documents about the site will indicate whether the team members should be looking for petroleum residues or other contaminants; aerial photography and records from earlier investigations will help to identify specific areas that are potential sites of contamination.



At the site, the team collects soil, sediment, and water samples from the exact location where a contaminant was originally introduced to the environment, as well as samples from the area over which the contaminant might have spread. Wayne and his teammates may also collect small mammals or fish that have been exposed to the contaminants. After having collected the necessary samples, the team members return home quickly because some of the collected samples can degrade or change characteristics soon after collection.

Wayne works in an office in Anchorage during the rest of the year, analyzing and interpreting data and test results from the field investigations. He and his colleagues calculate concentrations of hazardous substances, including organochlorines, PCBs (polychlorinated biphenyls), pesticides, petroleum residues, and trace metals. Then they determine whether any of these substances present a risk to humans or the surrounding ecosystems.

Using these results, Wayne and his teammates recommend procedures for removing and treating contaminated soil and other material. In some situations, they decide that the best solution is to do nothing; the cleanup itself could destroy wetlands, disturb endangered wildlife, or have other negative effects on the environment. The Corps of Engineers uses the team's recommendations to direct the work of the contractor performing the actual cleanup.

Solving Scientific Problems . . .

This icon indicates an opportunity to consult resources on the World Wide Web. See your teacher for further instructions.

Scientists often solve problems in unique ways—ways that are different from the methods used in other areas of academic research.

- Outline the problem-solving steps that the Environmental Contaminants Specialists use in planning their investigations as described in this article.
- Compare the steps used by these scientists with the steps that you have used in studying science.
- Conduct a World Wide Web search for any United States Army Corps of Engineers or United States Environmental Protection Agency investigations or projects that might be underway in your community.

SECTION SUMMARY

Reviewing the Concepts

- **Physically combining two or more substances produces a mixture. Mixtures are considered heterogeneous or homogeneous, depending on the distribution of materials in the mixture.**

1. When gasoline and water mix, they form two distinct layers. What do you need to know in order to determine which liquid will be found in the top layer?

2. Identify each of the following materials as a solution, suspension, or colloid. Explain your choice in each case.

a. a medicine accompanied by the instructions "shake before using"
b. Italian salad dressing
c. mayonnaise
d. a cola soft drink
e. an oil-based paint
f. milk

3. You notice beams of light passing into a darkened room through blinds on a window. Does this demonstrate that the room air is a solution, suspension, or colloid? Explain.

4. Sketch a visual model on the molecular level that represents each of the following types of mixtures. Label and explain the features of each sketch.

a. a solution   c. a colloid
b. a suspension

5. a. Given a mixture, what steps would you follow to classify it as a solution, a suspension, or a colloid?

b. Describe how each step would help you to distinguish among the three types of mixtures.

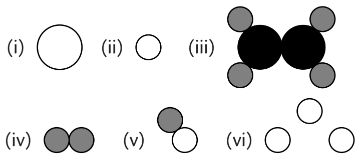
- **All matter is composed of atoms. An element is composed of only one type of atom; compounds consist of two or more types of atoms. Elements and compounds are considered pure substances, each having unique physical and chemical properties.**

6. Using your knowledge of chemical symbols, classify each of the following substances as an element or a compound.

a. CO	c. HCl	e. $NaHCO_3$	g. I_2
b. Co	d. Mg	f. NO	

7. Compare the physical properties of water (H_2O) with the physical properties of the elements of which it is composed.

8. Look at the following drawings.



a. Which represent a pure element?
b. Which represent a compound?

- **A chemical formula for a substance contains chemical symbols and subscripts (if needed) that identify the type and number of atoms present in one molecule or unit. A chemical equation states how a substance or substances react to form new substances.**

9. Represent each chemical equation with drawings of the molecules and their component atoms. Use circles of different sizes or shading for each type of element.

a. $H_2(g) + Cl_2\,(g) \longrightarrow 2\,HCl(g)$
b. $2\,H_2O_2(aq) \longrightarrow 2\,H_2O(l) + O_2(g)$
Let  represent a hydrogen peroxide molecule, H_2O_2.

c. Using complete sentences, write a word equation for the chemical equations given in a and b. Include the numbers of molecules.

10. Name the elements and list the number of atoms of each for the following substances.

a. phosphoric acid, H_3PO_4 (used in some soft drinks and to produce some fertilizers)

b. sodium hydroxide, NaOH (found in some drain cleaners)
c. sulfur dioxide, SO_2 (a by-product of burning most, if not all, types of coal)

11. Write chemical equations that represent the following word equations:

a. Baking soda ($NaHCO_3$) reacts with hydrochloric acid (HCl) to produce sodium chloride, water, and carbon dioxide.
b. During respiration, one molecule of glucose, $C_6H_{12}O_6$, combines with six molecules of oxygen to produce six molecules of carbon dioxide and six molecules of water.

◆ **An atom is composed of smaller particles (protons, neutrons, and electrons), each possessing a characteristic mass and charge. An electrically neutral atom has an equal number of protons and electrons.**

12. For each of the following elements, identify the number of protons or electrons needed for an electrically neutral atom.

a. Carbon:	6 protons	__ electrons
b. Aluminum:	__ protons	13 electrons
c. Lead:	82 protons	__ electrons
d. Chlorine:	__ protons	17 electrons

13. Decide whether each of the following atoms is electrically neutral.

a. Oxygen:	16 protons	18 electrons
b. Iron:	26 protons	24 electrons
c. Silver:	47 protons	47 electrons
d. Iodine:	53 protons	54 electrons

◆ **Ionic compounds are composed of equal numbers of positively and negatively charged ions (atoms that have lost or gained electrons), thus giving the compound no net charge.**

14. Write the symbol and show the charge (if any) on the following atoms or ions:

a. hydrogen with 1 proton and 1 electron
b. sodium with 11 protons and 10 electrons
c. chlorine with 17 protons and 18 electrons
d. aluminum with 13 protons and 10 electrons

15. Indicate whether an Fe^{3+} ion would be attracted to or repelled from each particle in Question 14.

16. a. Classify each of the following as an electrically neutral atom, an anion, or a cation.

i. O^{2-} iii. C v. Hg^{2+}
ii. He iv. Ag^{+}

b. For each ion, indicate whether the electrical charge resulted from an atom gaining electrons, losing electrons, or neither.

17. Write the name and formula for each compound that will be formed from the following combinations of cations and anions:

	OH^-	PO_4^{3-}	S^{2-}
Fe^{3+}	a.	b.	c.
K^+	d.	e.	f.
Ca^{2+}	g.	h.	i.

Connecting the Concepts

18. Explain the possible risks in failing to follow the direction "Shake before using" on the label of a medicine bottle.

19. Why is it important that the symbols of the elements be internationally accepted?

20. Draw a model of a solution in which water is the solvent and oxygen gas (O_2) is the solute.

21. An iron atom that has 26 protons and 23 electrons combines with an O^{2-} ion to form a compound.

a. What is the ionic charge on the iron atom?
b. Write the chemical formula for the compound.

Extending the Concepts

22. Is it possible to have a food product that is 100% "chemical free"? Explain.

23. Some elements in Figure 16 (page 29) have symbols that are not based on their modern names (such as K for potassium). Look up their historical names and explain the origin of their symbols.

24. The symbols of elements (such as Na, Cu, and Cl) are accepted and used by chemists in all nations, regardless of the country's official language. However, the name of an element often depends on language. For example, the element N is "nitrogen" in English but "azote" in French. The element H is "hydrogen" in English but "Wasserstoff" in German. Investigate the names of some common elements in a foreign language of your choice. What are the meanings or origins of the foreign element names that you have found? How do those meanings or origins compare with those for the corresponding English element names?

25. Investigate and report on why "100% pure water" would be unsuitable for long-term human consumption—even if taste were not a consideration.

26. Using an encyclopedia or other reference, compare the maximum and minimum temperatures naturally found on the surfaces of Earth, the Moon, and Venus. The large amount of water on Earth serves to limit the natural temperature range on the planet. Suggest ways that water accomplishes this. As a start, find out what *heat of fusion, heat capacity,* and *heat of vaporization* mean.

27. Look up the normal freezing point, boiling point, heat of fusion, and heat of vaporization of ammonia (NH_3). If a planet's life forms were made up mostly of ammonia rather than water, what special survival problems might they face? What temperature range would an ammonia-based planet need to support "life"?